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# THÈSE présentée par :


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# Methods to improve zoonotic disease surveillance in poor rural settings:

# the example of highly pathogenic avian influenza (A) H5N1 in Southeast Asia

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**“La négligence ruine, la surveillance épargne”**

Sentences et proverbes cambodgiens (1915)

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# Long French summary

La propagation en Asie, en Europe et en Afrique du virus Influenza Aviaire hautement pathogène (IAHP) H5N1, l'épidémie de A/H1N1pdm en 2009, l'émergence de l'Influenza Aviaire faiblement pathogène (IAFP), mais zoonotique, H7N9 en Chine en 2013 et la circulation récente de l'IAHP H5N8 en Europe, montrent que l'évolution permanente de ces virus chez les oiseaux, les humains et les porcs, représente un risque en santé humaine et animale au niveau mondial. Au cours des 10 dernières années, de nombreux efforts ont été faits pour renforcer les capacités en santé publique et vétérinaire. Malgré tout, le virus IAHP H5N1 reste endémique dans certains pays où il peut passer inaperçu dans les populations de volailles tout en provoquant des cas humains. Ces pays sont caractérisés par le fait qu'une majorité de leur population vit en zones rurales, par l'absence de systèmes de santé primaire et par l'inefficacité des secteurs de santé.

Le virus IAHP H5N1 est apparu en Chine méridionale en 1998, avec les premiers cas humains à Hong Kong (Claas et al., 1998). La maladie se propagea par la suite à l'extérieur de la Chine fin 2003, entrainant des flambées épidémiques chez les producteurs de volailles dans plusieurs pays d'Asie. A partir de 2005, le virus de l'influenza aviaire hautement pathogène H5N1 se déplaça plus à l'Ouest et fut détecté dans 63 pays (Fournie et al., 2012) en Asie, en Europe et en Afrique. De nos jours, le virus circule encore dans plusieurs pays (Chine, Vietnam, Cambodge, Indonésie, Bangladesh, Inde, Népal et Égypte) avec quelques foyers sporadiques en République démocratique populaire du Laos et au Myanmar (FAO, 2013). En 2014, la maladie fut de nouveau détectée chez la volaille au Cambodge, au Vietnam et au Laos (pour la première fois depuis 2007). Aucun foyer ne fut déclaré par l'Indonésie du fait que la maladie a été officiellement déclarée endémique par l'OIE en septembre 2011 (tableau 1). Le contrôle de la maladie reste un enjeu de santé publique, en raison des inquiétudes sur le potentiel du virus IAHP H5N1 à devenir la prochaine souche pandémique (Pongcharoensuk et al., 2011). Depuis le début des épidémies, plus de 400 millions de volailles sont mortes suite à la maladie ou à l'abattage (FAO, 2013), dont plus de 175 millions pour l'Asie du Sud-Est seulement (Pfeiffer et al., 2013). L'influenza aviaire hautement pathogène H5N1 a ainsi eu un impact dévastateur sur le secteur de la volaille en raison des mesures préventives d'abattage et des restrictions sur le commerce, mais également sur les

moyens de subsistance de milliers de petits producteurs asiatiques qui gagnaient leur vie grâce à l'élevage de volailles, du fait que le taux de mortalité de la maladie est supérieur à 50.
Le nombre de cas humains depuis le début de l'épidémie est encore relativement faible. A la date du 2 octobre 2014, on recensait un total de 668 cas humains confirmés et de 393 décès notifiés à l'OMS dans 16 pays (OMS, 2014a). Quatre cent huit cas ont été signalés en Asie du Sud-est ; l'Indonésie ayant le taux de létalité le plus élevé au monde, estimé à 83 % (tableau 1). La voie de transmission principale de la maladie de la volaille à l'homme est le contact direct et prolongé avec des animaux malades (Fournie et al., 2012). Toutefois, il est très probable que les taux de létalité basés sur les déclarations officielles à l'OMS soient surestimés en raison des sous-déclaration, notamment des cas humains non mortels (Pfeiffer et al., 2013). Toutefois, il n'y a à l'heure actuelle aucune preuve sérologique sans équivoque concernant la proportion de cas asymptomatiques ou modérément symptomatiques chez l'homme (Toner et al., 2013).

Le secteur de la volaille dans le bassin du Mékong (LBM) se caractérise par une forte proportion de petits éleveurs. Le Cambodge et le Laos ont le secteur industriel le moins avancé de la région, avec 85 % à 95 % des troupeaux présents dans les systèmes villageois (Behnek, Otte et Roland-Holst, 2010 ; Otte, 2008). Pour le Vietnam, bien que 90 % des troupeaux sont aussi produits de façon familiale, les secteurs industriels et semi-intensifs sont plus importants avec seulement 50 % de la totalité de la population de volaille nationale élevée dans des cheptels de moins de 50 animaux (Otte et al., 2008). Pour la Thaïlande, le secteur intensif inclue 70 % de la population de volaille nationale même si 90 % des troupeaux sont toujours élevés à petite échelle (Heft-Neal, Roland-Holst et Otte, 2012). La Thaïlande et le Vietnam se distinguent par leur grande population de canards en divagation ; 13 millions pour la Thaïlande et 65 millions pour le Vietnam. Ceux-ci sont élevés de façon traditionnelle, les animaux étant nourris des reliquats de récolte de riz (Gilbert et al., 2007 ; Henning et al., 2012).

**Tableau 1: Nombre cumulatif de foyers d'influenza aviaire hautement pathogène à H5N1 en Asie du Sud-est (20 Janvier 2015)**

| Pays | Foyers aviaires déclarés à l'OIE (première – dernière déclaration) | Nombre cumulatif de cas humains déclarés à l'OMS (mortalité totale) | Foyers aviaires détectés en 2014 | Cas humains en 2014 (morts) |
|---|---|---|---|---|
| **Vietnam** | 2720 (2004-2014) | 127 (64) | 45 | 2 (2) |
| **Indonésie** | 261 (2003-2006) | 197 (165) | Endémique depuis 26/09/2006 | 2(2) |
| **Cambodge** | 42 (2005-2014) | 56 (37) | 5 | 9 (4) |
| **Laos** | 19 (2006-2014) | 2(2) | 1 | 0 (0) |
| **Thailande** | 1141 (2003-2008) | 25(17) | Pas de foyer depuis 2008 | 0 (0) |
| **Myanmar** | 115 (2006-2012) | 1(0) | Pas de foyer depuis 2012 | 0(0) |
| **Malaisie** | 16 (2004-2007) | 0 | Pas de foyer depuis 2007 | 0(0) |
| **Philippines** | Pas de foyers | | | |

http://www.who.int/influenza/human_animal_interface/EN_GIP_20140727CumulativeNumberH5N1cases.pdf?ua=1
http://www.oie.int/fileadmin/Home/fr/Animal_Health_in_the_World/docs/pdf/Graf_avian_influenza/graphique_IAHP_04_12_2014.pdf

En réponse aux crises de la grippe aviaire hautement pathogène H5N1 dans la région, les organisations internationales et les différents bailleurs de la région ont mis au point plusieurs initiatives de renforcement des capacités dans les pays touchés et ont mis en place divers programmes de surveillance active (surveillance sérologique et virologique des troupeaux de canard, surveillance dans les marchés de volailles vivantes, échantillonnage d'oiseaux sauvages etc..) (FAO, 2011 a). Dans certaines régions, ces méthodes ont réussi à révéler la présence du virus ou à détecter sa circulation au tout début de la maladie dans les populations de volailles. Elles sont cependant difficiles à maintenir en raison de leur coût élevé en ressources humaines et en matériel de laboratoire. Ainsi, la surveillance passive et la déclaration volontaire des suspicions restent nécessaires au maintien de la surveillance de l'influenza aviaire hautement pathogène H5N1 dans les pays à faible revenu de la région, d'autant plus du fait du déclin actuel des financements extérieurs réguliers.

La surveillance passive (évènementielle) des maladies animales et humaines est souvent le seul type de surveillance applicable en milieu rural, même si ce type de surveillance est soumis à de nombreuses limites dans les deux secteurs. En effet, il y a clairement un manque de sensibilisation de certaines communautés qui ne parviennent pas à reconnaître, à un stade suffisamment précoce, les signes cliniques de la maladie chez les oiseaux tout comme à relier la présence de la maladie chez les animaux à des symptômes chez l'homme. S'ajoutent à ce manque de connaissances des réticences de la part des éleveurs à déclarer les cas animaux en raison des impacts négatifs directs ou indirects des mesures de lutte. Cela a souvent conduit à la découverte de la circulation de IAHP H5N1 dans une région d'abord par la détection d'un cas humain. Ces zones rurales sont de plus généralement confrontées à une pénurie de centres de santé dans le secteur humain comme dans le secteur animal, amenant la population à se tourner vers le secteur privé, les revendeurs de médicaments ou les guérisseurs traditionnels, qui ont des compétences insuffisantes et qui ne sont souvent pas impliqués dans les systèmes nationaux de déclaration des maladies. Produisant une information incomplète, biaisée ou transmise avec des délais importants, la surveillance passive a besoin d'être améliorée par de nouvelles approches mises en œuvre dans un cadre «One Health », prenant en compte les interfaces entre humains, animaux et environnement. Nous avons donc, dans cette thèse, conçu et/ou appliqué de nouvelles méthodes d'évaluation, de conception ou d'amélioration de la notification des cas d'IAHP H5N1 chez l'animal et chez l'homme en Asie du sud-est.

## OBJECTIFS

L'objectif principal de ce travail de recherche était de tester et de proposer des méthodes novatrices pour accroître la participation des communautés rurales dans la déclaration des maladies zoonotiques afin d'améliorer l'efficacité des systèmes de surveillance en santé humaine tout comme en santé animale. Cependant, faute de temps et en raison de contraintes pratiques, nous avons dû limiter notre champ d'étude, la population à cibler, les attributs de surveillance que nous voulons améliorer et, par conséquent, le type de méthodes ou d'outils à mettre en œuvre.

Nous avons concentré nos recherches principalement sur la situation de l'influenza aviaire hautement pathogène H5N1 au Cambodge, à l'exception de l'une des méthodes d'évaluation (modélisation en arbre de scénario) qui a été appliquée en Thaïlande pour des raisons pratiques. Nous avons travaillé principalement sur la sensibilité, l'acceptabilité et la rapidité de la surveillance. Nous n'avons pas pris en compte les critères économiques du fait des difficultés d'accès aux données financières sur le coût de la surveillance. Nous avons sélectionné différents outils et méthodes que nous avons considérés comme étant les plus appropriés à notre contexte de recherche (modélisation en arbre de scénario, évaluation qualitative et semi qualitative, évaluation participative, intervention pilote, analyses multivariées, analyse spatio-temporelle et analyse multicritère).

Dans ce travail, nous avons examiné deux aspects différents de la surveillance : la conception et l'évaluation, qui sont en réalité interdépendants. Une évaluation adéquate est nécessaire pour identifier les éléments clés de la surveillance à améliorer et pour être en mesure de sélectionner les outils ou les méthodes les plus appropriés pour parvenir à une amélioration.

*Les objectifs spécifiques sur l'évaluation de la surveillance*

L'évaluation est un élément clé dans l'amélioration des systèmes de surveillance. En effet, des évaluations régulières et transparentes peuvent permettre une meilleure utilisation des ressources pour la surveillance (surtout dans les zones où les ressources sont limitées). Elles permettent également une prise de décision plus objective, des améliorations dans la conception du système et une acceptation accrue des résultats du système par les intervenants au niveau local (par exemple, les agriculteurs, les vétérinaires) et au niveau national (par exemple, le laboratoire de référence, les vétérinaires au niveau central).
Plusieurs cadres d'analyse ont été utilisés en santé humaine et animale, décrivant les attributs qui peuvent être évalués afin d'estimer le rendement et l'efficacité de la surveillance. Dans ce contexte, le terme « attributs » est utilisé pour désigner les nombreuses caractéristiques quantifiables des systèmes de surveillance. Dépendants de facteurs épidémiologiques, sociologiques et économiques, les systèmes de surveillance peuvent être complexes, comme le sont les attributs pour les décrire. Selon un rapport qui compile les discussions d'experts de la surveillance lors d'un atelier qui a eu lieu en 2011 juste avant la première conférence ICAHS (International Conference on Animal Health Surveillance, Lyon, France) et qui est mis en ligne sur le site du AHVLA (http://www.defra.gov.uk/ahvla-en/disease-

control/surveillance/icahs-workshop/), on recense 29 attributs qui peuvent potentiellement être évalués. Le choix des attributs à évaluer est étroitement lié à l'objectif de l'évaluation et à l'objectif du système de surveillance. Lorsque l'on considère la surveillance de maladies zoonotiques, l'un des objectifs les plus importants consiste précisément à détecter la maladie chez les animaux afin d'éviter des cas humains. Par la suite, si une maladie zoonotique est déjà présente dans le compartiment humain, le système de surveillance doit être en mesure de la détecter et d'en identifier la source afin d'éviter une contamination. Afin d'évaluer si la composante passive de la surveillance peut assurer la détection précoce des maladies zoonotiques, et plus spécialement de l'IAHP H5N1, nous avons principalement besoin d'évaluer la qualité de la preuve fournie par le réseau de surveillance, ce qui revient à une estimation de la sensibilité de la surveillance (Se) et de sa rapidité de détection. Selon l'évolution de la maladie, la sensibilité (Se) peut être la probabilité (i) de détecter la maladie au-dessus d'un certain taux de prévalence (pour les zones indemnes de maladie) ou (ii) de détecter les vrais cas ou foyers (pour les zones ou la maladie est endémique). La rapidité d'un système de détection est souvent définie par l'intervalle de temps entre l'apparition de la maladie et la mise en place du contrôle. La sensibilité et le respect des délais dans le système de surveillance sont connectés aux autres attributs importants d'une surveillance passive, comme l'acceptabilité. Cet attribut est lié à l'adéquation et la pertinence des objectifs de la surveillance, ainsi qu'aux attentes et perceptions des intervenants qui font partie du système.
La sensibilité, la rapidité de détection et l'acceptabilité étaient considérés dans ce travail de recherche comme des attributs clés à évaluer. Nous avons ainsi sélectionné plusieurs méthodes d'évaluation afin de vérifier leur utilité dans la situation des pays en développement et dans le but de fournir des indications sur la façon dont ils peuvent être appliqués.

Nous avions trois objectifs spécifiques selon le type de méthode choisie :

(1) examiner la faisabilité des méthodes qualitatives et semi quantitatives de l'évaluation des systèmes de surveillance (en santé humaine et animale) et les appliquer à notre contexte d'étude ;

(2) appliquer des méthodes de modélisation d'arbre de scénario dans un pays en voie de développement ;

(3) développer une méthode participative d'évaluation afin de souligner la valeur de la participation au processus d'évaluation de la surveillance.

*Les objectifs spécifiques sur la conception des systèmes de surveillance*

Dans des contextes où les ressources pour la surveillance sont restreintes et souvent tributaires de financements extérieurs incertains et variables, une priorité doit être placée sur l'utilisation de méthodes de surveillance rentables telles que l'utilisation de téléphones portables ou de la surveillance basée sur le risque. Une autre priorité conviendrait à l'élaboration de programmes de formation sur mesure pour les auxiliaires de santé animale afin d'améliorer leur pérennité, l'acceptabilité des activités de déclaration et de permettre une allocation optimale des ressources. Dans ce travail de recherche, nous avons sélectionné et testé quatre approches différentes qui pourraient être utilisés pour concevoir une surveillance plus efficace. L'utilisation des téléphones mobiles pour déclarer la mortalité animale, l'évaluation des critères qui pourraient influer sur l'efficacité des auxiliaires de santé animale dans la surveillance, l'utilisation de l'analyse spatio-temporelle pour comprendre la propagation de la maladie au niveau local et les analyses multicritères afin d'élaborer une carte de risque de l'IAHP H5N1 chez l'homme.

Nous avions trois objectifs spécifiques pour cette section :
(4) tester la faisabilité de l'utilisation de téléphones mobiles par les auxiliaires de santé animale pour déclarer la mortalité animale ;
(5) valider nos outils d'évaluation participative et utiliser les résultats afin de proposer des recommandations pour la formation des auxiliaires de santé animale ;
(6) mieux comprendre le risque d'infection humaine associé à la propagation de la maladie au niveau local, afin de produire une carte de risque pour la conception de surveillance basée sur le risque.

Dans la dernière partie de l'étude, nous avons mis en place une analyse systématique des projets de recherche menés par le CIRAD sur les systèmes de surveillance à Madagascar et au Cambodge. Nous avons produit une synthèse narrative des résultats de la recherche afin d'analyser et de revoir leur faisabilité, dans le but de déterminer leurs avantages et de stratégiquement formuler des recommandations et des interventions efficaces et ciblées.
L'objectif (7) de cette section était de fournir des recommandations génériques pour l'amélioration des méthodes de surveillance dans les milieux pauvres.

LES ETUDES DE RECHERCHE

Afin d'atteindre notre objectif principal et les objectifs spécifiques détaillés dans la section précédente, neuf (9) études ont été mises en œuvre (Table 2) :

(1) Evaluation semi-qualitative de la surveillance IAHP H5N1 chez les animaux à l'aide de l'outil d'analyse des systèmes de surveillance pour les pays tropicaux (SNAT Trop) au Cambodge.

(2) Evaluation qualitative de la surveillance IAHP H5N1 dans les populations humaines et animales à l'aide de la méthode "Faiblesses, Opportunités, Menaces, Forces" (SWOT) au Cambodge.

Au cours de ces deux études, nous avons réalisé une évaluation critique de l'organisation et du fonctionnement de la surveillance au Cambodge de l’IAHP H5N1 dans les populations humaines et animales en utilisant des méthodes qualitatives et semi-qualitatives afin de produire des recommandations pour améliorer la détection précoce des foyers et d'intégrer surveillance humaine ET animale.

(3) Evaluation quantitative du système de surveillance IAHP H5N1 dans la population de volaille traditionnelle en Thaïlande en utilisant l'analyse d’arbres de scénarios (STA Thai). Nous avons développé un arbre de scénarios stochastiques pour modéliser et évaluer le système de surveillance de l’influenza aviaire à H5N1 en Thaïlande dans les systèmes traditionnels (basse-cour et volailles en parcours libres). L'objectif était d'estimer la sensibilité de chacune des composantes de la surveillance, et plus spécifiquement la sensibilité de la surveillance passive, afin de démontrer l'utilité de cette méthode pour évaluer l’absence de la maladie dans les pays à ressources limitées.

(4) Conception d'une grille d'évaluation participative pour les agents communautaires/villageois en santé animale (PE VAHW) au Cambodge. L'objectif était d'impliquer, par des méthodes participatives, les agents villageois de santé animale dans leur propre évaluation afin d'améliorer leur participation active à la surveillance de l'IAHP H5N1, et plus particulièrement en termes de déclaration des cas.

(5) L'analyse multivariée des facteurs qui influencent l'efficacité des agents villageois en santé animale (EF VAWH) au Cambodge. L'objectif était de valider la grille d'évaluation participative conçue dans l'étude 4, en évaluant le niveau d'efficacité de 251 agents dans trois provinces limitrophes du Vietnam.

(6) Étude pilote sur les apports de la téléphonie mobile (REPORTING SMS). Nous avons défini et mis en place une étude pilote pour tester l'utilisation de la messagerie par téléphone

mobile avec 112 volontaires de 68 villages. L'objectif était d'obtenir des données de mortalité de référence afin de détecter les pics de mortalité et d'identifier les épidémies de maladies infectieuses plus rapidement.

(7) Analyse spatio-temporelle des foyers de IAHP H5N1 au Cambodge (STC Analysis). Les villages déclarés officiellement infectés représentent souvent la pointe de l'iceberg ; les délais entre le premier cas et sa détection permettent la propagation du virus de maison en maison, de village en village, par transmission directe ou indirecte. Cette étude visait à comprendre comment la propagation locale a eu lieu et à identifier les déterminants les plus importants dans cette propagation afin de limiter le nombre et la taille des futurs foyers dans les populations de volailles.

(8) La cartographie des risques d'infection à H5N1 chez les humains (MCDA) au Cambodge. Dans la dernière section, nous avons utilisé l'analyse spatiale combinée à l'analyse décisionnelle multicritères (MCDA) pour réaliser une carte représentant le risque d'infection humaine au Cambodge. Cela permet d'ajuster et de renforcer la surveillance dans les zones où il y a des risques accrus d'apparition de la maladie.

(9) Pour conclure ce travail sur les outils et méthodes destinés à l'amélioration des systèmes de surveillance dans les régions des pays les moins avancés, nous avons effectué une analyse comparative (revue narrative) du Cambodge et de Madagascar en termes de surveillance. L'objectif était de proposer de nouvelles approches en surveillance pour des pays à environnements socio-économiques difficiles.

**Tableau 2: Correspondance entre les objectifs spécifiques de la thèse et des études de terrain.**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1- examiner la faisabilité des méthodes qualitatives et semi quantitatives de l'évaluation de systèmes de surveillance (en santé humaine et animale) et les appliquer à notre contexte d'étude. | | | | | | | | | |
| 2- appliquer des méthodes de modélisation d'arbre de scénario dans un pays en voie de développement. | | | | | | | | | |
| 3- de développer une méthode participative d'évaluation afin de souligner la valeur de la participation au processus d'évaluation de la surveillance. | | | | | | | | | |
| 4- tester la faisabilité de l'utilisation de téléphones mobiles par les auxiliaires de santé animale pour déclarer la mortalité animale. | | | | | | | | | |
| 5- valider nos outils d'évaluation participative et utiliser les résultats afin de proposer des recommandations pour la formation des auxiliaires de santé animale. | | | | | | | | | |
| 6- mieux comprendre le risque d'infection humaine associé à la propagation de la maladie au niveau local, afin de produire une carte de risques pour la conception de surveillance basée sur le risque. | | | | | | | | | |
| 7- fournir des recommandations génériques pour l'amélioration des méthodes de surveillance dans les milieux pauvres | | | | | | | | | |

ORGANISATION ET PLANNING DES ETUDES

Ces neuf études ont été réalisées sur une période de 4 ans (de 2010 à 2012, puis en 2014), comme le montre le tableau 3.

**Tableau 3: Planning des neuf études au cours de 4 années de recherche**

| | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|
| Collecte de données pour l'analyse qualitative du système de surveillance animal | | | | | |
| Mise en place de la mèthode SNAT | | | | | |
| Collecte de données pour l'analyse qualitative du système de surveillance huamain | | | | | |
| Mise en place de les arbres de scénario en Thailande | | | | | |
| Evaluation participative | | | | | |
| Analyse multifactorielle des scores d'effectivités des VAHWs | | | | | |
| Etude pilote sur les déclarations par SMS | | | | | |
| Investigation de foyers pour les analyses spatio-temporelles | | | | | |
| Analyse par décisions multicritères | | | | | |
| Synthèse narrative: comparaison entre Madagascar et le Cambodge | | | | | |

La majorité des études ont été financées par le programme REVASIA (Research for Evaluation of Avian Influenza Surveillance in South East Asia), programme pris en charge tout d'abord par la "Direction Générale de l'Alimentation" (DGAL), puis par l'Agence Française de Développement (AFD), http://revasia.cirad.fr/en/ .

La figure 1 représente un résumé des sujets de recherche ainsi que des différents terrains utilisés au cours de cette thèse. Concernant la section dédiée à l'évaluation, nous avons décrit le type d'outils ou de méthodes utilisés (en bleu) en lien avec le niveau de l'évaluation mise en place (e.g. évaluation globale du système ou évaluation d'un seul attribut (sensibilité) - en rouge). Pour la section sur la conception des systèmes de surveillance, nous avons décrit le type d'outils ou de méthodes utilisés (en bleu), la composante de surveillance concernée par l'amélioration (collecte d'information, conception basée sur le risque, formation, - en noir) en lien avec l'attribut de surveillance affecté (couverture, acceptabilité, sensibilité, spécificité, - en rouge).

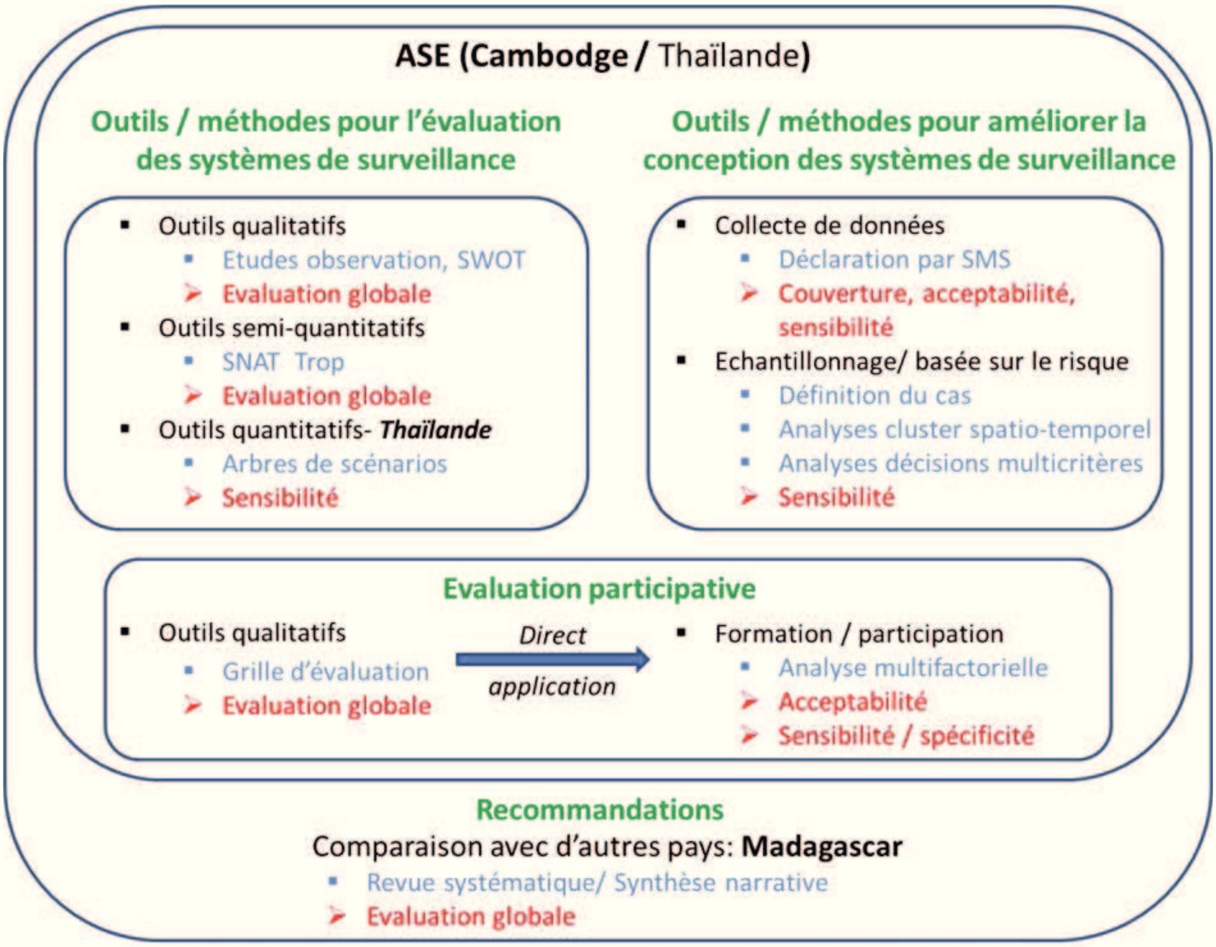


**Figure 1: Schéma illustrant les relations entre les 9 études réalisées au Cambodge et en Thaïlande, entre 2010 et 2014, afin d'améliorer la surveillance des maladies zoonotiques en zones rurales défavorisées.**

RESULTATS DES DIFFERENTES ETUDES DE RECHERCHE

*Méthodes d'évaluation des systèmes de surveillance*

1. Principaux résultats de l'évaluation de la surveillance de l'IAHP H5N1 au Cambodge

a-) Evaluation qualitative des deux systèmes

L'influenza aviaire hautement pathogène (IAHP) H5N1 est actuellement considérée comme endémique dans les populations de volailles du Cambodge, avec l'existence d'un nouveau virus de clade 1.1A détecté uniquement dans ce pays (Sorn et al., 2013). Dans de nombreux cas, la maladie diagnostiquée H5N1 est d'abord rapportée chez l'Homme entraînant par la suite une enquête en élevage.

Les deux systèmes de surveillance, animale et humaine, reposent sur un vaste réseau de bénévoles au niveau du village : les agents villageois de santé animale pour le secteur vétérinaire et les volontaires de santé villageois (VSV) (ou les membres des groupes de soutien de santé villageois) pour le secteur de la santé publique. Ces bénévoles ne sont pas payés par le gouvernement. Dans le secteur de la santé publique, la majorité des VSV reçoivent des incitations des ONGs alors que les agents villageois de santé animale doivent générer leurs propres revenus. L'efficacité de la détection de la maladie dépend de la qualité de la relation qui existe entre le bénévole et le patient ou l'éleveur. Dans les deux systèmes, ce lien est généralement ténu. En santé publique, comme mentionné lors de nos entretiens et dans la littérature scientifique, les patients se méfient généralement du secteur public préférant d'abord chercher l'aide du secteur privé (55,5% des patients pour la première consultation) ou du secteur non médical (6% les patients) (NIS, 2011). L'absence d'implication du secteur privé au système de surveillance de santé publique retarde alors souvent le temps de détection d'un cas de H5N1. Dans le système de surveillance vétérinaire, l'option de contrôle appliquée par le gouvernement, à savoir l'abattage de toutes les volailles présentes dans le village, et ce sans compensation aucune, est redoutée par les éleveurs et les agents communautaires. Par conséquent, pour la grande majorité des personnes interrogées, la première stratégie consiste à gérer les foyers localement. Certains éleveurs utilisent des désinfectants virucides eux-mêmes (le plus souvent TH4 + qui est une combinaison synergique de composés de glutaraldéhyde et d'ammoniums quaternaires), ou parfois avec l'aide du service vétérinaire local quand il une relation de confiance est établie entre eux. Mais le plus souvent les éleveurs préfèrent vendre leurs animaux malades, ou suspects, à d'autres villages afin d'éviter une perte économique importante en cas abattage obligatoire.

Un autre parallèle entre les systèmes de surveillance humaine et vétérinaire est la présence de composantes de surveillance actives financées par des bailleurs externes (sur les marchés de volailles vivantes ou dans des fermes de canards sentinelles ; surveillance syndromique fébrile chez l'Homme). Ces composantes sont souvent plus sensibles et permettent une détection virale. Sur les marchés de volailles vivantes, le virus est régulièrement détecté chez des animaux ou dans des échantillons environnementaux (18% des échantillons ont été trouvés positifs, et 2% ont permis un isolement viral (Horm et al., 2013)). Cependant, aucune mesure n'est prise et il est généralement impossible de connaître l'origine de ces animaux. Chez l'homme, cette surveillance active a permis la détection de 4 cas humains (voir annexe 12), mais la couverture réelle de la population reste très faible. Même si les méthodes de surveillance active ont réussi à démontrer la présence du virus, elles sont trop coûteuses pour être maintenues durablement par les autorités nationales, en particulier avec la diminution post-crise des aides financières.

Un défaut commun entre le système humain et animal a été mis en évidence : l'absence d'une stratégie d'évaluation interne régulière. En effet, les deux systèmes ont été évalués seulement de manière partielle.

Pour le système de surveillance animal, une mission d'évaluation menée par l'OIE a été mise en place en juillet 2007, basée sur l'utilisation de l'instrument PVS. L'objectif de cette évaluation était d'évaluer les points forts des services vétérinaires et leurs capacités à répondre aux normes de l'OIE (Hamilton et Brückner, 2010). Cette évaluation a été suivie par une mission d'analyse des carences en janvier 2011 (Weaver et al., 2011), mais très peu d'éléments de cette évaluation concernaient la surveillance de l'IAHP H5N1. Depuis lors, et au moment de la rédaction, aucun projet n'a été fait pour la mise en œuvre d'une évaluation systématique du système de surveillance des animaux.

Pour le secteur de la santé publique, une évaluation globale a été menée en octobre 2006, par le Ministère de la Santé cambodgien. Le ministère a réuni plusieurs agents et acteurs impliqués dans le système de santé pendant trois jours, et leur a demandé de remplir des questionnaires. Les résultats ont révélé l'absence de mécanisme d'incitation aux déclarations, l'absence d'évaluations de l'exhaustivité ou de la cohérence des rapports de terrain, ainsi qu'un taux de déclaration de seulement 50% des épidémies au niveau du district. Un deuxième atelier a été organisé en 2008 pour produire un plan stratégique sur le Système d'information en santé (Département de l'information de la planification et de la santé, 2008). L'objectif principal était de définir et d'utiliser des indicateurs d'évaluation pour 2015.

b- Evaluation qualitative et comparaison par la méthode SWOT

L'analyse SWOT (Forces, Faiblesses, Opportunités et Menaces) pour le système de surveillance animale a été effectuée après les entrevues qui ont été mises en œuvre au cours des visites de terrain avec le personnel impliqué au niveau central, au niveau des provinces et des districts. Nous avons tout d'abord fourni un tableau avec les forces et les faiblesses des systèmes de surveillance passive de l'influenza aviaire hautement pathogène H5N1 comme mentionné par les personnes interrogées (tableau 4). Ce tableau a été validé par le coordonnateur du système de surveillance. Puis, nous avons inclus les données qui avaient été recueillies au cours des entretiens accomplis avec les responsables des différentes composantes du système de surveillance de la santé publique. Cette analyse SWOT des deux systèmes (tableau 10) a été présentée, discutée et validée lors d'un atelier organisé par la FAO à Phnom Penh en Mai 2012 portant sur la surveillance de l'Influenza aviaire et des maladies infectieuses émergentes, et sur l'intervention au Cambodge. L'atelier a réuni 42 participants représentant les différentes institutions œuvrant dans le domaine de la surveillance au Cambodge (le MAFF, le DAHP, le NaVRI, le Ministère de la Santé, l'IPC, l'OMS, le WCS, l'USAID et la FAO). Cet atelier visait à examiner les objectifs de la stratégie actuelle de surveillance IAHP H5N1 faite au Cambodge et à identifier des options pratiques, mettant l'accent sur la collaboration multisectorielle en vertu de l'approche One Health, pour améliorer la surveillance de l'IAHP H5N1.

**Tableau 4: Forces et faiblesses du système de surveillance passif de l'IAHP H5N1 chez la volaille au Cambodge en fonction du niveau administratif.**

| Forces | Faiblesse |
|---|---|
| **Unité centrale** | |
| NaVRI est le point focal de la surveillance et des analyses de laboratoire.<br>Appuis de l'IPC pour la confirmation des cas de H5N1.<br>Projets financés par l'USAID et la FAO.<br>Objectifs bien définis de la surveillance.<br>Utilisation d'outils précis : procédures de notification, collecte d'échantillons, formulaires de déclaration, définition des cas.<br>Efficacité du laboratoire. | Pas de définition claire de l'organisation institutionnelle (pas de coordonnateur officiel).<br>Absence de réglementation spécifique.<br>Aucun budget spécifique pour la surveillance.<br>Personnel pas assez qualifié, manque de moyens.<br>Besoin de bases de données relationnelles entre les différentes composantes de la surveillance. |
| **Niveau du Vétérinaire de Province** | |
| Bonne sensibilisation des PV sur les besoins de surveillance et le H5N1.<br>Disponibilité de véhicules, de matériel de prélèvement et de biosécurité.<br>Gestion régulière (avec les réunions trimestrielles au niveau central).<br>Formations régulières des PV. | Aucun budget spécifique pour la surveillance.<br>Multiplication des tâches avec peu de personnel (pas d'unité d'épidémiologie au niveau régional).<br>Manque d'activités prévues selon la surveillance.<br>Absence de budget d'intervention de terrain.<br>Aucune réglementation sur la procédure de notification.<br>Aucun moyen d'indemniser les agriculteurs (manque de confiance des agriculteurs). |

| **Niveau du Vétérinaire de District** | |
|---|---|
| Bonne répartition géographique.<br>Bonne sensibilisation sur le H5N1 et la biosécurité.<br>Réunions régulières au niveau régional (tous les mois).<br>Contacts réguliers avec VAHW (réunions mensuelles).<br>Une bonne communication avec le PV. | Aucun budget spécifique pour la surveillance.<br>Seuls pour de grandes superficies.<br>Aucune standardisation de la collecte de données.<br>Aucun équipement d'échantillonnage.<br>Aucune activité prévue sur la surveillance.<br>Manque de confiance de l'agriculteur.<br>Peu de connexion avec VHWs. |
| **VAHW** | |
| Grand nombre avec une bonne répartition géographique.<br>Réunions régulières au niveau des districts.<br>Une bonne communication avec les DV.<br>En relation étroite avec les agriculteurs. | Hétérogénéité de la formation/connaissance.<br>Niveau disparate de sensibilisation au H5N1.<br>Fréquence des contacts avec le DV selon la distance (aucun moyen de transport).<br>Pas capable de vivre de leurs activités.<br>Pas de déclarations standardisées.<br>Dépendent de la confiance des agriculteurs donc réticents à déclarer H5N1.<br>Aucun lien avec VHW.<br>Concurrence entre VAHW. |

**Tableau 5: Analyse SWOT et comparaison des deux systèmes de surveillance du IAPH H5N1 au Cambodge.**

| | **INTERNE** | | **EXTERNE** | |
|---|---|---|---|---|
| | Forces | Faiblesses | Opportunités | Menaces |
| Système de surveillance animal | Objectifs bien définis.<br>Outils précis conçus pour la surveillance (formulaires de déclaration, définition de cas...).<br>Efficacité du laboratoire.<br>Réunions régulières à différents niveaux (province, centrale, VAHW). Bonne répartition géographique (VAHW). | Pas de coordinateur officiel pour la surveillance.<br>Non-respect des procédures de notification.<br>Aucune évaluation interne ou externe du système.<br>Aucun retour d'information aux agriculteurs.<br>Hétérogénéité et durabilité médiocre des VAHW.<br>Manque d'incitations pour les agriculteurs ou VAHW. | Mise en œuvre de l'outil PVS de l'OIE et de l'analyse des lacunes.<br>La FAO a financé des projets de surveillance.<br>Projets financés par l'USAID.<br>Possibilités de formation (FAO, USAID, FEPTv).<br>Appuis de l'IPC pour la confirmation des cas de H5N1<br>Collaboration avec le ministère de la santé. | Manque de reconnaissance du NaVRI comme unité centrale.<br>Manque de budget spécifique et durable pour la surveillance.<br>Impact négatif de la politique de contrôle pour les agriculteurs et le personnel vétérinaire.<br>Absence d'une approche globale de la surveillance (évaluation non axée sur les risques…)<br>Peu de liens avec les VHW.<br>Aucune politique de compensation. |
| Système de surveillance humain | Objectifs bien définis.<br>Outils précis pour la surveillance (formulaires de déclarations).<br>Système de notification par SMS (standardisation et régularités des rapports).<br>Réunions régulières.<br>Couverture élevée (VHW…).<br>Soutien des ONG aux VHW.<br>Soutien des organisations internationales (IPC, NAMRU, AFRIMS) dans la surveillance. | Aucune évaluation interne ou externe du système.<br>Hétérogénéité des VHW.<br>Manque de confiance des particuliers dans le secteur public.<br>Manque de matériel de diagnostic au niveau local.<br>Faible sensibilité du système pour le H5N1 au niveau local. | Projets financés par l'USAID, le CDC. Collaboration avec le MAFF. Développement de nouvelles lignes directrices pour la surveillance des zoonoses.<br>Nouveau règlement pour la gestion de VHW.<br>Existence d'une Université Médicale. | Aucun système de régulation sur le rôle des ONG dans la surveillance et sur la formation des VHW.<br>Secteur privé non inclus dans le système de surveillance.<br>Faible sensibilité du système de surveillance vétérinaire pour détecter les cas de H5N1.<br>Aucune réglementation sur le secteur privé.<br>Absence d'assurance de santé. |

2. Méthodes d'évaluation quantitative de la surveillance en Thaïlande dans le secteur avicole traditionnel

Nous avons appliqué la méthode des arbres de scénarios dans un contexte de pays émergent, en utilisant un avis d'experts pour compenser le manque de données disponibles (Martin et al., 2007). La méthode nous a permis de quantifier, de manière transparente et structurée, la sensibilité (Se) de la composante de surveillance passive. En utilisant un modèle de simulation, nous avons pu mettre en évidence les paramètres critiques de cette sensibilité : par exemple, la probabilité que les propriétaires d'une ferme avicole déclarent la maladie aux autorités sanitaires vétérinaires. Lorsque nous avons comparé les trois composantes de surveillance : passive (SSC1), active sur des cas cliniques (SSC2) et active par prélèvements (SSC3) ; nous avons montré que la sensibilité « pays » des deux composantes SSC2 et SSC1 avaient des valeurs similaires, avec des moyennes respectives de 0,49 et 0,50 ; et que la composante SSC3 a une sensibilité plus basse avec une valeur moyenne de seulement 0,25 mais avec un coût beaucoup plus élevé. Nous avons calculé qu'au cours des deux mois (Janvier et Juin) ou les 3 composantes sont mises en place de façon simultanée, la surveillance a une probabilité élevée (82%) de détecter la maladie à un stade précoce (seulement 3 fermes infectées). Nos résultats montrent également que la composante SSC3 (basée sur la recherche active de signes cliniques dans les fermes situées en zones à haut risque) est la plus efficace en raison certainement de la sensibilité élevée de la définition de cas utilisée. Nous avons en plus démontré que l'utilisation d'une surveillance basée sur le risque permet d'avoir une sensibilité 3,24 fois plus élevée qu'une surveillance basée sur un échantillon représentatif de la population. La sensibilité élevée de SSC1 (surveillance passive) peut sembler surprenante, mais elle est sans doute la conséquence d'une campagne de sensibilisation très intensive entreprise par le gouvernement thaïlandais et de la présence d'agents communautaires dans chaque village. Nous sommes conscients que cette estimation reste subjective et qu'elle nécessite d'être régulièrement réévaluée car elle est susceptible de changer au fil du temps, notamment si le pays reste indemne de la maladie ce qui entrainerait une perte d'intérêt des éleveurs envers la surveillance de la grippe aviaire. (Hadorn et Stark, 2008b).

3. Développement d'une grille d'évaluation des agents communautaires en santé animale

Nous avons développé notre propre méthode participative pour recueillir des informations de la part des « agents villageois de santé animale » (ou agents communautaires), utilisées pour la construction d'une grille de critères permettant leur évaluation. Dans ce cadre, plusieurs approches participatives ont été utilisées comme les arbres à problèmes, les entretiens semi-structurés, le classement par paires et les groupes de discussion. La grille a été conçue avec l'aide d'acteurs impliqués dans le système de santé animale au Cambodge afin (i) d'identifier les fonctions des agents communautaires ; (ii) de mettre en place des critères et des questionnaires associés, et (iii) de remplir la grille avec tous les acteurs. L'outil a été organisé en cinq critères d'évaluation : la durabilité, le traitement, la production, la vaccination et la déclaration des maladies. Des indicateurs locaux ont été développés et utilisés par les agents eux-mêmes, ce qui devrait conduire à une amélioration de l'acceptabilité de cette évaluation. Cette méthode vise à amener les décideurs et autres acteurs à entrer dans un processus d'apprentissage mutuel. Elle devrait permettre la construction d'une confiance réciproque entre les agents communautaires et les représentants officiels de la santé animale, et ainsi favoriser les actions correctives après l'évaluation.

***Méthodes sur la conception des systèmes de surveillance***

1. Identification des facteurs améliorant le réseau d'agents communautaires

A partir de notre analyse multivariée, plusieurs facteurs ont été identifiés comme étant significativement associés à un score d'évaluation élevé des « agents villageois de santé animale » au Cambodge (Tableau 6). Ainsi, un bon score d'évaluation est fortement corrélé à l'organisation de réunions régulières avec le vétérinaire de district, au nombre de bovins présents dans le village et au fait de faire partie d'une association d'agents communautaires. D'autres facteurs liés à l'organisation de la formation - tels que la présence de cours de recyclage, l'utilisation de travaux pratiques au cours de la formation initiale ou de la durée de la formation (score plus élevé si la formation a duré au moins 30 jours) - sont également statistiquement corrélés à l'obtention d'un bon score d'évaluation.

**Tableau 6: Facteurs associés à un score d'évaluation élevé pour les VAHWs, obtenus par une régression linéaire multivariée à partir des données collectées lors de l'évaluation de 3 provinces du Cambodge entre Novembre 2011 et Janvier 2012.**

| Facteur | Coefficient | p | Intervalle de confiance à 95% | VIF |
|---|---|---|---|---|
| Ordonnée | 12.32 | 0.002 | [4.75 – 19.89] | |
| Durée de formation | | | | |
| <30 | base | . | | |
| >30 | 0.16 | 0.048 | [0.01– 0.32] | 1.04 |
| Cours de recyclage | 6.47 | 0.0001 | [2.97 – 9.97] | 1.06 |
| Travaux pratique | 7.02 | 0.007 | [1.97 – 12.07] | 1.06 |
| Membre d'une association | 7.47 | 0.001 | [2.91 – 12.02] | 1.13 |
| Nombre de bovin | | | | |
| <100 | base | . | | 1.78 |
| 100-200 | 6.46 | 0.018 | [1.12 – 11.81] | 1.92 |
| 200 | 12.50 | 0.0001 | [7.77 – 17.22] | |
| Réunion avec le DV | 14.62 | 0.0001 | [10.67 – 18.56] | 1.17 |

F= 28.08 , $p<0.001$, n=251, $R^2$= 0.4814, Adj $R^2$= 0.4642, VIF (Facteur d'inflation de la Variance)

2. Faisabilité des déclarations par SMS au Cambodge

Tout au long des 13 semaines de mise en œuvre de l'étude pilote, le taux de participation a diminué régulièrement, passant de 98,28% à 13% d'agents communautaires actifs dans la déclaration. La même tendance est apparue dans le taux de participation des chefs de village avec dans leur cas, un plus grand taux d'erreur (18,93%) et un plus grand nombre de valeurs aberrantes (5%) dans leurs SMS. Cette baisse d'intérêt s'est produite malgré l'organisation d'une visite de terrain deux mois après le début de l'étude. Cette visite de terrain nous avait permis de rencontrer tous les participants et de faire un sondage sur leur volonté à poursuivre l'étude pilote. Ainsi, 98% des participants étaient satisfait de l'étude et voulaient continuer.

Aucun des envois de SMS n'a été suivi d'une visite des services vétérinaires, et seulement 17 participants ont reçu un appel téléphonique des services centraux afin de vérifier la validité de leurs SMS et des signes cliniques qu'ils avaient observé.

La répartition des taux de mortalité hebdomadaires chez les porcs, les canards et les poulets a été estimée et le 95ème percentile a été calculé afin d'aider les services vétérinaires à identifier un taux de mortalité anormal. Les seuils suivants ont été estimés : 20% de mortalité hebdomadaire pour les porcs, 3,6% pour les canards et 13,7% pour les poulets.

3. Utilisation des SIG pour la conception d'une surveillance basée sur le risque

Deux sites de foyers ont été étudiés suite à la confirmation de cas d'IAHP H5N1 chez des volailles ou chez l'homme. Sur ces foyers nous avons utilisé une « définition de cas » basée sur des signes cliniques pour identifier les cas supplémentaires autour des premiers villages confirmés comme infectés. Dans notre première enquête menée dans la province de Takeo, sur 209 villages enquêtés, 115 villages ont été trouvés positifs à notre « définition de cas » ; dans le second site d'investigation, dans la province de Prey Veng, sur 229 villages enquêtés, 39 ont été trouvés positifs. Ces résultats ont montré qu'entre 17% et 55% des villages n'ont pas déclaré de suspicions d'influenza aviaire aux autorités compétentes au cours des 4 mois où la maladie circulait dans les provinces.
Par analyse spatiale, nous avons pu détecter les cas index et calculer la période écoulée entre le cas index et le premier cas signalé aux autorités (83-87 jours), ainsi que la durée possible des foyers (entre 2,5 et 4 mois). La répartition spatiale des cas pour Takeo semble montrer une corrélation entre la propagation de la maladie et la présence de routes principales. La densité de canard et la présence de rizières sont également fortement associées à la suspicion d'IAHP H5N1 dans les villages.

Les cartes de risques sont généralement produites à partir de l'analyse spatiale des cas confirmés et de leur corrélation avec les facteurs existants. Dans le cas du Cambodge, le nombre de cas de IAHP H5N1 chez les volailles (et certainement le nombre de cas humains à H5N1) est sous-estimé en raison de la faible performance des systèmes de surveillance. Malgré cela, l'analyse décisionnelle multicritère spatialisée nous a permis de produire des cartes indiquant le risque de propagation de l'IAHP H5N1 dans la population aviaire et d'estimer le risque d'infection humaine par ce virus.

La carte représentée dans la figure 2 nous montre la distribution du risque d'infection humaine à IAHP H5N1 à partir de l'analyse décisionnelle multicritères. Certaines des zones sur la carte, en orange et jaune, sont plus à risque d'infection que le reste du pays, où la probabilité d'infection humaine atteint les 0.59. En superposant les cas humains confirmés depuis 2004 à notre carte, nous avons remarqué que la plupart de ces cas sont survenus dans les zones où le risque prévu était le plus élevé (en jaune et orange sur la carte), ce qui valide en partie notre méthode d'estimation des risques.

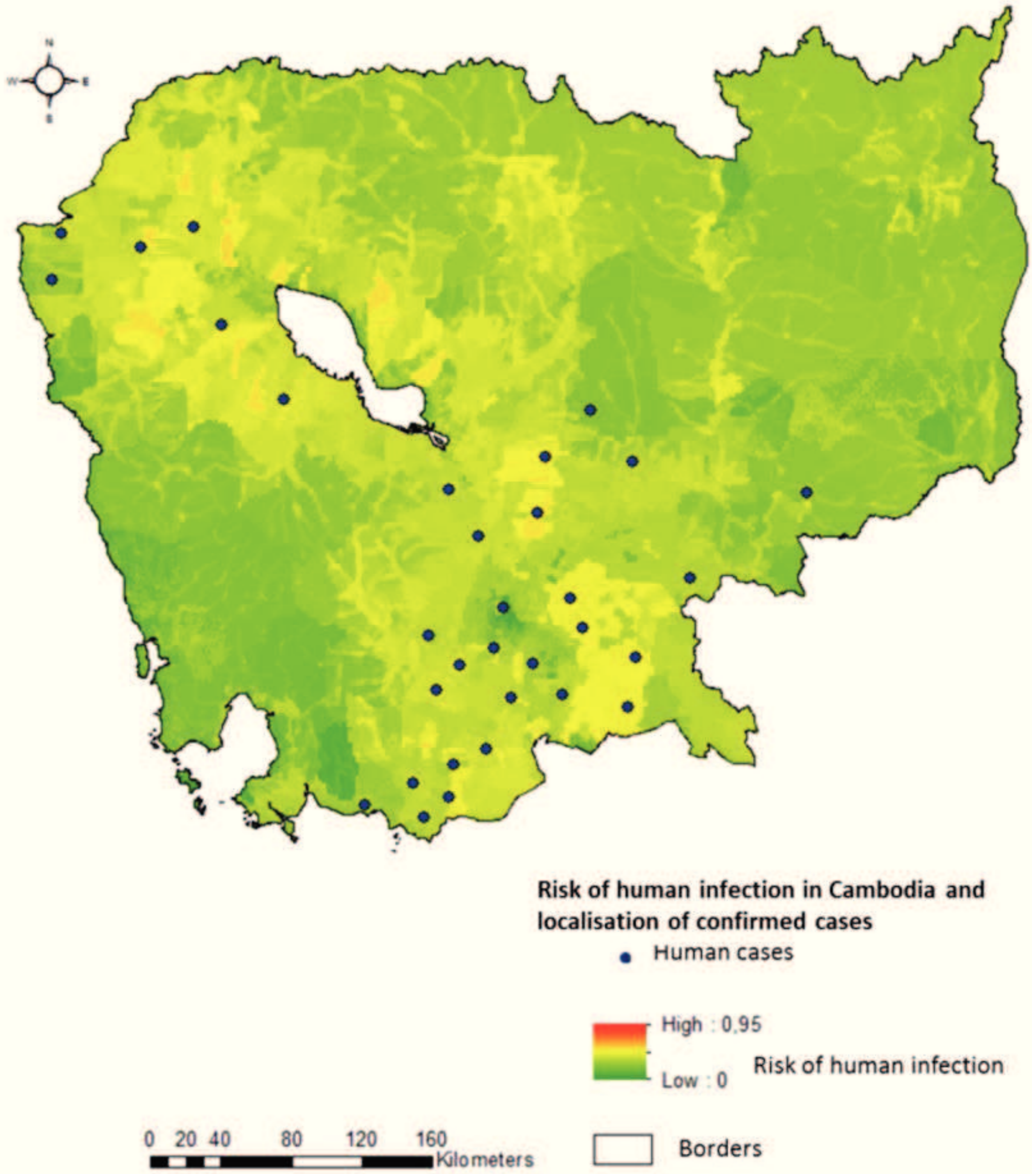


**Figure 2: Carte de répartition du risque d'infection humaine IAHP H5N1 au Cambodge par l'utilisation de l'analyse multicritères avec 10 experts en 2014 et la localisation des cas humains confirmés depuis 2004.**

Dans notre modèle, les facteurs de risque ayant le poids le plus élevé pour les risques d'infection humaine sont la présence de foyers précédents dans le voisinage et la densité de canards en libre parcours. Cependant, il est à noter que les zones à haut risque d'infection ne sont pas corrélées avec les régions hébergeant les populations les plus pauvres. Ceci pourrait être expliqué par la faible densité de canards en liberté dans ces régions, diminuant ainsi le risque d'infection.

4. Revue narrative et recommandations générales pour les pays en développement

Trente-trois documents ont été extraits d'une revue systématique sur les recherches menées par le Cirad sur la surveillance sanitaire à Madagascar et au Cambodge. Ces documents ont tous été intégrés dans la synthèse de connaissance que nous avons produite. Les principales limites des outils ou méthodes mis en œuvre ou décrits dans les documents sont leur manque de représentativité, de spécificité, de durabilité et de simplicité. Les principaux avantages sont leur sensibilité, la possibilité d'appropriation, leur utilité et leur flexibilité d'utilisation. Pour surmonter les déficiences importantes dans les systèmes de surveillance, diverses méthodes ou outils ont été évalués avec des succès variables. Certaines de ces méthodes (par exemple, la surveillance participative) ont confirmé leur efficacité et pourraient être reproduites dans d'autres contextes. D'autres méthodes ont montré un certain potentiel (par exemple, la transmission de données via SMS), mais auront besoin d'adaptations pour être vraiment efficace dans de tels contextes. Cela pourrait se faire en particulier au travers un dialogue et le partage d'expériences entre les chercheurs travaillant dans différents contextes. Enfin, certaines méthodes telles que la surveillance syndromique ont été jugées trop complexes à mettre en œuvre telles quelles.

OPTIONS ET RECOMMANDATIONS

Pour la surveillance des zoonoses, l'intégration de différentes approches dans la conception des systèmes de surveillance pourrait aider à surmonter certaines des contraintes inhérentes aux pays les moins avancés. La surveillance axée sur les risques doit être préconisée, mais avec une approche « Une seule santé/One Health » dans laquelle les facteurs de risque pour la santé animale et publique sont inclus, et où les décisions concernant la planification, l'exécution et le budget sont prises conjointement. En mutualisant moyens et ressources humaines, l'approche « One Health » permettrait d'être plus rentable que deux types de surveillance séparés. Selon (Barboza et al., 2013), « une seule surveillance » permet de combiner les systèmes de surveillance humaine et animale et pourrait ainsi augmenter la détection des cas HPAI H5N1 chez l'homme de 57% à 93% et les épizooties de 40% à 53 %. Cependant, il reste nécessaire (i) de démontrer la faisabilité de l'intégration de la surveillance humaine et animale pour l'influenza aviaire et d'autres zoonoses et (ii) d'évaluer l'impact de la surveillance intégrée entre Homme et animal. En effet, il n'existe encore que peu de preuves démontrant la valeur ajoutée de cette « OH surveillance ». Certaines études au sein de populations pastorales en Afrique exposent les multiples avantages du « One Health », tels que la réduction du risque d'émergence d'une zoonose, un meilleur accès aux soins de santé primaire et une amélioration globale de la santé animale et humaine (Greter et al., 2014). Cependant, il n'existe pas de méthodologie clairement définie pour l'évaluation quantitative des activités « One Health ». Cette insuffisance est actuellement traitée au sein d'un nouveau réseau européen (NEOH : Network for Evaluation of One Health, http://neoh.onehealthglobal.net/), coordonné par le Royal Veterinary College de Londres, et dans lesquels nous sommes impliqués depuis novembre 2014. Son principal objectif est de développer un cadre pour évaluer l'efficacité économique des initiatives existantes d'une seule santé et d'étudier les facteurs qui influencent ses performances.

Pour surmonter les problèmes de sous-déclaration, les sources de données dans les pays les moins avancés devraient être davantage fondées sur les connaissances des éleveurs, en utilisant en particulier des approches participatives. Ces approches permettent en effet d'explorer les réseaux d'information communautaires et utilisent une gamme de méthodes et d'outils (entretiens semi-structurés avec des informateurs clés, notations et techniques de visualisation) qui conduisent les communautés à partager leurs connaissances traditionnelles sur les caractéristiques cliniques et épidémiologiques de maladies locales, ce qui leur permet de pouvoir prendre des décisions en terme de contrôle (Jost et al., 2007). La participation communautaire est un prérequis à la viabilité d'un système de surveillance : les propriétaires d'animaux doivent sentir les effets directs de leur participation dans le système de surveillance pour *in fine* aller vers une amélioration de la santé de leurs animaux et de leurs moyens de subsistance.

Les nouvelles technologies telles que les téléphones portables ou les assistants numériques personnels sont prometteurs et ont déjà, dans de nombreux contextes, montré leur efficacité. Le problème principal est alors d'identifier les incitations (financières ou autres) qui permettront de garder la motivation des acteurs concernés. Au-delà des relations individuelles développées avec les éleveurs confrontés à des foyers de maladies, des routines en termes de communication devront être établies.

La modélisation est de plus en plus utilisée dans le domaine de l'épidémiologie et de la santé publique. Outre l'utilisation de la modélisation épidémiologique classique (modèles mathématiques), y compris l’analyse des réseaux sociaux ou la modélisation par arbres de scénarios, de nouvelles méthodes ont été proposées et évaluées par les chercheurs du Cirad : *loop analysis*, modélisation d'accompagnement (Etienne, 2011), (Collineau et al., 2013). Barreteau et al. (2001) ont proposé d'utiliser conjointement les systèmes multi-agents et les jeux de rôle à des fins de recherche, de formation et d'aide à la négociation dans le domaine de la gestion des ressources renouvelables. Ainsi la «modélisation d'accompagnement» (Barreteau et al., 2003) implique directement les divers acteurs impliqués dans la conception du modèle et la simulation. Ces approches participatives permettent aux intervenants de tester leur scénario de gestion et de faciliter leur appropriation des résultats de la simulation. Dans le domaine de la surveillance, la modélisation d'accompagnement semble prometteuse, mais reste encore à être concrètement mise en œuvre et évaluée sur le terrain. En comparant les expériences menées dans plusieurs pays en développement, nous pourrons générer de nouvelles connaissances et alimenter les débats parmi les scientifiques et les décideurs politiques sur la façon d'améliorer les systèmes de surveillance.

En conclusion, comme le montre la figure 1, nous considérons que la combinaison de plusieurs systèmes de surveillance (santé publique, animale), de plusieurs stratégies et options de surveillance et de méthodes pour évaluer leurs performances, peut augmenter les taux de détection des maladies.

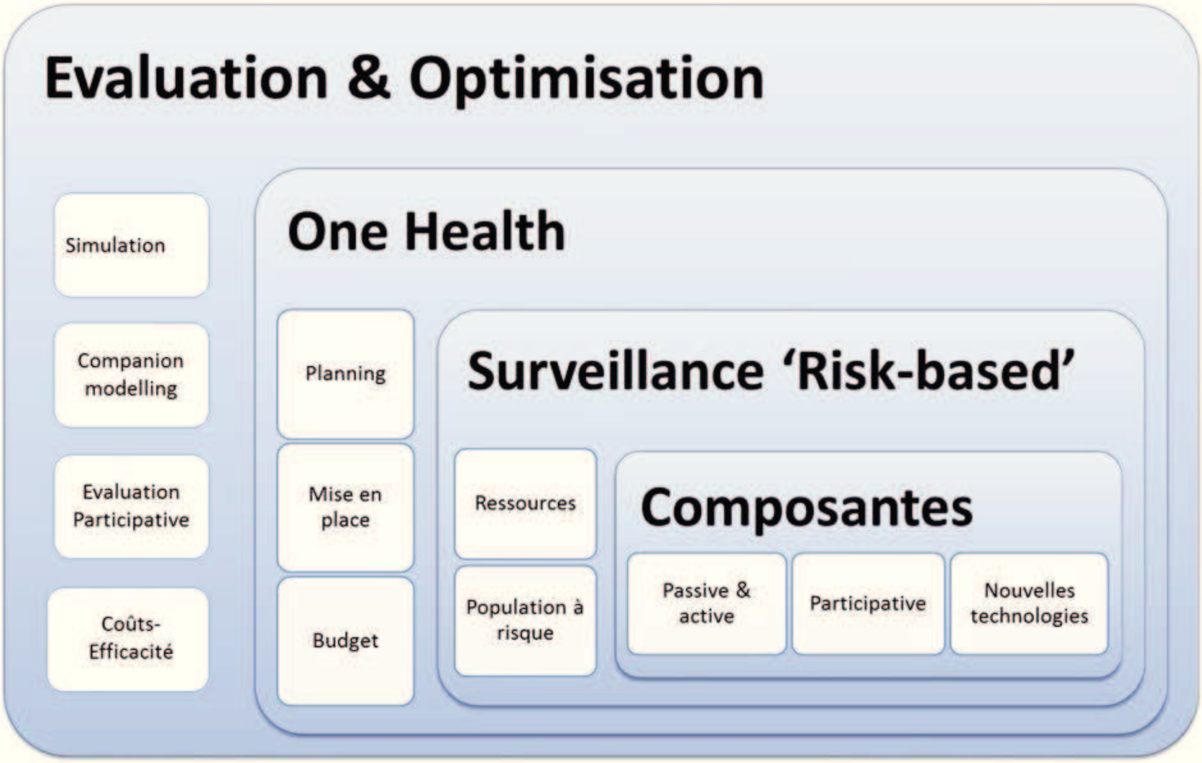


**Figure 1: Eléments essentiels à prendre en considération lors de la mise en place d'un système de surveillance sur les maladies zoonotiques.**

CONCLUSION

Le Cambodge fait partir des 10 premiers bénéficiaires du financement mondial pour l'influenza aviaire avec, en 2011, un total de 34 millions d'US Dollars attribués au gouvernement Cambodgien pour financer les stratégies de prévention et de préparation aux urgences (Ear, 2011b). Cependant, en dépit de cette mobilisation financière importante et efficace, les ressources mises à disposition n'ont pas suffi pas à atténuer les risques. Ainsi, en 2014, le Cambodge déclarait encore 5 foyers en élevage avicole, 9 cas humains dont 4 décès. Les raisons en sont nombreuses et les responsabilités sont partagées entre les différents secteurs, les décideurs nationaux et les bailleurs de fonds internationaux. Quoi qu'il en soit, la mauvaise performance des systèmes de surveillance du secteur de la volaille a très probablement joué un rôle majeur dans la persistance de la maladie.

> *Suite à la récente propagation du virus IAHP H5N8 en Asie et en Europe, l'Organisation mondiale de la santé animale (OIE) alerte sur la nécessité de renforcer les systèmes de surveillance et de détection précoce pour les maladies des animaux domestiques et sauvages à travers le monde et recommande d'en faire un objectif majeur des politiques de santé. [...]. L'existence de services vétérinaires nationaux*

> *compétents, quel que soit le niveau de développement d'un pays, est une condition préalable pour la détection précoce des maladies animales et pour une réponse rapide. "(OIE, 2015, Press com).*

Cette déclaration de l'OIE confirme la nécessité de développer des services vétérinaires fiables comme fondement de systèmes de surveillance efficaces, quelle que soit la situation socio-économique du pays. Mais dans un pays dépendant de l'aide comme le Cambodge, où plus de la moitié du budget national provient de l'aide étrangère, les services officiels souffrent encore d'une pénurie de ressources humaines et financières. Dans cette perspective, outre le renforcement obligatoire de l'éducation, la formation du personnel vétérinaire et le soutien des infrastructures nationales, la gestion de la santé dans des environnements difficiles a besoin de méthodes et d'outils innovants adaptés. La priorité devra alors se porter sur l'utilisation de méthodes financièrement viables ainsi que sur l'intégration des disciplines (biologie, sciences sociales, modélisation) et des secteurs (vétérinaires, médicaux et environnementaux).

L'une des problématiques majeures de la mise en œuvre de la surveillance est l'existence de conflits d'intérêts entre les bailleurs de fonds internationaux, les dirigeants nationaux, et les populations locales. En effet, si nous examinons le risque associé à l'IAHP H5N1, les principales préoccupations sont fondamentalement opposées (Ear, 2011b). Les éleveurs sont davantage préoccupés par la façon de préserver leurs moyens de subsistance et leur santé, alors que les décisions des responsables nationaux sont plus orientées par le maintien de leur statut économique, et que les bailleurs de fonds internationaux – et les agences internationales - s'intéressent principalement à la façon de réduire le risque d'émergence et de diffusion d'une souche pandémique de l'IAHP H5N1. Malheureusement, dans les pays en développement, les intérêts des plus pauvres sont en général ignorés, ce qui compromet la qualité de vie d'une importante partie de la population des pays les moins avancés. En outre, les risques réels (en cas d'abattage) ou supposés (ex. dissensions dans les réseaux sociaux) de sanctions suite à des suspicions de maladie n'incitent pas les éleveurs à déclarer. Nous proposons donc de passer d'une approche top-down, dans lequel aucun processus de consultation n'est utilisé, à des approches participatives. Ce processus devrait permettre discussions, communications, négociations, et un partage des connaissances pour enfin conduire concrètement à l'identification commune de solutions socialement acceptables. Ainsi la surveillance participative peut certainement compléter un système de surveillance en comblant les lacunes identifiées par des processus d'évaluation.

# French summary

La propagation en Asie, Europe et Afrique du virus Influenza Aviaire hautement pathogène (IAHP) H5N1, l'épidémie de A/H1N1pdm en 2009, l'émergence de l'Influenza faiblement pathogène (IAFP), mais zoonotique, H7N9 en Chine en 2013 et la circulation récente de l'IAHP H5N8 en Europe, montrent que l'évolution permanente de ces virus chez les oiseaux, les humains et les porcs, représente un risque en santé humaine et animale au niveau mondial. Au cours des 10 dernières années, des efforts ont été faits pour renforcer les capacités en santé publique et vétérinaire. Malgré tout, le virus IAHP H5N1 reste endémique dans certains pays où il peut passer inaperçu dans les populations de volailles mais provoquer des cas humains. Ces pays sont caractérisés par une majorité de leur population vivant en zones rurales, une absence de systèmes de santé primaire et des secteurs de santé inefficaces.

La surveillance passive (évènementielle) des maladies animales et humaines est souvent le seul type de surveillance applicable en milieux ruraux. Produisant une information incomplète, biaisée ou transmise avec des délais importants, elle a besoin d'être amélioré par de nouvelles approches mises en œuvre dans un cadre « One Health » prenant en compte les interfaces entre humains, animaux et environnement. Nous avons donc dans cette thèse conçu et/ou appliqué de nouvelles méthodes d'évaluation, de conception ou d'amélioration de la notification des cas d'IAHP H5N1 chez l'animal et chez l'homme en Asie du sud-est.

Nous avons en premier examiné différentes alternatives d'évaluation. Nous avons appliqué des arbres de scénario (stochastique) pour modéliser et évaluer le système de surveillance de l'IAHP H5N1 en Thaïlande dans les systèmes traditionnels de productions avicoles. Nous avons estimé la sensibilité de la surveillance passive à 50 % (IC95 % 0,04-0,75) pour une détection maximale de 3 fermes infectées. Cela a montré l'utilité de cette méthode pour prouver l'absence de maladie dans les pays à ressources limitées. Par des méthodes participatives, nous avons impliqué les « agents communautaires de santé animale » dans leur propre évaluation et développé une nouvelle grille, qui comprend des indicateurs de succès utilisés par les agents eux-mêmes.

Dans la seconde partie, nous avons examiné les méthodes pour améliorer la conception et l'efficacité de la surveillance passive. Nous avons appliqué la grille, pour évaluer 283 agents villageois dans trois provinces du Cambodge. La grille nous a permis de noter leur niveau d'activité et d'analyser, par régression logistique, les facteurs qui influencent l'obtention d'un score élevé. Puis, nous avons mis en place une étude pilote pour tester la déclaration par texto

(SMS) auprès de 112 participants de 68 villages. L'objectif était de détecter des pics de mortalité et d'identifier plus rapidement les foyers de maladies infectieuses. Nous avons enfin utilisé l'analyse décisionnelle multicritère (MCDA) pour cartographier les risques de diffusion de l'IAHP H5N1 chez les volailles et les populations humaines en Thaïlande et au Cambodge, afin de renforcer la surveillance dans les zones à risque.

En conclusion de ce travail, nous avons effectué une analyse comparative de deux environnements socio-économiques contraints : le Cambodge et Madagascar. Nous avons analysé les recherches mises en œuvre au cours des 10 dernières années par le CIRAD (Centre International de Recherche Agronomique pour le Développement) et ses partenaires dans ces 2 pays. L'objectif était de montrer comment de nouvelles approches appliquées aux systèmes de surveillance peuvent être transférées entre différents pays aux contextes difficiles. A partir de cela, de nouvelles perspectives sont proposées.

# English summary

The latest events such as the spread over Asia, Europe and Africa of the Highly Pathogenic Avian Influenza (HPAI) virus H5N1, the epidemic of A/H1N1pdm in 2009, the emergence of the Low Pathogenic Avian Influenza (LPAI) but zoonotic virus H7N9 in China in 2013 and the recent circulation of HPAI H5N8 in Europe, show that the permanent evolution of influenza virus in birds, humans and pigs is exposing the world to the risk of new strains with unpredictable consequences in public and animal health. In the last 10 years, a lot of efforts have been put in the improvement of capacity of animal and public health systems. However the disease is now endemic in several countries where the virus goes often undetected within the poultry population resulting in sporadic human cases and mortality. These countries are characterized by a large proportion of their population living in rural areas with poor incomes, a lack of primary care system and inefficient public or veterinary health sectors.

Passive surveillance is often the only type of method feasible in poor rural settings in human and animal surveillance. With often incomplete, biased or delayed information this method will benefit from new methods of evaluation or new design concepts that could be implemented within a “One Health” framework to take into account the interfaces between human, animals and environment. We have in this thesis conceived and/or applied new methodologies for the evaluation, the design or the improvement of volunteer case-reporting of human or animal HPAI H5N1 in South-east Asia.

We have first looked at different options of evaluation. We have applied stochastic scenario tree to model and assess the surveillance system of HPAI H5N1 in Thailand in backyard and free-range poultry production systems. We have estimated the sensitivity of the passive surveillance at 50% (CI95% 0.04-0.75) for a maximum detection of 3 infected farms, and showing the usefulness of this method to demonstrate freedom of disease in countries with limited resources.  Thanks to participatory methods, we have involved Village Animal Health Workers (VAHWs) in their own evaluation and developed a new criteria grid, which includes local indicators of success developed and used by the VAHWs themselves.

In a second part, we have considered methods to improve the design and the efficiency of passive surveillance. We have applied the grid conceived previously, to evaluate 283 VAHWs in three provinces of Cambodia. The grid allowed us to give a score to their level of activity and to analyse through logistic regression the factors influencing the most “good score”. Then

we have implemented a pilot-study to test the use of SMS reporting from 112 participants from 68 villages, the objective was to detect peaks of mortality, to identify more rapidly outbreaks of infectious diseases. In a final section we have used multiple criteria decision analysis (MCDA) to map the risk of diffusion of HPAI H5N1 in poultry and in human, in order to adjust and reinforce the surveillance in the zones with greater risk of occurrence of the disease in Thailand and Cambodia.

To conclude this work about tools and methods to improve surveillance systems in remote areas, we have done a comparative analysis of two challenging environments, Cambodia and Madagascar. We have done a cross analysis of the researches implemented by CIRAD (French International Research Centre for Agricultural Development) in these countries during research projects implemented over the past decade. The objective was to show how new approaches for surveillance systems could be transferred between different countries with difficult socioeconomic environments and to propose new perspectives.

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# List of Abbreviations

AFRIMS: Armed Forces Research Institute of Medical Sciences

ADB: the Asian Development Bank

AR: Adjusted Risk

AusAID: the Australian Agency for International Development

AVSF: Agronomists and Veterinarians without Borders Cambodia

CAHA: Community Animal Health Agent (Vietnam)

CDC: Center for Disease Control

DAPH: Department of Animal Health and Production

DLD: Department of Livestock Development (Thailand)

ENVT: Ecole Nationale Vétérinaire de Toulouse

EU: the European Union

FAO: Food and Agriculture Organization of the United Nations

HA: Hemagglutinin test

HC: Health Center

HMIS: Health Management Information System

HP: Health Post

HRA: High Risk Area

HPAI: Highly Pathogenic Avian Influenza

ILI: Influenza-like Illness

IPC: Pasteur Institute of Cambodia

LBM: Lower Basin Mekong

LDV: Livestock Development Volunteer (Thailand)

LPAI: Low Pathogenic Avian Influenza

LRA: Low Risk Area

MAFF: Ministry of Agriculture, Forestry and Fisheries

MoH: Ministry of Public Health

NAMRU: the US Naval Medical Research Unit

NaVRI: National Veterinary Research Institute

NIPH: National Institute of Public Health

NGO: Non-governmental Organisation

OD: Operational district

OH: One health

OIE: World Animal Health Organisation

PCR: Polymerase Chain Reaction

RH: Referral Hospital

RR: Relative Risk

Se: Sensitivity

SEA: Southeast Asia

SNAT: Surveillance Network Analysis Tool

Sp: Specificity

SSC: Surveillance System Component

SSSe: Surveillance System Sensitivity

SWOT: Strength, Weakness, Opportunity and Threat analysis

UNICEF: the World Children's Fund

USAID: United States Agency for International Development

VAHW: Village Animal Health Worker (Cambodia)

VHV: Village Health Volunteer (Thailand)

VVW: Village Volunteer Worker (Lao PDR)

WHO: the World Health Organisation

# PART 1
# CONTEXT OF THE RESEARCH QUESTION

In this first section, we describe the context of this research work. We focus on the challenges of implementing surveillance of zoonoses in developing countries, taking as an example the surveillance of highly pathogenic avian influenza A (H5N1) virus (subsequently referred to as HPAI H5N1) in the countries of the Lower Mekong Basin (LMB) in Southeast Asia (Laos, Thailand, Vietnam and Cambodia). We first describe the specific characteristics of human health and veterinary systems in poor rural settings in Southeast Asia (SEA) and the epidemiological situation of zoonoses and of emerging infectious diseases (EID) in this part of the world. We also give a detailed update of the situation of highly pathogenic avian influenza (H5N1, H7N9, and other H5Nx) in the region with some features on poultry production systems in LMB. Then we introduce the definition of surveillance in human and animal health systems, focusing on passive surveillance that we consider as the cornerstone of surveillance in poor rural settings.

Finally, we describe the various modalities of the current passive surveillance of HPAI H5N1 as currently applied in the LMB countries, giving details of case definitions (in humans and animals) and the involvement of farmers and other stakeholders in the surveillance system.

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# 1. Characterising human and animal health sectors in rural areas of developing countries

Rural areas in developing countries are defined as areas with low population density, a lack of infrastructure and access to education, low human resources and skills, and where the majority of the population is employed in the agricultural sector (Katrak, 2008). Due to seasonal fluctuations and sanitary crises, rural communities face food and income insecurity, and therefore a high degree of economic vulnerability (Kanbur et Venables, 2003). Access to medical or veterinary services are difficult due to a limited number of health centres, often with long distances to travel to and from these health care facilities and a lack of mobility amongst the population. While some studies have shown that rural communities in developing countries encounter more health hazards and so have greater needs for medical treatment (Katrak, 2008) the environment remains characterised by a very low ratio of qualified physicians to unqualified health practitioners. In such isolated settings, cultural beliefs are still strong and the use of traditional medicines and practices to treat animal and human diseases is widespread (Pelto et Pelto, 1997). These behaviours often result in the late detection of cases as health care is sought only by the most seriously sick persons (Leboeuf, 2009) or when the number of sick animals is already too large to be managed (Salman, 2008). In these contexts of social isolation, access to medical education systems is poor and there is a real challenge to sustain good disease awareness within the communities especially for rare conditions (Hadorn et Stärk, 2008a; Kanbur et Venables, 2003).

## 1.1. Human and animal health systems in SEA

The population of Southeast Asia (SEA) is growing rapidly, with almost 600 million people (9% of the world population) in 2010 (Chongsuvivatwong *et al.*, 2011). The average population density (132 persons per sq. km) is not very high, but differs greatly between countries (Indonesia, Philippines and Vietnam being the most densely populated) and between provinces within these countries (Jones, 2013). In these countries, 43% of the population lives in urban areas (Chongsuvivatwong *et al.*, 2011). The less developed countries are more rural with 85% of the population for Cambodia and 73% for Lao PDR (Jones, 2013), residing in rural areas but disparities exist within countries with the northern part of Thailand being more rural than Cambodia. The SEA region is characterised by significant differences in people's livelihood and living standards resulting in wide socio-economic inequalities across countries.

These differences are also reflected in the level of development of national health-care systems in the region, in human and animal sectors, with problems of health workforce shortage, quality and distribution of health care (Forman *et al.*, 2008; Kanchanachitra *et al.*, 2011) that are further exacerbated in rural areas. Countries such as Cambodia, Laos, Indonesia, Myanmar and Vietnam have a substantial shortage of human resources with a density of health-care professionals below the threshold recommended by the World Health Organization (WHO) (Coker *et al.*, 2011).

## 1.2. Features of human and animal health systems in SEA in rural areas

### 1.2.1. Human health systems

Rural areas in SEA concentrate the majority of the poor (people living on less than US$ 2 per day) who depend mainly on small-scale farming and livestock production (Caspari, Christodoulou et Monti, 2007). These areas remain heavily burdened by infectious diseases, especially respiratory infections and diarrheal diseases (Coker *et al.*, 2011a) with high morbidity and mortality and a lower life expectancy. They are characterised by the uneven distribution of health infrastructures, scarcity of human resources, poor quality of services and difficulties in payment (Kanchanachitra *et al.*, 2011). The lack of primary care systems in remote areas forces people to use self-medication, traditional health practices or to seek private health providers to begin with (Caspari *et al.*, 2007). Such behaviour increases the cost of health-care for poor people (Kruk *et al.* 2010), and often gives rise to safety concerns regarding the quality of care provided and the origin of the pharmaceutic products. In addition, the primary use of private healthcare can delay the detection of major health issues, with an unwillingness or incapacity to provide information (Coker *et al.*, 2011a) and the fact that people will finally visit public health facilities only when the course of the disease becomes too serious (Caspari *et al.*, 2007).

### 1.2.2. Animal health systems

The control of infectious and zoonotic animal diseases is essentially the task of National Veterinary Services which vary greatly in terms of quality and capacities. For low-income countries (Cambodia, Lao PDR), veterinary institutional capacities are extremely weak, with no specific legal framework, limited human resources, a poor level of staff education and technical skills, and insufficient laboratory facilities (Coker *et al.*, 2011a; Forman *et al.*, 2008). Despite the progress achieved following the HPAI H5N1 crises, persistent gaps remain between countries. During the last 10 years, the SEA region has experienced a rapid growth and intensification of the livestock sector, with a current livestock population of 167.2 million, not including poultry (Mehta, 2013). Despite industrialisation, 50 to 70% of the global agricultural production still comes from smallholders with mixed farming systems (Mehta, 2013) and livestock rearing represents the livelihood for over 35% of the poor (Forman *et al.*, 2008). Backyard and village farms continue to be the predominant production system, with low and ill-orientated investments in biosecurity (Coker *et al.*, 2011a). Weak animal health systems might jeopardise the health of poor populations in remote areas. Any death livestock in a poor household will have an impact on the livelihood of the entire family, as few animals are owned and these are relied upon almost exclusively for food, transport and farm work (Bordier et Roger, 2013). In addition, the risk of contracting zoonotic diseases will increase and people will tend to be more severely impacted because of the difficulties to access health care (Bordier et Roger, 2013). Rural areas with poor and marginalised populations and inefficient public or veterinary health systems are especially exposed to the spread of zoonotic diseases (Bhatia et Narain, 2010).

# 2. Avian Influenza in SEA

## 2.1. The context of emerging infectious diseases in SEA

Although tremendous efforts have been made to improve the quality of health systems in SEA, infectious diseases remain a constant threat for the population, being responsible for 47% of deaths among children under 5 years old (Horby, Pfeiffer et Oshitani, 2013). Moreover, the rapid socio-economic and environmental modifications that are ongoing in the region, with uncontrolled urbanisation, population growth, intensification of farming systems with low biosecurity practices, deforestation and climate change, foster the emergence or re-emergence of new infectious diseases (Coker *et al.* , 2011b). The region is recognised as one of the “hot spots” for emerging disease events (Jones *et al.*, 2008), especially zoonoses. In a recent review published by Bordier and Roger (2013), 23 zoonoses are commonly described in SEA, and most of the neglected zoonotic diseases, as defined by WHO, are present. In rural settings, where human-livestock interactions are unavoidable, zoonoses can affect a large proportion of people through animal promiscuity, lack of sanitation and socio-cultural practices (Bhatia et Narain, 2010) and consequently place a large burden on the health care system of countries with the lowest incomes.

## 2.2. HPAI H5N1 situation in SEA

The Highly Pathogenic Avian Influenza H5N1 (HPAI H5N1) emerged in southern China with the first human cases occurring in Hong Kong in 1998 (Claas *et al.*, 1998). The disease spread outside China by the end of 2003, causing extensive outbreaks among poultry producers in several countries in East and Southeast Asia. From mid-2005, the HPAI H5N1 virus moved further west and was reported in 63 countries (Fournie, Glandville et Pfeiffer, 2012) in Asia, Europe and Africa. Nowadays, the virus circulates in several countries (China, Vietnam, Cambodia, Indonesia, Bangladesh, India, Nepal and Egypt) with some regular outbreaks in Lao PDR and Myanmar (FAO, 2013). In 2014, the disease was reported in poultry in Cambodia, Vietnam and Laos (for the first time since 2007). Indonesia did not report any official outbreak in poultry but the disease was officially declared endemic by OIE in September 2011 (Table 1). Multiple genotypes of HPAI H5N1 have been identified since 1996, with the establishment of distinct regional sub-lineages reflecting the endemic occurrence of the disease (Pfeiffer *et al.* , 2013).

The control of the disease is still a public health challenge, due to concerns that HPAI H5N1 holds the potential of becoming the next pandemic strain (Pongcharoensuk *et al.*, 2011). More than 400 million poultry have been lost by culling or direct mortality (FAO, 2013), of which more than 175 million in SEA alone (Pfeiffer *et al.*, 2013). HPAI H5N1 has not only had a devastating impact on the poultry sector due to preventive culling and trade restrictions, but the disease, with a flock mortality rate above 50%, has also had a dramatic effect on the livelihood of thousands of backyard farmers in SEA who made their living from poultry rearing.

The number of human cases since the start of the epidemic is still relatively low; by 2 October 2014, a total of 668 confirmed human cases, 393 deaths reported to the WHO from 16 countries (WHO, 2014a). Four hundred eight cases were reported for SEA alone, with Indonesia having the highest case fatality estimates worldwide amounting to 83% (Table 1). The main transmission route is from poultry to human after direct and extended contact with sick animals (Fournie *et al.*, 2012). However it would appear that the level of case fatality rates based on official WHO reporting is most likely overestimated due to under-detection and under-reporting of non-fatal human cases (Pfeiffer *et al.*, 2013), even if there is no unequivocal serologic evidence regarding the proportion of asymptomatic or mildly symptomatic cases in humans (Toner *et al.*, 2013).

**Table 4: Cumulative numbers of outbreak of HPAI H5N1 in SEA (20 January 2014)**

| Country | Poultry outbreaks reported to OIE (first – last reporting) | Cumulative number of human cases reported to WHO (total deaths) | Detected outbreaks in poultry 2014 | Human cases in 2014 (deaths) |
|---|---|---|---|---|
| **Vietnam** | 2720 (2004-2014) | 127 (64) | 45 | 2 (2) |
| **Indonesia** | 261 (2003-2006) | 197 (165) | Endemic since 26/09/2006 | 2(2) |
| **Cambodia** | 42 (2005-2014) | 56 (37) | 5 | 9 (4) |
| **Lao PDR** | 19 (2006-2014) | 2(2) | 1 | 0 (0) |
| **Thailand** | 1141 (2003-2008) | 25(17) | No outbreak since 2008 | 0 (0) |
| **Myanmar** | 115 (2006-2012) | 1(0) | No outbreak since 2012 | 0(0) |
| **Malaysia** | 16 (2004-2007) | 0 | No outbreak since 2007 | 0(0) |
| **Philippines** | NO OUTBREAK | | | |

http://www.who.int/influenza/human_animal_interface/EN_GIP_20140727CumulativeNumberH5N1cases.pdf?ua=1
http://www.oie.int/fileadmin/Home/fr/Animal_Health_in_the_World/docs/pdf/Graf_avian_influenza/graphique_IAHP_04_12_2014.pdf

## 2.3. Emergence of zoonotic strains of the low pathogenic avian influenza (A) H7N9

At the end of March 2013, the first human infections with the low pathogenic avian influenza (A) virus H7N9 (subsequently referred to as LPAI H7N9) occurred in eastern China; so far this strain was not known to infect humans (CDC, 2013). On July 4, 2013, 133 human infections with 43 related deaths in 9 provinces of China were reported to WHO (WHO, 2014b). The majority of cases happened in males over the age of 60 with a history of recent contact with live poultry, more especially at live-bird markets (Cowling *et al.*, 2013). The transmission is mainly zoonotic even if four family clusters of two or more confirmed cases have been reported (WHO, 2013). Unlike HPAI H5N1, the virus circulates amongst domestic poultry or wild birds without any symptoms making its detection prior to human infection unlikely (WHO, 2013). However, the prevalence in domestic animals appears to be low, since more than ten thousand samples from animals and their environment were tested and only 0.07% of the birds were confirmed positive by culture and pigs were shown to be completely free of the virus (CDC, 2013). Even if the closure of live-birds markets in affected provinces appears to have been an efficient measure to control the spread of the disease, the loss for the Chinese agricultural sector has been tremendous with an estimation of 57 billion Chinese Yuan ($ 9.17 billion) (Wu et Gao, 2013). The potential for silent virus circulation in the animal population combined with the existing formal or informal trade of poultry between China and its neighbouring countries is a real concern for the other SEA countries. There is a clear need to further enhance influenza virus surveillance in human and animal populations using a "One Health" approach while focusing on the most vulnerable populations in the rural areas of the region.

### 2.4. Emergence of new H5Nx strains in Asia

Very recently, several new strains of the HPAI virus have been circulating in Asia, resulting in several outbreaks in domestic poultry (H5N8, H5N2, H5N3, H5N6) and wild birds (H5N8) (OIE, 2014). Of particular concerns, the HPAI H5N8 virus that emerged in China in 2010. This virus started to spread over Asia in 2014 with outbreaks in Japan then in South Korea, leading to the slaughter of 12 million of poultry (Lee *et al.*, 2014). It is has also been present in Europe (Germany, the Netherlands, UK). So far no human cases have been reported. However, this is not the case for the HPAI H5N6 which was detected in Laos and in Vietnam following its emergence in China, where it caused one human infection in April 2014 (WHO China, 2014). These new emerging strains (H5N8 and H5N6) are all similar to the sub-type 2.3.4.6 of HPAI H5N1 that was circulating first in China and recently in Vietnam (FAO, 2014a).

## 3. The region of the Lower Mekong Basin: The poultry production situation

The poultry sector in the Lower Mekong basin (LBM) is characterised by a high proportion of small-scale production systems. Cambodia and Lao PDR are in SEA countries with the least developed industrial sector, with 85% to 95% of the flocks in backyard systems (Behnek, Otte et Roland-Holst, 2010; Otte, 2008). For Vietnam, 90 % of the flocks are also backyard production, but industrial and semi-intensive sectors are more significant with only 50% of the whole bird population being raised in flocks of less than 50 animals (Otte *et al.*, 2008). For Thailand, the intensive sector consists of 70 % of the poultry population but 90% of the flocks are still small-scale (Heft-Neal, Roland-Holst et Otte, 2012). Thailand and Vietnam stand out due to their large population of free-grazing ducks; 13 million for Thailand and 65 million for Vietnam. These are bred in a traditional way, with animals scavenging in post-harvest rice paddy fields (Gilbert *et al.*, 2007; Henning *et al.*, 2012).

As a response to the HPAI H5N1 crises in the region, international organisations and donor-funded projects have developed several capacity-building initiatives within the affected countries and have implemented various active surveillance programs (serological and virological surveillance of duck flocks, market surveillance, wild bird sampling etc.) (FAO, 2011a). In some settings these methods have been successful in revealing the presence of the virus or in detecting the early circulation of the disease among the poultry population, but they are difficult to sustain because of their high cost in human resources and laboratory reagents. Therefore passive reporting systems will continue to underpin the surveillance of HPAI H5N1 in the region's low-income countries, especially with the current decline of regular funding.

# 4. Features and challenges of surveillance in rural areas of developing countries

Public health surveillance is the “continuous, systematic collection, analysis and interpretation of health-related data needed for the planning, implementation, and evaluation of public health practice” (« WHO Public health surveillance », 2012). Surveillance data are promptly disseminated to decision-makers for the potential implementation of prevention and control actions (Thacker et Berkelman, 1988). In veterinary medicine, the definition of surveillance remains substantially the same but applies to animal populations, “the on-going systematic collection, collation and interpretation of accurate information about a defined animal population with respect to disease and/or infection, closely integrated with timely dissemination of that information to those responsible for control and prevention measures” (Meah et Lewis, 2000). Surveillance objectives vary but are similar between health sectors: detecting introductions of new or exotic pathogens in the population under surveillance, identifying significant changes in the occurrence of a disease, evaluating the efficacy of control and prevention programs and preventing transmission or reducing morbidity and mortality in the human and animal populations.

## 4.1. Values of passive surveillance in poor rural settings

In developing countries, voluntary case-reporting of specified diseases still remains the backbone of surveillance in the public health and veterinary sector. The notification of cases is usually done by primary health practitioners (Health Workers, VAHW, private physicians or veterinarians, public health or veterinary officers, etc.) and the notification can be made mandatory for some diseases within the legislation of the country. For animal surveillance the first actor in reporting chain is typically the livestock producer (Meah et Lewis, 2000). This type of surveillance, for which health information is directly provided by field actors, is commonly referred to as “passive surveillance” as opposed to “active surveillance” where specialised health staff search for cases by visiting communities or periodically request information from health practitioners or facilities (Curtis *et al.*, 2003; Doherr et Audige, 2001). Active surveillance is usually used for specific diseases during a short period of time and in a targeted population, because it is more labour-intensive and more expensive to implement (Curtis *et al.*, 2003; Doherr et Audige, 2001).

Passive surveillance is an integral component of the health system in developing countries, being particularly appropriate for rural or remote areas where the density of health actors or facilities is low. Based on observations (by livestock owners or by primary health care), it is a system which potentially covers the whole susceptible human or animal population; simple and inexpensive, largely relying on existing infrastructures (Doherr et Audige, 2001). Information from passive surveillance systems can be used to estimate disease trends and to detect any epidemiological changes (Doherr et Audige, 2001; FAO, 2011b). In veterinary surveillance, this is the key element of early warning systems (Paskin, 1999).

## 4.2. Challenges of passive surveillance

Despite its merits, passive surveillance also has inherent disadvantages and carries challenges when applied. Reporting is often delayed, with incomplete or biased data (Deen, von Seidlein et Clemens, 2011; Sharma et Baldock, 1999). Several factors linked to human and veterinary health systems have been identified as contributing to under-diagnosis and under-reporting of zoonotic diseases in developing countries; a low density of health facilities, poor communication systems, poor awareness of patients or livestock owners, a risk of penalties or stigmatisation, distrust of governmental authorities and a lack of qualified staff are the most significant ones (Halliday *et al.*, 2012). Disease notification follows a complex communication chain, involving multiple actors. Consequently, if one actor of the chain retains the information, this can trigger a domino effect delaying disease detection and the implementation of appropriate control measures.

# 5. Passive surveillance for HPAI H5N1: various modes of implementation in LMB

## 5.1. Adequacy of case definition

The first important element of passive reporting is a clear definition of what constitutes a reportable case in the population: the case definition. It usually encompasses a set of inclusion and/or exclusion criteria (a group of signs and symptoms) with various levels of sensitivity and specificity. This case definition should ideally be understood and used by the different actors of the reporting chain and be flexible enough to function as knowledge or disease situation change.

### 5.1.1. For animal case detection

The case definition used to detect avian influenza varies between countries. For Thailand, the Department of Livestock Development has reviewed their HPAI H5N1 case definition a number of times, ending up with something rather complex which is described by a mortality threshold above 5% in 2 days, or the occurrence of any sudden death in a flock, or any typical clinical signs of highly pathogenic poultry diseases (respiratory, neurologic and behavioural symptoms) (Goutard *et al.*, 2012). This highly sensitive case definition has proven to be efficient over the past years, but is costly to maintain and increases the risk of false-positives due to a lack of specificity. When control measures are applied before laboratory confirmation this could lead to mistrust of official authorities by farmers (Goutard *et al.*, 2012). For Cambodia, the case definition is based on the general description of disease occurrence given by FAO (FAO, 2009): chicken mortality rate over 50%, in several households for 4 to 5 days with clinical signs in chicken or ducks. Typically, HPAI H5N1 is described as mild or asymptomatic in ducks resulting in its silent circulation among the flocks (Yee *et al.*, 2009). In Cambodia, however, several outbreaks in free-grazing ducks led to high mortality rates, from 38 % to 46% (Conan, 2008). Therefore the case definition may not be adapted to the real epidemiological situation in ducks and might lead to an under-detection of the disease. In countries where vaccination has been used to control the disease, the epidemiology has changed with partially immunised chicken flocks showing low levels of mortality. This is the case, for instance, in Vietnam where in some areas the case definition used by farmers to recognise HPAI H5N1, based on massive and sudden mortality in chickens, has become obsolete (Desvaux, 2012).

### 5.1.2. For human case detection

A standardised case definition for the detection of HPAI H5N1 cases in humans has been developed by WHO. The case definition is broad. Suspected cases are people presenting clinical signs (fever over 38°C with coughing or shortness of breath) with a potential link (by time, place or exposure) to human or animal HPAI H5N1 cases (WHO, 2006). WHO advises each country to adapt this case definition to local situations. Cases are confirmed after positive results (isolation, PCR or serologic testing) provided by national, regional or international influenza laboratories recognised by WHO. In Thailand, during the first epidemic between 2004 and 2006, the Ministry of Public Health (MoH) established the National Avian Influenza Surveillance system (NAIS) using an even broader case definition than the one recommended by WHO. Suspected HPAI H5N1 cases were considered for persons with fever and respiratory symptoms or pneumonia and potential exposure to sick or dead poultry, or living in area with poultry mortality or previous contact with suspected HPAI H5N1 human cases or persons with pneumonia (Kitphati *et al.*, 2008). This case definition was considered non-specific with 80 times more detection of human influenza cases than HPAI H5N1, but allowed the MoH to detect 4 cases that would not have been detected by the standard WHO case definition (Shinde *et al.*, 2011). However this unspecific case definition was really resource intensive and ill adapted to countries such as Cambodia or Lao PDR with little capacities. Early human case detection is challenging. The clinical signs are similar to the ones of influenza-like illnesses (ILI) which are common in SEA and usually only reported when symptoms with fever are described. Moreover, the association between clinical signs and potential exposure to poultry is not easy to assess considering the ubiquity of poultry in rural populations and the reluctance of farmers to declare poultry mortality.

## 5.2. Awareness of farmers and health workers

Passive surveillance relies on the capacity and willingness of farmers, community workers or private animal health actors to observe and accurately detect clinical signs in their own poultry or those of their village and to take the decision to notify the disease to official veterinary services (Doherr et Audige, 2001).

In LMB countries, a great number of actions to increase farmer awareness and to train community animal health workers have been implemented through various projects, funded by the FAO or international and local NGOs (FAO, 2013). A large number of institutions funded communication materials for HPAI awareness campaigns: United States Agency for International Development (USAID), the Australian Agency for International Development (AusAID), the European Union (EU) Commission, the World Bank, the Asian Development Bank (ADB), Food and Agriculture Organization of the United Nations (FAO) and the United Nation Children‘s Fund (UNICEF). These organisations mostly funded one-way communication activities with the distribution of posters, leaflets, tee-shirts or the broadcasting of radio / TV messages about biosecurity and personal protection against the disease (Caro, 2013). Some farmer or community meetings were also organised but these generally used top-down approaches, and their main objectives were to produce behavioural changes in relation to poultry diseases. Knowledge, attitude and practice surveys were implemented in several countries to assess the impact of these communication strategies (Hickler, 2007). The surveys showed that besides a high degree of awareness and theoretical knowledge about the disease among farmers and community workers, with the highest awareness in Thailand, communication strategies were far less successful in changing biosecurity practices and in improving disease reporting to health authorities (Caro, 2013). Toll free reporting hotlines were set up in every LMB country. These hotlines are used mainly by farmers or consumers to ask information about the disease but they also enabled the detection of cases in Laos and in Cambodia.

## 5.3. Actors involved in the reporting mechanism

To compensate for the lack of field veterinarians in rural areas at the start of the epidemic, some SEA governments have developed several strategies. In Laos and Cambodia, community workers (Village Animal Health Workers (VAHW) for Cambodia and Village Veterinarian Workers (VVW) for Lao) have been trained by NGOs or by the government, under projects funded by international agencies, to provide animal health services (treatment, husbandry advice, vaccination) to their communities' farmers. Initially, the majority of their activities targeted the health of livestock, but after the start of the HPAI H5N1 crisis, governments, with the help of the FAO, decided to train additional VAHW and VVW in HPAI H5N1 only, in order to have at least one trained person per village and to increase the surveillance coverage (Burgos, *et al.*, 2008; Burgos, Otte et Roland-Holst, 2008). These workers do not belong to the governmental staff and so do not receive any salary or compensation for their services, but they are supposed to produce reports on disease outbreaks and vaccinations to their direct supervisor within the veterinary services (Caro, 2013). These systems are characterised by a high variability of skills because of non-harmonised training plans between teaching organisations, poor sustainability with a large number of community workers stopping their activities within the following five years and a legal status that is not always clear (Calba *et al.*, 2014). Due to their position and close relations with official authorities, the VAHW/VVW have an important "gatekeeper" function for animal health information (FAO, 2013). But as their incomes depend directly on farmer satisfaction, they often try to solve animal health problems by themselves to avoid compromising their credibility with regard to their customers. This means that reports are often forwarded only when the situation is out of control, thus delaying the detection of outbreaks (Caro, 2013). The same situation has also arisen in Vietnam, where the network of private veterinarians is more established. Primary health actors are called "Communal Animal Health Actors" and in contrast with Cambodia and Laos, they are members of the national veterinary services and therefore receive a monthly compensation (Nguyen, 2011). However the problems of late and under-reporting remain the same (Desvaux, 2012), with issues related to a lack of recognition from central authorities, the burden of the extra reporting duty and a lack of compensation for outbreak responses in remote areas. Moreover, in these three countries, the consequences for farmers and the community when an outbreak of HPAI H5N1 is declared are disastrous, because there are no compensation mechanisms in Laos and Cambodia (Burgos, *et al.*, 2008; Burgos, Otte, *et al.*, 2008) and the mechanism in Vietnam is deficient (Desvaux, 2012). After detection, the national authorities cull the village's entire poultry population; sometimes even the poultry population of several villages in the same commune, causing extreme financial lost for poor small-scale breeders. These types of situations where reporting disease increases the risk of penalty for farmers are known to be unsustainable.

In public health, the responsibility for reporting suspected cases of HPAI H5N1 lies with the primary health care system at communal hospitals or with private practitioners. Since 1997, Thailand has developed a passive surveillance system for emerging infectious disease, structured around a tight network of Village Health Volunteers (VHV), 750,000 in total, at sub-district level. The VHV are not paid by the government but they receive incentives in the form of free health services or care, and their operating costs are refunded. In 2004, AI surveillance was included in the routine work of VHVs, with additional activities around the reporting of poultry death or illness and specific awareness raising actions on HPAI H5N1 prevention at farm level (WHO, 2007). One VHV per village is nominated as Livestock Development Volunteer (LDV) and is officially dedicated to reporting suspected disease in animals to the Department of Livestock Development (DLD). They are involved in the passive reporting system but are also part of the X-Ray campaign; an integrated active surveillance programme where each household in every village is visited twice a year to actively search for clinical cases of HPAI H5N1 in humans and poultry (WHO, 2007). This health volunteer system also exists in the other countries of the region with some variants. In Laos, the national primary health care service relies also on a network of VHV. The latter are trained during 2 to 3 weeks as lay health workers in order to communicate advice to famers and to report surveillance activities in their village on a monthly basis (Akkhavong *et al.*, 2013). In Cambodia, there are two kinds of health volunteers. The VHVs, of which there are 2 to 6 according to the size of the village, with different kinds of activities depending on the type of institutions they are affiliated to (Ministry of Rural Development, MoH, NGOs…), and the members of the Village Health Support Groups (VHSG), usually 2 per village, belonging to the MoH and with the role of ensuring a regular flow of information between the community and the Health Centre (MoH, 2008). In Vietnam, in addition to these volunteers there are health collaborators used by the family planning clinics to promote good health practices from household to household and to conduct the population census (Kotsila, 2012). None of these volunteers are employed by the government but they do receive incentives, through the exemption of medical charges, and they can be temporarily employed by NGOs. Even if they are not always included in the national health surveillance system (as in Cambodia), they play an important role in outbreak reporting.

Anyhow, passive surveillance based on these volunteer networks are of varying effectiveness. In countries were the percentage of people with health insurance coverage is very low, especially in rural areas, the acceptance and the use of public primary health care remain inadequate. In fact, because of the high level of out-of-pocket payments and the poor perceived quality of public health facilities, patients prefer to use traditional medicine, self-treatment from drug sellers or private health facilities (Akkhavong *et al.*, 2013; de Sa *et al.*, 2010). For example, in Cambodia, HPAI H5N1 patients visited private practices 2.5 times on average before diagnosis. This can create a delay in case detection as the private sector is often not covered by the national surveillance system.

# PART 2

# OBJECTIVES OF THE RESEARCH STUDY

As discussed in Part 1 Section 4, passive surveillance in the human and animal sectors is a key element in the process of detecting HPAI H5N1 in remote areas of developing countries. But we have also highlighted that this type of surveillance is subject to many limitations in both sectors. There is clearly a lack of awareness in some communities which fail to recognise, at a sufficiently early stage, the clinical signs of the disease in birds and to link the presence of animal disease with symptoms in humans (Caro, 2013). Combined with this lack of knowledge there is often reluctance of farmers to declare animal cases because of the direct or indirect negative impacts of disease control measures. This has often led to the discovery of the presence of HPAI H5N1 in a region with subsequent to the detection of a human case (Leboeuf, 2009). Moreover these areas are facing a shortage of health care facilities (Halliday *et al.*, 2012), in human and animal sectors, leading the population to turn toward private sectors, drug dealers or traditional healers, with inadequate skills and often not included in the national reporting system (de Sa *et al.*, 2010). The current research was implemented to overcome these gaps and limitations. In the Part 2, we are going to describe our main objective, our specific objectives as well as some details about the rationale behind the selected approaches.

# 1. Main objective

In this research work, our main objective was to test and propose innovative methods to increase the involvement of rural communities in the reporting of zoonotic diseases and to improve the effectiveness of surveillance systems in human and animal health systems. However, due to time and practical constraints we had to limit our field of study, the population to be targeted, the attributes of surveillance that we want to improve and therefore the type of methods or tools to be implemented. We have focused our research mainly on the HPAI H5N1 situation in Cambodia, except for one method of evaluation (scenario-tree modelling), which was easier to implement in Thailand. We worked mainly on the sensitivity, acceptability and timeliness of the surveillance (see rationale in the section below). We did not look at economic criteria, as it was not possible to have access to any financial data about the cost of surveillance. We selected different tools and methods that we considered the most appropriate for our research context (scenario-tree modelling, qualitative and semi-qualitative methods of evaluation, participatory evaluation, pilot intervention study, multivariable analysis, spatiotemporal analysis and multi-criteria analysis).

# 2. Specific objectives

In this work we looked at two different aspects of surveillance, evaluation and design, which are in fact interdependent. Adequate evaluation is needed to identify key elements in the surveillance to be improved and to be able to select appropriate tools or methods to achieve this improvement.

## 2.1. Specific objectives regarding surveillance evaluation

Evaluation is a key element in the improvement of surveillance systems. Indeed, timely and relevant evaluations are critical to make the best use of scarce available resources, they allow more objective decision making, improvements in system design and enhanced acceptance of system outputs by stakeholders at local (e.g., farmers, veterinarians) and national levels (e.g., reference laboratory, veterinarians at central level).

Several frameworks have been used in animal and human health (Declich et Carter, 1994; Drewe *et al.*, 2013; German *et al.*, 2001; Hendrikx *et al.*, 2011; WHO, 2008) describing the attributes to be assessed in order to estimate the performance and the efficiency of the surveillance. In this context, ‘attributes’ are used to refer to the many quantifiable characteristics of surveillance systems (Drewe *et al.*, 2013). Depending on epidemiological, sociological and economic factors, surveillance systems can be complex, as are the attributes to describe them. According to a report compiled after discussions during a workshop including surveillance experts prior to the International Conference on Animal Health Surveillance (ICAHS) in 2011, and made available on the website of the Animal Health and Veterinary Laboratories Agency (AHVLA) (http://www.defra.gov.uk/ahvla-en/disease-control/surveillance/icahs-workshop/), 29 attributes have been identified which can be potentially be assessed. The choice of the attributes to be evaluated is closely linked to the purpose of the evaluation, and to the objective of the surveillance system.

When considering the surveillance of zoonotic diseases one of the most important objectives is to accurately detect the disease in animals in order to prevent human cases (Hadorn et Stärk, 2008b). Subsequently, if a zoonotic disease is already present in the human compartment, the surveillance system should be able to detect it and to identify the source in order to avoid further contamination.

To assess if the passive surveillance component can ensure the early detection of zoonotic diseases, especially HPAI H5N1, we primarily need to evaluate the quality of the evidence provided by estimating the surveillance sensitivity (Se) and its timeliness. Depending on the disease situation, the sensitivity (Se) can be the probability of detecting the disease above a certain prevalence (for areas free of disease) or to detect true cases or outbreaks (for areas where the disease is endemic) (Hoinville *et al.*, 2013a). In situations where cases are found, as for the HPAI H5N1 surveillance in SEA, where the human cases are rare but with great consequences, sensitivity becomes synonymous with completeness (Declich et Carter, 1994). Timeliness for early detection is often defined by the time interval between disease occurrence and control responses (Hoinville *et al.*, 2013a). Sensitivity and timeliness are connected to other important attribute for passive surveillance as the acceptability. This attribute relates to the adequacy and relevance of the surveillance objectives and is linked to the expectations and perceptions of the stakeholders who are part of the surveillance (Auer et Andersson, 2001)

Considering that sensitivity, timeliness and acceptability were considered in this research work as key attributes to be evaluated, we selected several methods of evaluation in order to review their usefulness in the situation of developing countries and to provide guidance on the way they can be applied.

We had three specific objectives according to the type of method selected:

(1) To review the feasibility in our study context of qualitative and semi-quantitative methods of surveillance systems evaluation (from the human and the animal field) and to apply them.

(2) To apply scenario-tree modelling methods in resource-scarce environments.

(3) To develop a participatory method for evaluation in order to highlight the value of participation in the process of surveillance evaluation

## 2.2. Specific objectives regarding surveillance design

In contexts where resources for surveillance are restricted and often dependent on uncertain and variable external funding, a priority should be placed on the use of cost-effective surveillance methods such as mobile phone surveillance system or risk-based surveillance, using exposure and risk assessment methods (Stärk *et al.*, 2006). Another priority should be given to the development of tailored training programmes for VAHW in order to improve their sustainability, to improve the acceptability of the surveillance activities and to allow for optimal allocation of resources. In this research work, we have selected and tested four different approaches that could be used to design more efficient surveillance. The use of mobile phones to declare animal mortality, the evaluation of criteria that could influence the effectiveness of VAHW in the surveillance, the use of spatio-temporal analysis to understand the spread of disease at the local level and multi-criteria analyses to develop a risk map for human infection.

We had three specific objectives for this section:

(4) To test the feasibility of using mobile phone text messages for VAHW to declare animal mortality.

(5) To validate our participatory evaluation tools and to use the results to propose recommendations for VAHW training

(6) To better understand the risk for human infection associated with the local disease propagation, in order to produce a risk map for risk-based surveillance design.

In a final study we implemented a systematic review of the research projects conducted by CIRAD on surveillance systems in Madagascar and Cambodia. We have produced a narrative synthesis of the research outputs to critically analyse and review their field feasibility in order to determine their benefits, and to strategically provide effective, targeted correctional interventions and recommendations.

The specific objective of this section was:

(7) To provide generic recommendations for improving surveillance methods in poor resource settings

# PART 3
# OVERALL ORGANISATION, MATERIAL AND METHODS

In the Part 3, we are introducing the nine research studies that were implemented between January 2010 and June 2014 to address the specific objectives of this PhD. The studies all looked at the Cambodian surveillance system except for one study which was done in Thailand and one which compares Cambodia with Madagascar. We describe, for each study, the population of interest, the specific objectives and how these objectives relate to our main objective, the time frame and conditions of implementation, and finally give details on the material and methods applied in each work.

# 1. Rational planning and implementation

In the section 1, we will describe the objectives of the nine field studies, their connections and the time frame of their implementation

## 1.1. General framework: specific objective, timing and practical constraints in the field implementation

### 1.1.1. Objectives of the studies

In order to meet our main objective and the specific objectives detailed in the previous section, nine studies were implemented:

**(1)** Semi-qualitative evaluation of HPAI H5N1 surveillance in animal systems using the Surveillance Network Analysis Tool for Tropical countries (**SNAT Trop**) in Cambodia.

**(2)** Qualitative evaluation of HPAI H5N1 surveillance in human and animal systems using the "Strength, Weaknesses, Opportunities, Threats" **(SWOT)** method in Cambodia.

During these two studies we carried out a critical assessment of the organisation and functionality of the Cambodian HPAI H5N1 surveillance in human and animal systems using qualitative and semi-qualitative methods in order to make recommendations to enhance the early detection of outbreaks and to integrate human and animal surveillance.

**(3)** Quantitative evaluation of the HPAI H5N1 surveillance system in backyard production in Thailand using scenario-tree analysis modelling (**STA Thai**)

We developed a stochastic scenario tree to model and assess the surveillance system of HPAI H5N1 in Thailand in backyard and free-range poultry production systems. The objective was to estimate the sensitivity of each of the surveillance components, but more specifically sensitivity of the passive surveillance in order to demonstrate the usefulness of this method to assess freedom from disease in countries with limited resources.

**(4)** Design of a participatory evaluation grid for VAHW (**PE VAHW**) in Cambodia.

The objective was to involve Village Animal Health Workers in their own evaluation in order to improve their active participation in HPAI H5N1 case-reporting. By using participatory methods, we developed a new criteria grid which includes local success indicators developed and used by the VAHW themselves.

**(5)** Multivariable analysis of factors influencing the efficiency of VAHW (**EF VAWH**) in Cambodia.

The objective was to validate the participatory evaluation grid conceived in the study 4, by assessing the level of effectiveness of 251 VAHW in three provinces bordering Vietnam. The grid allowed us to give a score for their level of activity and to analyse, through multiple linear regression, the factors influencing the best score.

**(6)** Pilot study on mobile phone reporting (**SMS Reporting**)

We implemented a pilot-study to test the use of text messaging by 112 participants from 68 villages. The objective was to obtain baseline mortality data in order to detect peaks of mortality and to identify outbreaks of infectious diseases more rapidly.

**(7)** Spatio-temporal cluster analysis of HPAI H5N1 outbreaks (**STC Analysis**) in Cambodia.

Notified villages are often the tip of the iceberg; delays between the first case and detection enable the virus to spread from house to house and then from village to village through direct or indirect transmission. Recent spatial analysis showed that during the several outbreaks occurring in Thailand there were few occasions of disease emergence and that most of the outbreaks were the consequence of short distance dissemination (Souris *et al.*). This study aimed to understand how local spread occurred and to identify the most important determinants in order to limit the number and size of future outbreaks in the poultry population.

**(8)** Risk mapping of HPAI H5N1 infection in humans (**MCDA**)[1] in Cambodia.

In the final section we used spatial analysis combined with multiple criteria decision analysis (MCDA) to produce a map displaying the risk of human infection in Cambodia, in order to adjust and reinforce the surveillance in the zones with greater risks of disease occurrence.

**(9)** Lessons from CIRAD experiences in Cambodia and in Madagascar **(Narrative Synthesis**)

To conclude this work on tools and methods to improve surveillance systems in remote areas, we carried out a comparative analysis of two challenging environments, Cambodia and Madagascar. We analysed the results of several research projects implemented by CIRAD (French International Research Centre for Agricultural Development) in these 2 countries over the past decade. The objective was to show how new approaches for surveillance and response systems could be transferred between different countries with difficult socioeconomic environments.

[1] A map displaying the risk of HPAI H5N1 spread in poultry population in Cambodia has been made during this study (using as well MCDA), the details of this work will be not given in this manuscript, only the final product of the map will be displayed.

**Table 5: Correspondence between PhD specific objectives and the different field studies**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1- To review the feasibility of qualitative and semi-quantitative methods of surveillance systems evaluation (from the human and the animal field) and to apply them. | | | | | | | | | |
| 2-To validate the use of scenario-tree modelling methods in resource scarce environments. | | | | | | | | | |
| 3-To demonstrate the value of participation in the process of surveillance evaluation | | | | | | | | | |
| 4-To validate our participatory evaluation tools and to use the results to propose recommendations about VAHW | | | | | | | | | |
| 5-To test the feasibility of using mobile phone text messages to declare animal mortality from VAHW. | | | | | | | | | |
| 6-To understand risk of human infection associated with disease spread at local level to produce risk maps. | | | | | | | | | |
| 7-To provide generic recommendations for improving surveillance methods in a context of resource poor settings | | | | | | | | | |

## 1.1.2. Background and context of the populations studied

### 1.1.2.1. Thailand

Thailand covers an area of 513,120 km² with a population of 68 million, of which 14 million live in the capital Bangkok. The population density is 122 inhabitants/km². The country is divided into 5 regions which are broken down into 77 provinces, 877 districts (or Amphoe), 7,410 sub-districts and 72,335 villages according to the National Statistics Office (NSO). Thailand is the 2nd largest economy in Southeast Asia after Indonesia and has advanced to the status of a middle income country. The poverty level has declined noticeably, but remains high in the Northern provinces (National Economics and Social Development Board, 2014). About 49% of Thailand's labor force is still employed in agriculture, but the share of gross domestic product (GDP) coming from agriculture has largely decreased to only 11% (World Bank, 2012). Thailand is one of the top rice exporters in the world.

#### 1.1.2.1.1. Poultry production

In 2010, the FAO census of animals estimated the Thai livestock population to constitute of about 6.5 million cattle, 1.6 million buffaloes, 7.6 million pigs, 232 million chickens and 29 million ducks (Ahuja, 2013). The poultry sector in Thailand is very important. Poultry sales form more than half the total added value from livestock in the GDP. This production includes backyard producers, small to medium-scale commercial producers, large commercial producers and vertically integrated industrial producers (Safman, 2009). Backyard chicken production is by far the most common, 80% of households in rural areas raise between 30 to 50 chicken, but the total number of flocks is difficult to assess, a study done by *Otte et al.* in 2006 estimated the total number of flocks to be 2 million (three quarters of the global number of flocks). Backyard poultry has economic value and it also plays an important social and cultural role. Between 1 and 6 million birds are raised for the purpose of fighting (Paul *et al.*, 2013). Large-scale farms represent 6.6% of the total production; they range in size from 1,000 to 5,000 birds and have controlled biosecurity conditions. Then there are the vertically integrated farms with 10,000 birds per house and between 2 to 10 houses. There are no more than a few hundred of these but they represent 25% of the production. The farms have highly bio-secure facilities with on-site hatcheries, slaughter houses and post-slaughter processing facilities (Safman, 2009).

#### 1.1.2.1.2. The current HPAI H5N1 situation in Thailand

The first case of HPAI H5N1 occurred in January 2004. During two years (up to end 2006), Thailand experienced four main epidemics with 1 700 outbreaks reported (Tiensin *et al.*, 2007). The majority of the outbreaks took place in the central plain and in backyard production. Then only sporadic cases occurred until 2008. During this time 25 human cases were detected, 68% of which were fatal (Chantong et Kaneene, 2011). The economic impact was huge with 65 million birds culled and one billion Thai baht (more than 28 million of Euros) spent on compensation (Paul *et al.*, 2013). Production of broilers dropped from 22 million per week to 15 million during the first years of epidemics. From the outset, the Department of Livestock Development (DLD) developed specific active surveillance strategies (X-Ray campaigns relying upon Village Health Volunteers), restricted movement (with bird passports) and the control of outbreaks through pre-emptive culling and compensation schemes (75% of the value of the bird) (Tiensin *et al.*, 2007).

#### 1.1.2.2. Cambodia

Cambodia covers an area of 181,035 km² and has a population of 14.96 million with a population density of 75 inhabitants/km²; 1.35 million inhabitants live in the capital Phnom Penh. The country is divided into 24 provinces which are broken down into 183 districts, 1,623 communes and 13,408 villages (NIS, 2011). More than 80% of Cambodia's population lives in rural areas and about 73% of this population depend exclusively on agriculture for their livelihood; 17% of the population is considered to be malnourished (FAOSTAT, 2014). The Khmer Rouge period (1975-1979) was one of the most devastating periods in history; nearly a quarter of the total population of Cambodia was exterminated. Today, the country is still struggling to rebuild, undermined by corruption and poverty. Cambodia remains one of the poorest countries of the region, ranked 136 out of 187 on the Human Development Index (UNDP, 2014), and 63% of the population is illiterate, one of the world's highest illiteracy rates.

##### 1.1.2.2.1. Livestock production

The livestock sector is of critical importance in Cambodia, accounting for 7.6% of the country's GDP. Animals represent a significant source of food and are thus vital for consumers, income, employment and trade (FAO, 2005). This sector is mostly composed of small farmers; only 1% of farms are commercial (NIS, 2014). Poorer families generally have chicken and sometimes one or two pigs, while the richest have buffaloes or cows. In 2013, the animal census published by the Department of Animal Health and Production ( DAHP ) (NIS, 2014), estimated the cattle population to be about 2.7 million, 472,000 buffaloes, 1.5 million pigs, 27.8 million chickens and 5.1 million ducks .

##### 1.1.2.2.2. Poultry production

Poultry production is divided between traditional breeding (backyards), semi- commercial and commercial (with high biosecurity and more than 10,000 head) systems. The semi-commercial production is separated into 3 categories: small (500-1,000 birds), medium (1,000-5,000) and large productions (over 5,000). Semi-commercial and commercial farms include laying hens, broilers and ducks are concentrated around the major cities and along the Thai border in the northwest and the Vietnamese border in the southeast.

The majority of poultry farms are backyard types (80%) (Anonymous, 2006). For these farms the average number of birds is between 10 and 30 and they are raised in backyards often in close contact with other livestock and humans (Desvaux *et al.*, 2006). Most chicken are local breeds. The backyard system is low input-output system, with no additional nutrient intake or veterinary care. New birds usually come from self-renewal. Chicken meat and eggs are kept for home consumption. Birds sold alive can represent a significant source of income (Dinesh *et al.*, 2009b). Ducks are also important providers of eggs, both for sale and consumption. There are more than 1,000 commercial duck farms in Cambodia with, on average, 900 heads per farm. The majority of the farms are layer farms growing "free-ranging ducks". This activity very much follows the rice cycle (Dinesh *et al.*, 2009a). Ducks are transported to the rice fields, sometimes over long distances, so that they can feed on the seeds remaining after harvest. Ducklings are usually bought from markets or commercial hatcheries in October/November, and their laying cycle varies from 4 months (in Takeo) to 24 months (Dinesh *et al.*, 2009a). Live poultry are often traded with Vietnam. The volume of birds depends on the period of the year, with an increase of movement during festive seasons in February (Chinese new year), April (Khmer new year) and September (Pchum Ben) for consumption and cash needs (Conan, 2013).

##### 1.1.2.2.3. The current HPAI H5N1 situation in Cambodia

The first poultry case of HPAI H5N1 appeared in Cambodia on 24$^{th}$ January 2004, in a broiler farm in Poung Pey village not far from Phnom Penh. The first human case occurred in 2005. Since then Cambodia has reported 42 avian outbreaks and 56 human cases (CDC, MoH Cambodia, 2014). In all, 79% (44/56) of the human cases were under 14 years of age and 66% (37/56) were fatal. Currently, only the clade 1 virus has ever been detected in Cambodia, suggesting that this virus is endemic in the southern Mekong basin. There is even some evidence that that recurring outbreaks in Cambodia are caused by an internal circulation of a virus endemic to the country (Sorn *et al.*, 2013). The latest human case, dating back to March 2014 was detected in Kampot province. It was a 2 year-old girl that got infected while her parents prepared dead chicken for food and she died 7 days after the onset of symptoms (CDC, MoH Cambodia, 2014).

The detection of poultry cases relies almost only on passive surveillance, i.e. notifications by the stockbreeders (Conan, 2013). In rural areas, other avian diseases, like Newcastle disease, avian cholera, Gumboro or viral enteritis in ducks are endemic (Conan, 2013). They often present a very similar clinical picture to that of avian influenza, with high mortalities. The burden of diseases in poultry flocks is very high and stockbreeders do not judge it necessary to systematically notify them (Ly *et al.*, 2007). Moreover, when HPAI H5N1 outbreaks are confirmed, the current policy in Cambodia is based on massive culling of poultry in the affected village, without economic compensation. These control measures lead to the under-reporting and under-detection of HPAI H5N1. In this context, vigilance in both animal and public health sectors must be maintained in order to detect, report and characterise the animal influenza viruses.

## 1.2. Timing and implementation

The implementation of the nine different studies took place over a period of 4 years (2010 to 2012, and 2014), as shown in the Table 3.

**Table 6: Timetable for the different activities during the nine studies**

| | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|
| Data collection for qualitative analysis of animal surveillance system | | | | | |
| Implementation of the SNAT method | | | | | |
| Data collection for qualitative analysis of human surveillance system | | | | | |
| Implementation of Scenario tree analysis in Thailand | | | | | |
| Participatory evaluation | | | | | |
| Multifactorial analysis of VAHWs effectiveness score | | | | | |
| Pilot study on SMS reporting | | | | | |
| Outbreak investigation for spatio-temporal analysis | | | | | |
| Multicriteria decision analysis | | | | | |
| Narrative synthesis: comparison between Cambodia and Madagascar | | | | | |

Most of the studies were funded by REVASIA (Research for Evaluation of Avian Influenza Surveillance in South East Asia), a program which was first funded by the "Direction Générale de l'Alimentation" (DGAL) and the French Cooperation Agency (AFD), http://revasia.cirad.fr/en/ .

### 1.2.1. Implementation of the "SNAT Trop" evaluation

In 2011, the pattern of HPAI H5N1 in Cambodia changed with an increase in the number of human cases. Eight human cases of HPAI H5N1 infection were reported between February and August with people under 19 years of age and with a case fatality of 100% (CDC, MoH Cambodia, 2014). This was the highest number of human HPAI H5N1 cases reported in one year for Cambodia (see Annex 12). The basis for the increased incidence and the high mortality remained unclear. The human cases were not linked to each other, with the exception of a mother and her child, who got infected in Prey Veng province in February 2011. The important fact to mention was the absence of outbreak detection in poultry. Only two fatalities were related to contact with sick poultry, but not confirmed to be HPAI H5N1 (CDC, MoH Cambodia, 2014). This was alarming for the Cambodian veterinary services. So the Department of Animal health and Production (DAHP) and the National Veterinary Research Institute (NaVRI) agreed on an evaluation mission, to assess the current HPAI H5N1 surveillance system and to provide recommendations to enhance early warning detection of outbreaks. The evaluation using SNAT tool was done in July 2011, by a Master's student Laetitia Minodier under my supervision. We used an adapted version of the SNAT tool. At the time of the first evaluation, only the passive component was in operation because of the withdrawal of external funding. The work resulted in a Master thesis: ”*Minodier, L., 2011. Adaptation de l'outil SNAT au contexte de la surveillance de l'IAHP H5N1 au Cambodge (Master BGAE, Spécialité BIMP, Parcours SAEPS). Université de Montpellier II, Montpellier, France.”*

This research was presented during the first International Conference on Animal Health Surveillance (ICAHS) in 2011 in Lyon, France and was published in Epidémiologie et Santé Animale in 2011 (See Annex 1 for the full paper), with the following reference "*Peyre, M., Hendrikx, P., Do Huu, D., **Goutard, F**., Desvaux, S., Roger, F., others, 2011. Evaluation of surveillance systems in animal health: the need to adapt the tools to the contexts of developing countries, results from a regional workshop in South East Asia. Épidémiologie et Santé Animale 415–417.”*

### 1.2.2. Implementation of the "SWOT" analysis

A second evaluation was done at the request of FAO Cambodia. This mission was funded by FAO, and was implemented between October 2011 and May 2012.

Data on the human surveillance system were in part collected by a research assistant from AVSF, Dr Aurélia Ponsich, and by a veterinary student from ENVT, Lucie Collineau, both under my supervision.

### 1.2.3. Implementation of the "STA Thai" study

The research study in Thailand was partly funded by REVASIA and by the French National Research Agency (ANR), through the ECOFLU project (http://ur-agirs.cirad.fr/en/projects/ecoflu )

This research was the subject of an oral presentation during the first International Conference on Animal Health Surveillance (ICAHS) in 2011 in Lyon, France and was published in Preventive Veterinary Medicine in 2012 (See Annex 2 for the full paper), with the following reference "***Goutard, F.L***., *Paul, M., Tavornpanich, S., Houisse, I., Chanachai, K., Thanapongtharm, W., Cameron, A., Stärk, K.D.C., Roger, F., 2012. Optimizing early detection of avian influenza H5N1 in backyard and free-range poultry production systems in Thailand. Preventive Veterinary Medicine 105, 223–234.*"

### 1.2.4. Implementation of the "PE VAHW" study

This study was done in collaboration with Agronomists and Veterinarians without Borders Cambodia (AVSF), and the field study was implemented by a Master's student Clémentine Calba, who was under my supervision between March and August 2011. The work resulted in a Master thesis: "*Calba, C., 2011. Adaptation de la méthode des critères au contexte des VAHW au Cambodge par l'utilisation de méthode participatives (Master BGAE, Spécialité BIMP, Parcours SAEPS). Université de Montpellier II, Montpellier, France.*"

This research was the subject of an oral presentation during the first International Workshop of the Participatory Epidemiology Network for Animal and Public Health in 2012 in Chiang Mai, Thailand and was published in Acta Tropica in 2014 (See Annex 3 for the full paper), with the following reference *"Calba, C., Ponsich, A., Nam, S., Collineau, L., Min, S., Thonnat, J.,* ***Goutard, F.L.,*** *2014. Development of a participatory tool for the evaluation of Village Animal Health Workers in Cambodia. Acta Tropica 134, 17–28. doi:10.1016/j.actatropica.2014.02.013"*

### 1.2.5. Implementation of the “EF VAHW” study

This study was done at the request of FAO Cambodia. It was funded by REVASIA and FAO. The FAO contracted Clémentine Calba for 3 months (November 2011 to January 2012), and she carried out the field survey under my supervision in collaboration with AVSF.

### 1.2.6. Implementation of the “SMS Reporting” study

The study was organised in collaboration with the Pasteur Institute of Cambodia (IPC). The study was implemented by a Master's student, Sophie Baron, who obtained a scholarship from the “Pierre Ledoux” foundation. She was under my supervision and the supervision of Dr Arnaud Tarantola from IPC. Another pilot study was in fact implemented at the same time. We were also testing the tool for the notification of adverse events after vaccination within the International Vaccination Center at the IPC. The study lasted 72 days and was conducted in 184 patients. Participation rate was high (71.7%), especially for people living in urban settings.

This research was published in the Journal of Medical Internet Research (See Annex 4 for the full text), with the following reference “*Baron, S., **Goutard, F.,** Nguon, K., Tarantola, A., 2013. Use of a Text Message-Based Pharmacovigilance Tool in Cambodia: Pilot Study. Journal of Medical Internet Research 15, e68. doi:10.2196/jmir.2477.*”

### 1.2.7. Implementation of the “STC Analysis” study

This study was done in collaboration with IPC and at the request of the NaVRI. In 2010, there was a very large outbreak of HPAI H5N1 in free-grazing ducks in the village of Pralay Meas, in the Koah Andaet district (Takeo province), killing thousands of birds (16,000 deaths were reported to the OIE (OIE, 2010)). When a village is officially declared as infected with HPAI H5N1 to the OIE, veterinary services are obliged, by law, to cull all of the poultry present at the time of the outbreak. Usually only one village is declared as infected even if the disease has spread further. In order to assess the local spread of the disease, we organised outbreak investigations of all villages within a 20 km radius of the first village to be declared. We did the same type of investigation in April 2010 around the village of Peam Sdey, in the Kampong Leav district (Prey Veng province), where an outbreak of HPAI H5N1 occurred,

killing 903 poultry. Both field surveys were implemented with the NaVRI staff and in collaboration with IPC.
The field investigations lasted 3 weeks each.

This research was the object of a poster presentation at the International conference on Options for the Control of Influenza VII in Hong Kong, China, in September 2010: *"Conan, A., Holl, D.,* ***Goutard, F****., Buchy, P., San, S., Vong, S., 2010. Clinical definition of highly pathogenic avian influenza (H5N1) outbreaks in Cambodian backyard flocks. In: Proceedings of the International Conference on Options for the Control of Influenza VII, Hong Kong, China, 3–7 September 2010"* and an oral presentation (see the summary of the presentation in Annex 5) at the 8th International Symposium on Avian Influenza in London, UK in April 2012: *"****Goutard, F****., Vong, S., Conan, A., San, S., Dab, W., Staerk, K., Paul, M. (2012). Spatio-temporal analysis of avian influenza H5N1 outbreaks in human and poultry population in Cambodia."*

### 1.2.8. Implementation of the "MCDA" study

This study was conducted by a Master's student, Floriane Roulleau, between March and June 2014, under my supervision and the supervision of Dr Annelise Tran, from Cirad, providing her expertise in spatial-analysis expertise and Dr Mathilde Paul, from ENVT, providing her expertise in HPAI H5N1 in Thailand. The work resulted in a Master thesis : "*Roulleau, F., 2014. Cartographie du risque de propagation et d'infection par le virus H5N1 en Thaïlande et au Cambodge par la Méthode d'Analyse Multi-Critères (Master 2 Santé Publique). Université de la Méditerranée Aix-Marseille, Marseille".* A manuscript is under preparation, to be submitted to Preventive Veterinary Medicine.

### 1.2.9. Implementation of the "Narrative Synthesis" study

The comparative analysis of the research studies done on surveillance and control strategies in Cambodia and in Madagascar was carried out between January and May 2014, with a systematic review and a narrative synthesis of the results of the review.

This research was the subject of an oral presentation during the second International Conference on Animal Health Surveillance (ICAHS) in 2014 in La Havana, Cuba and is going to be published in Preventive Veterinary Medicine in 2015 (See Annex 6 for the full paper), with the following reference *"**FL Goutard**, A Binot, R Duboz, H Rasamoelina-Andriamanivo, M Pedrono, D Holl, MI Peyre, J Cappelle, V Chevalier, M Figuié, S Molia, FL Roger. (2015) How to Reach the Poor? Surveillance in low-income countries, lessons learned from experiences in Cambodia and Madagascar. Accepted. Preventive Veterinary Medicine"*

# 2. Overall description of the material and method used in each research study

## 2.1. Surveillance system evaluation methods

### 2.1.1. Use of qualitative and semi-quantitative methods in Cambodia

#### 2.1.1.1. Data collection

##### 2.1.1.1.1. Description of the animal disease surveillance system

Data were collected at three different points in time. The first period was between February and March 2010, during which we organised field trips in 3 provinces (Siem Reap, Kampong Cham, Svay Rieng) to meet and interview provincial veterinarians, district veterinarians, VAHW and farmers in order to collect baseline information about backyard poultry production system, disease occurrence and poultry mortality, and to have their opinion about how well the surveillance system worked. Data were collected through semi-structured interviews which were conducted individually or in groups. In each province, 2 districts were selected. The meetings were organised at the office of the district veterinarians and an average of 7 VAHW were invited to join the meeting. Meetings with farmers took place in their villages. In total, 3 provincial veterinarians, 6 district veterinarians, 43 VAHW and 20 farmers were interviewed.

The second period was in July 2011. We used SNAT Trop which was the adapted version of the SNAT tool for developing countries. The tool consists of a 42 pages questionnaire to collect precise information about network operation and functionality, a scoring grid composed of 78 criteria (score between 0 and 3) and a guide explaining how to implement the scoring (Hendrikx *et al.*, 2011). The study was done in three parts. First, the questionnaire was pre-completed by the director, the acting director and the head of the virology section of the NaVRI. Then, to complete the questionnaire, we interviewed three officers of the intermediate unit (provincial chiefs from Siem Reap, Kampong Cham, Prey Veng) and five field agents (district veterinarians). These people were selected by the director of the NaVRI himself. Three people were then in charge of scoring the criteria assessment: the coordinator of the surveillance system, and two external experts from CIRAD.

The next period of data collection was carried out between October 2011 and March 2012. Several sources of information were used: i) review of official documents available at the Department of Animal Health and Production (DAHP) and the National Veterinary Research Institute (NaVRI) (monthly reports, specific reports on outputs of active surveillance, previous project reports, guide for H5N1 HPAI outbreak investigation and emergency response developed by FAO and DAHP), ii) access to databases hosted by NaVRI (laboratory analyses, monthly census, mortality declaration, market / sentinel surveillance, hotline) iii) review of the scientific literature published on H5N1 HPAI surveillance systems in Cambodia for animal and public health. Semi-structured interviews were also organised with people involved in the surveillance system at the central level (12 persons) or representatives of partner institutions (IPC, WHO, FAO, OIE, USDA – 6 persons in total), and with 2 provincial chiefs (Takeo and Prey Veng) and 8 district veterinarians. Questions about their role in the surveillance (acceptability, communication, and training), the overall performance of the system (sensitivity, specificity, timeliness, and associated costs) and the functionality of the surveillance (data processing, analysing, and laboratory management) were part of the discussions.

##### 2.1.1.1.2. Description of the public health surveillance systems

Data were collected in May 2012 through individual interviews with people responsible for the different components of the surveillance system at the central level. In total, 15 persons from 7 different institutions were interviewed (MoH of Cambodia, CDC Cambodia, WHO, Armed Forces Research Institute of Medical Sciences (AFRIMS), the US Naval Medical Research Unit (NAMRU), National Institute of Public Health (NIPH), IPC). Information about the surveillance organisation (actors, stakeholders, and communication), the overall performance of the system (sensitivity, specificity, timeliness, and associated costs), the functionality of the surveillance (data processing, analysing, and laboratory management) and the link with the animal surveillance system were explored.

##### 2.1.1.1.3. Description of the Village Health Worker system

Data were collected in August 2011 and completed in March 2012. Thirty-four individual interviews were conducted (6 from the governmental staff – MoH, Ministry of Rural development, National Centre for Health promotion- and 28 representatives of local and international NGOs). Additionally, a structured questionnaire was completed with organisations that were involved in the training of VHW (see Annex 7). Official documents and reports from NGOs were also reviewed and compiled.

#### 2.1.1.2. Data analysis

##### 2.1.1.2.1. Descriptive analysis

First a descriptive analysis of both surveillance systems was carried out. We summarised the various types of information collected into an information flow chart (describing the flow of the information which is transferred within the surveillance systems, and the different actors that are involved). The characteristics and outputs of each component were described: details on the case definition, details on the type of diagnostic analysis performed, number of monthly reports from the field, number of suspicions, number of confirmed cases detected by the different components (when available), training plans, communication tools and acceptability of the surveillance by the actors. The link between the two surveillance systems was also described. The economic information related to the cost of surveillance, both human and animal, was not available at the time of our research.

##### 2.1.1.2.2. Surveillance Network Analysis Tool (SNAT Trop)

During the time of the evaluation of the Cambodian animal health surveillance system we were working on the adaptation of the Surveillance Network Analysis Tool (SNAT tool) (Hendrikx *et al.*, 2011) so that it could be applied generically for and by developing countries. The ultimate goal was to offer a tool that is easy for the partners to use, with limited subjectivity and that would allow a reliable assessment of the system and a simple visualisation of the strengths, weaknesses and possible improvements. A first regional workshop was organised by CIRAD and the Vietnamese veterinary services in Hanoi in October 2010, with representatives of the veterinary services of Cambodia, Lao PDR and

Thailand. Then the tool was modified after numerous meetings and field tested in Cambodia (Minodier, 2011) and Lao PDR (Faverjon, 2011). At the time of the evaluation only the passive surveillance component was operating. It is important to highlight the fact that only the passive surveillance is run on governmental resources, all the other components of the active surveillance were funded by donors (FAO, ACIAR). Funding stopped in June 2011.

The outputs of the evaluation are displayed in three different formats (Hendrikx *et al.*, 2011):

- A table showing the 10 different sections of the surveillance system (objectives and scope; central institutional organisation; field institutional organisation; diagnostic laboratory; surveillance tools; surveillance procedures; data management; training; restitution and diffusion of information; evaluation and performance) with a pie chart representing the corresponding notation for each section.
- A histogram showing the scoring of seven critical control points that were developed by (Dufour, 1999).
- A radar chart displaying the score of 10 evaluation attributes that are recommended by CDC and WHO (Declich and Carter, 1994).

##### 2.1.1.2.3. Strengths-weaknesses-opportunities-threats analysis (SWOT)

For both systems the information collected was summarised using a SWOT analysis. This is a qualitative assessment technique that explores the external (forces and facts that are not under your control) and the internal (resources, activities, experiences) elements that may influence your system (KU Work Group for Community Health and Development., 2014)

### 2.1.2. Quantitative methods: scenario-tree analysis modelling

#### 2.1.2.1. Principles of the method

The SSe can be estimated in the same way as the Se of a diagnostic test. It is a measure of the confidence that our surveillance will detect the disease given that the population is really infected (Martin, Cameron et Greiner, 2007). This can be translated into:

$$SSe = P(T+ / D+)$$

*T+ = positive result from surveillance*

*D+ = truly infected population*

In other words, it is the probability to detect at least one infected individual in a population where the disease is present at a prevalence of P*. It is then calculated as below:

$$SSe = 1 - (1 - SeP^*)^n$$

*Se= the sensitivity of the test used for detection*

*P*= Prevalence of the disease*

*N= the number of animals included in the surveillance*

A various range of methods have been used to estimate the Se of surveillance components or systems: qualitative methods using expert opinion (Hendrikx *et al.*, 2011), descriptive methods comparing representative survey and surveillance results (Lynn *et al.*, 2007), stochastic simulation modelling (Audigé et Beckett, 1999), capture-recapture methods (del Rio Vilas *et al.*, 2005) and scenario tree modelling (Hadorn et Stärk, 2008b).

The scenario tree modelling is a relatively new method that has been increasingly used in the evaluation of complex surveillance systems in animal diseases (Christensen *et al.*, 2014; Frössling *et al.*, 2013; Martin *et al.*, 2007; Welby *et al.*, 2012) and also in public health (Watkins *et al.* 2009). It is usually used to help demonstrate freedom from disease. The method uses a tree structure to describe the population and the surveillance organisation and to capture the fact that some individuals will be more likely to be infected based on risk factors and some individuals will be more likely to be detected depending on the structure of the surveillance system. The method considers the population as homogenous subpopulations with the same probability of infection and detection (FAO, 2014b). This approach has the advantages of being able to compile all the available evidence provided by different surveillance activities, to include information about the quality of the surveillance, to be repeatable and objective and to provide a quantitative output (FAO, 2014b).

#### 2.1.2.2. H5N1 HPAI Thai surveillance system evaluation (STA Thai)

Our population of interest was restricted to the low biosecurity poultry systems listed in the DLD census from 2005. Our surveillance unit for the analysis was the farm, considering one flock per farm as a sampling unit. The number of farms was 2,589,342 chicken farms, 12,753 free-grazing farms and 365,358 mixed farms.

We described three surveillance system components: i) passive surveillance, ii) intensive active surveillance (or X-ray) based on clinical signs consisting of compulsory visits of backyard farms by village health volunteers to look for specific signs, iii) laboratory X-ray surveys consisting in the risk–based collection of samples in chickens and free-grazing ducks. X-ray components are both risk-based and run for a period of 2 months twice a year.

A positive output of the surveillance was considered when a sample was tested positive for RT-PCR. Two design prevalences were assigned to our model: the within farm prevalence,

which was set to 50% and the level of infection at farm level with three different levels tested (0.05%, 3 infected farms (3.4 $10^{-5}$%) and 1 infected farm ($10^{-4}$%)).
Data for the probability distributions were collected from the literature review and from an expert opinion elicitation that was conducted in 2011, through a web-based questionnaire and including 6 experts working in the field of avian influenza surveillance in Thailand for several years. Several scenarios of alternative surveillance designs were tested, according to the different zoning strategies that could be used to define the high risk areas.
A stochastic model was generated using @Risk 5.5® (Palisade Corporation) with Microsoft® Excel 2007. The specific sensitivity (Se) of each component and the overall Se of the surveillance system were estimated. The probability of country freedom was also calculated. Sensitivity analyse was performed using the regression analysis approach in @Risk, to evaluate the influence of input distributions on the SE of different components.
See the full paper presented in Annex 2 for details on the material and methods.

### 2.1.3. Participatory evaluation of VAHW in Cambodia (PE VAHW)

We adapted a methodology that has already been applied by AVSF in Madagascar and in Cambodia to develop an evaluation grid for farmer organisations (Gennet et Martin, 2012) This method is based on the use of participatory evaluation (PE). PE could be defined as applied social research that implies interactions between stakeholders (Garaway, 1995; Lahai, 2009), and focusing on the understanding of local priorities. With this approach, project participants are directly involved in formulating the evaluation questions or in collecting the data.
The study was implemented in two provinces (Prey Veng and Svay Reng) with contrasting situations in terms of the presence or not of NGOs working in the field of animal health. One district per province was selected. The design of the grid, which involved the selection of criteria, the formulation of questions to assess the criteria and the respective system of notation, was developed during 4 meetings, between March and November 2011, which each included a selection of different stakeholders involved in the VAHW network (VAHW themselves, district veterinarians, provincial chiefs, NaVRI representatives, FAO and NGO representatives). Each meeting brought together between 9 and 23 persons. During these meetings, participatory tools were used to facilitate discussion, experience sharing and to achieve a consensus on evaluation criteria and the notation system. We used tools such as a problem tree, the Metaplan method (©Metaplan GmbH, 2003), focus groups and pair-wise

ranking. The last step was a testing phase, during which the criteria grid was implemented in the field with the evaluation of 36 VAHW in order to validate the tools' feasibility. See the full paper presented in Annex 3 for details on the material and methods.

## 2.2. Tools and methods to improve surveillance design

### 2.2.1. Multivariable analysis of factors influencing the efficacy of VAHW (EFF VAHW)

#### 2.2.1.1. Data collection

For this study we applied the criteria grid that we had previously designed. The grid is composed of five categories and for each category a number of points has been allocated: sustainability (39 points), treatment (25 points), production (16 points), vaccination (13 points) and reporting (7 points). For each category, several evaluation criteria were defined and questions developed in order to assess if the criteria are fulfilled by the VAHW. To evaluate one VAHW, the method requires the interview of 14 persons (see the full paper in Annex 3): the VAHW himself, 10 villagers, the village chief, one representative of the Commune Council and the district veterinarian. The final result of this evaluation grid is a score between 0 and 100.

An additional questionnaire (Annex 8) was developed in order to collect data about factors that could influence the VAHW's score: training background (when, how long, by whom…), personal information (sex, age, means of transport, level of literacy…), professional environment (number of animals in his village per species, member of farmer associations…), financial aspects of his activities (average income, book keeping…) and relations with the state veterinary services. This structured interview was first tested during a pilot interview of one VAHW from Takeo which was not included in the results.

The study was implemented between November 2011 and January 2012, in three provinces bordering Vietnam (Kampong Cham, Prey Veng and Takeo). Two districts per province were selected, one with confirmed outbreaks of HPAI H5N1 and one apparently free of disease. Every commune within each district was included, and villages with past outbreaks of HPAI H5N1 were selected first. The other villages were selected using a proportional random sampling method. A total of 367 villages were visited. The face-to-face interviews were carried out with the help of 3 trained research assistants from AVSF who were speaking Khmer and English.

#### 2.2.1.2. Data analysis

All the data were entered in an Excel spreadsheet (Microsoft® 2007). Data cleaning, coding and further statistical analyses were conducted using Stata 11 (Stata Corporation, College Station, TX, USA). In order to determine factors associated with high scores for the VAHW evaluation, we applied a multivariable linear regression model. Our outcome variable was the score given to the VAHW by the evaluation grid (continuous variable). From the questionnaire, 31 explanatory variables were tested.

We first did some descriptive analyses of our results by calculating frequencies and relative frequencies in order to check for incoherence and to group some data into categories. We used univariate linear regression to examine the association between our outcome and each explanatory variable. Only variables with a p-value of $<0.20$ were considered for inclusion in the model. Pair wise correlation of explanatory variables were tested using Spearman's rank correlation coefficient ($\rho > |0.70|$) for ordinal and Pearson chi-square test ($p<0.05$) for categorical variables. Missing data were verified, observations with more than 6 missing data were excluded, and variables with more than 10% of missing data were excluded.

A manual backward stepwise approach was used to construct our linear regression model, by dropping the model variables which were the least significant and checking the amount of variation explained by the reduced model (adjusted $R^2$). Model assumptions were tested using the Shapiro-Wilks W test for the normal distribution of residuals, the Cook-Wesby test for homogeneity of residual variance, and we used the variance inflation factor (VIF<5) to test multi-collinearity.

### 2.2.2. Pilot intervention study (SMS reporting)

#### 2.2.2.1. Data collection

This pilot study was performed between February and June 2012. We decided to use a free software, FrontlineSMS (FrontlineSMS, 2014), that can be found on internet. Once downloaded onto a computer, and with the use of a 3G key (modem and SIM card), it can act as a communication hub, to which SMS can be sent and received in large quantities. Once the SMS are received in FrontlineSMS, they can be exported into CSV and Excel files, and further analysed if needed. FrontlineSMS has several advantages, among which is its low functionality cost and user friendliness. It is used by several NGOs in Cambodia, such as the Malaria Consortium and Equal Access.

The pilot study was implemented in 2 provinces (Takeo and Kampong Cham) which were chosen by the veterinary services because of their highly dense poultry and cattle population, and because of the high number of outbreaks (HPAI H5N1 and FMD) reported in the previous years. The 6 districts which were included relied on the voluntary participation of the district veterinarians. We asked the district veterinarians to select 10 villages per district. The localisation of the different villages is displayed in the Figure 4.

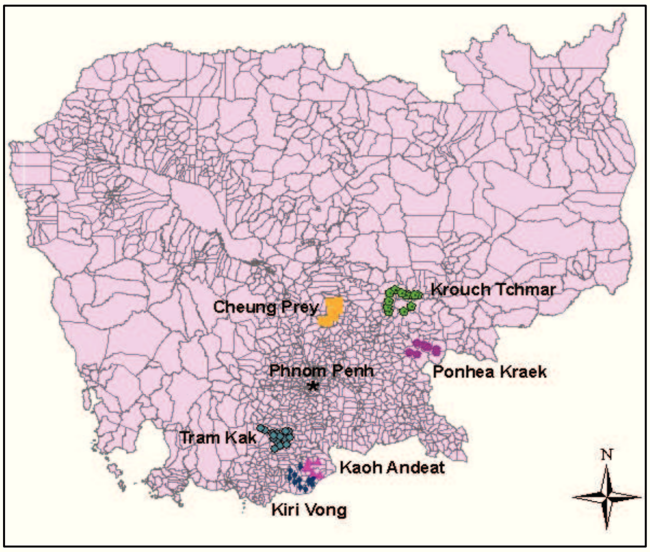



**Figure 2: Geographical location of the 58 villages visited included in the "SMS reporting" study between February and June 2012, in Cambodia.**

At the request of the veterinary services, in each village both the VAHW and the village chief were enrolled in the SMS reporting. In total, 58 VAHW and 54 village chiefs were asked to participate in the reporting system. They had a one-day training course at the beginning of the pilot study, during which the purpose of the study was explained and they were taught how to send weekly text messages. The veterinary services were especially interested about the reporting of foot-and mouth disease (FMD) and haemorrhagic septicaemia (HS) in cattle.
HS is endemic in Cambodia. The disease is caused by the serotype B2 of *Pasteurella multicida* and is responsible for many outbreaks in cattle and buffaloes every year.

The information obtained within the SMS was coded as follow:

- District number (1=Kiri Vong; 2= Kaoh Andeat; 3= Tram Kak; 4= Cheung Prey; 5= Ponhea Kraek; 6= Krouch Tchma)
- Participant code (8= VAHW; 9= village chief)
- Village number (1 to 60)

- C (cattle)
- Total number of dead cattle
- Number of cattle that died from suspected FMD
- Number of cattle sick from suspected FMD at the time of sending the SMS
- Number of cattle that died from suspected HS
- Number of sick cattle with suspected HS at the time of sending the SMS
- D (ducks)
- Number of dead ducks
- H (chickens)
- Number of dead chickens
- P (pigs)
- Number of dead pigs

Figure 5 shows an example of a text message. The message was sent by the VAHW from Bakrorng in Cheung prey district. According to the message, during the last week, 7 cattle died (2 suspicions of FMD and 2 suspicions of HS), 3 cattle sick from FMD and 5 from HS, 6 ducks died, 3 chickens died and 1 pig died.

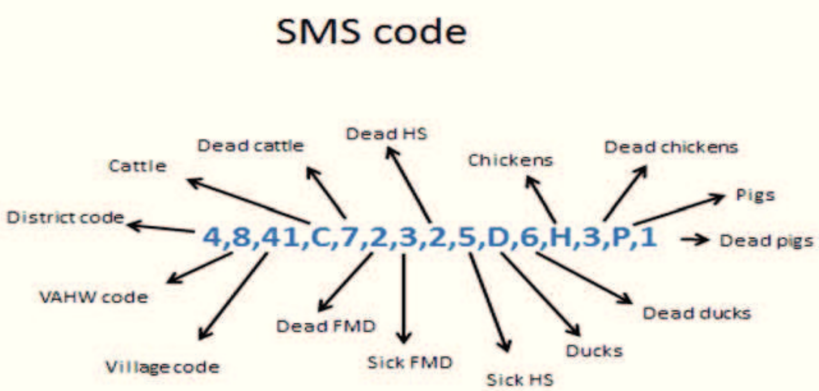



**Figure 3: Example of text message coding used during the "SMS reporting" study between February and June 2012, in Cambodia.**

Text messages were sent weekly. An automatic text message reply was sent to every participant once their text message had been received to inform them that their SMS had been correctly received.

The pilot study lasted for 3 months. A field survey, using a closed questionnaire of 22 questions and focus group meetings, was organized 2 months after the start of the pilot reporting system to collect information about the acceptability of this method by the participants and their main field constraints.

#### 2.2.2.2. Data analysis

The data transmitted by Frontline were automatically transferred to an Excel sheet every week. Data about animal census for each village were collected during the first training and verified again during the follow-up visit. Weekly mortality rates were calculated for every species and plotted. From the distribution of mortality rates, the detection threshold of abnormal mortality rate per species was calculated using the 95$^{th}$ percentile of the distribution of the weekly mortality rate declared by the participants. Descriptive analyses were done to estimate the perceptions of users.

### 2.2.3. Spatial analysis

#### 2.2.3.1. Spatio-temporal cluster analysis (STC Analysis)

##### 2.2.3.1.1. Data collection

Field investigations were implemented in two provinces (Takeo and Prey Veng) after confirmation of the HPAI H5N1 outbreak between February and April 2010. The team investigated all the villages within a 20 km radius of the village where the first case was reported and laboratory confirmed.

In each village, the Village Chief or VAHW was interviewed with the use of a questionnaire (see Annexe 9) on the number of poultry present in the village before and after the outbreak, the mortality level in the previous months, species affected, symptoms, date of onset, date of end and movement in and out of the villages. In the case of a suspicion based on clinical symptoms actually occurring, virological samples were taken for confirmation.

##### 2.2.3.1.2. Case inclusion

From the data collected we have developed an algorithm to help us to decide which village to include as a case or not. We used the inclusion criteria based on mortality level and clinical signs as defined by A. Conan in 2010.

To be included as a case the village needs to fulfil the following criteria (see Figure 3):

– (1) There must be mortality in poultry

– (2) For villages within a 5 km radius of a laboratory confirmed case of HPAI H5N1, villages are included in the analysis if there has been any mortality in ducks **OR** chickens in the month before or in the month after the date of confirmation.

– (3) For villages outside the 5 km radius of a laboratory confirmed case of HPAI H5N1, villages are included as case in the analysis if:

  - The village mortality is over 40% for chicken **AND** over 20% for ducks, **AND** if there is the presence of nervous signs **OR** white eyes in ducks
  - In villages with only ducks, if the mortality is over 40% with presence of nervous signs **OR** white eyes in ducks
  - Villages with only mortality in chickens are not included, because of the difficulty of making a clinical distinction between NCD and HPAI H5N1 outbreaks in chickens.

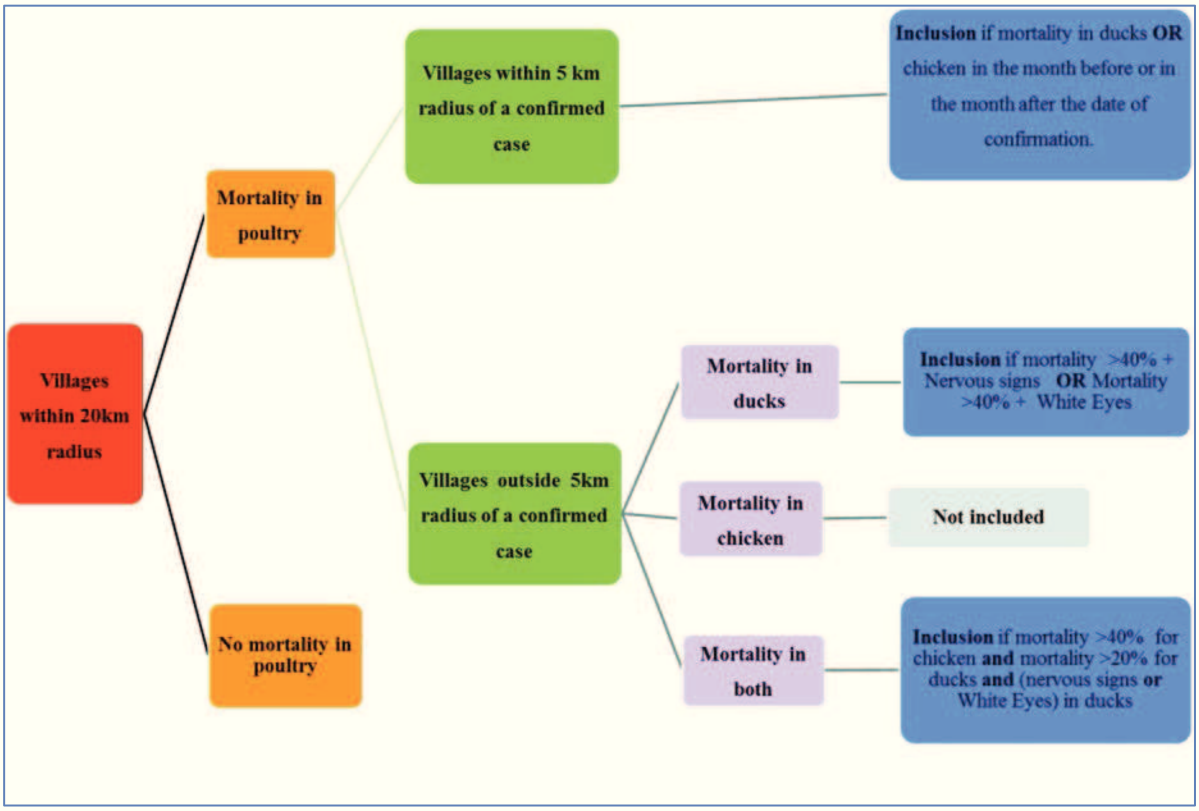



**Figure 4: Algorithm based on mortality and clinical signs at village level used to include a village as a case during the field investigation done between February and April 2010 in Takeo and Prey Veng provinces, Cambodia.**

2.2.3.1.3. Data analysis

Spatio-temporal analyses of the suspected villages were carried out in order to detect patterns in short distance spread. We used variography to investigate the spatial autocorrelation of the

date of village mortality occurrence. A semivariogram measures the dissimilarity between 2 observed variables according to the geographic distance between these 2 variables. In our case the variable was the number of days between the onset of the case and the date of disease occurrence in each village. We used these data to produce a semi-variogram from which we could estimate the parameters of our model using Variowin 2.2. with Kriging technique (Spatial Analyst: ArcGIS™ 9.0). These parameters were subsequently used to produce a map to visualize the spatio-temporal distribution of cases.
The risk factors analyse was based on spatial generalized linear models, which were run using the MASS package of the R software. The dependent variable was binomial (village infected/not infected by HPAI H5N1). Putative risk factors were first screened using univariable analysis. In a second step, multivariate models were run, including all of the significant covariables from the univariable analysis (p-value of 0.25, Wald test). Multicollinearity was examined through variance inflation factors (VIF) (Dohoo *et al.*, 2003). A stepwise backward selection was carried out until all of the remaining variables were significant (p=0.05) in the final model. As avian influenza is a contagious disease, villages located close to each other may exhibit more similar values of prevalence than those located further apart. This spatial dependency between observations was accounted for by introducing a correlation structure in the univariate and multivariate models. The extent of spatial autocorrelation was specified according to the range estimated from the spline correlogram of influenza outbreak data. A spherical function was selected for the correlation matrix, as indicated by the shape of the spatial correlogram. To verify whether spatial autocorrelation was correctly accounted for, we inspected the residuals of the logistic models using a Monte Carlo method. This consisted of comparing the observed variogram with variogram 'envelopes' that were computed by simulating 999 permutations of the data values across locations (Diggle et Ribeiro, 2007). Goodness-of-fit of the models was evaluated by using Hosmer-Lemeshow Chi-squared test. Odds-ratios (OR) and their 95% confidence intervals were derived from the coefficient estimates and variance parameters of the final model.

#### 2.2.3.2. Spatial multiple criteria decision analysis (MCDA)

The objective was to produce a map displaying the risk of human infection in Cambodia.

##### 2.2.3.2.1. Principles of the method

The spatial MCDA method was used to determine the environmental suitability of a location for a particular outcome (such as risk of infection) given the values of multiple factors at that location (such as vegetation cover, population density, and distance from markets). The relative importance of each factor can be estimated, through a literature review or expert opinions, and a weighted suitability across all factors is calculated (Boroushaki et Malczewski, 2010).

The method is composed of several steps (Stevens *et al.*, 2013): identification, characterisation and weighting of risk factors, mapping of these risk factors to create a spatial layers, combining the different layers, sensitivity analysis of the model and validation of the outcome. In our study, all the spatial analyses were done using ArcGIS, version 9.3 software (ESRI; Redlands, USA) and QGis software (QGis, 2011), the different steps of MCDA were done with the software IDRISI 17.0 (Selva, Clark Labs, Worcester MY 01610-1477 the USA) and the sensitivity analysis with the software R.

##### 2.2.3.2.2. Data collection – identification/characterisation and weighting of risk factors

This step was done through an expert elicitation process using a web-based questionnaire (SurveyMonkey). Ten experts, either working in public health organisations in Cambodia or having experience of HPAI H5N1 surveillance and/or risk factor analysis in Cambodia, were selected. They first had to validate the initial list of risk factors (from the literature review) that we proposed. Then we asked them to characterise the relation existing between these risk factors and the risk of human infection. We proposed several types of correlation functions (linear, sigmoid…) with the possibility to define threshold values for the risk factor level (in a qualitative format: very high, high, medium, low, very low) in order to better determine the shape of the function. Finally we asked the experts to weight the risk factors using an analytical hierarchy process, which consisted in comparing pairs of factors using the Saaty scale (Saaty, 1987).

| More important | | | | | | | | Less important |
|---|---|---|---|---|---|---|---|---|
| Extremely | Very strongly | Strongly | Moderately | Equal | Moderately | Strongly | Very strongly | Extremely |
| 9 | 7 | 5 | 3 | 1 | 1/3 | 1/5 | 1/7 | 1/9 |

**Figure 5: Saaty scale used by the ten experts to compare pairs of risk factors of HPAI H5N1 human infection in Cambodia.**

An additional weight was attributed to each expert according to the consistency ratio calculated by IDRISI. Then, for each risk factor, a weighted aggregation of each expert's answer was performed.

##### 2.2.3.2.3. Production and combination of spatial layers

From crude data, we produced spatial layers of the risk factors (for example, for the factor "proximity to main city", we calculated the distance between 2 cities). Then for the standardisation of data, the relation between the risk factor and the risk was normalised using the module "FUZZY" in IDRISI. The final combination was done using the "Multi-Criteria Evaluation" module of IDRSI.

##### 2.2.3.2.4. Sensitivity analysis

The "One factor at a time" approach was applied (variation of one risk at a time). The mean and variance of main effects were calculated, low means indicating a low impact of the risk factor and a high variance indicating correlation between several factors (Toulet, 2012).

##### 2.2.3.2.5. Map validation

For this map we just visually compared our map with the map of previous human outbreaks.

### 2.2.4. Systematic review of research findings from surveillance in Cambodia and Madagascar

The methodology consisted in a systematic review of papers related to the subject of surveillance in Madagascar or in Cambodia, followed by the use of a narrative synthesis to compare and analyse the results of the systematic review. In order to meet our objectives, we restrained our study to papers that were published only under projects financed in whole or in part by CIRAD.

#### 2.2.4.1. Sources of information: systematic review

Our objective was to produce an overview of methods and tools currently developed or implemented by the CIRAD researchers in Madagascar or in Cambodia in the field of surveillance, and to critically analyse and review their field feasibility in order to determine what works, and to strategically provide effective, targeted correctional interventions and recommendations.

We searched for the period 2004 to April 2014, on Scopus using the following key words AFFIL (CIRAD) AND ALL(“Madagascar OR Cambodia”) AND ALL(“Surveillance OR monitoring OR information system”) and Google Scholar TM with the following key words, “CIRAD” AND “Madagascar OR Cambodia” AND “Surveillance OR monitoring OR information system” AND “animal diseases”. Then additional searches were done on the Cirad database, AGRITROP, project websites (FSP project [GRIPAVI 2006-26] funded by the French Ministry of Foreign and European Affairs (MAEE) http://gripavi.cirad.fr/en/ , and DGAL funded projects [FRIA-08-009 REVASIA]. http://revasia.cirad.fr/en/ ). The search included papers in English or French.

Retrieved documents were screened to exclude papers that were not written by CIRAD authors (homonyms or presence of the word CIRAD in the article or in the reference list of the paper), that were not about infectious animal diseases and that did not issue recommendations on surveillance systems. The appraisal was conducted by two reviewers; authors of selected studies were also consulted in order to assess the contents and validity of the findings.

#### 2.2.4.2. Method of analysis: narrative synthesis

The narrative synthesis method was selected in view of the qualitative type of our approach. This method allows the aggregation of qualitative data in order to produce a comprehensive analysis and synthesis of the results of a systematic review, using a textual approach (Popay *et al.*, 2006).

The narrative synthesis method was mainly developed for the systematic review of intervention studies (Arai *et al.*, 2007). The process usually includes four parts (development of a theoretical model, preliminary synthesis, assessing relationships in the findings, and validation of the synthesis).

The studies included in our review differ from intervention studies and consisted of various types (observational and descriptive studies, analytical studies, qualitative studies). We therefore developed a modified process for our narrative synthesis with: 1) the description of the implementation background of the studies that we want to compare (country profile), 2) a synthesis with a textual description of each study, the grouping of the studies and tabulation of results across studies, 3) comparisons between studies and visualisation of the connection among findings with the use of spider diagrams, 4) the testing of the validity of interpretations by consulting the primary authors of the studies.

The following data were extracted from each study in the form of textual descriptions: details about the country in which the study was implemented, epidemiological and ecological conditions of the diseases (or health event) targeted in the study, type of surveillance described or mentioned (passive, active, risk-based, participatory…), population included in the surveillance, method or tool tested during the study, constraints and opportunities of these methods or tools, recommendations for surveillance and control systems. Data that described the current situation of Madagascar and Cambodia were completed with additional literature research and compiled under the form of a "country profile". The other data were grouped according to geographic areas, and disease or health event targeted by the study before being tabulated. Qualitative case description was used to compare data between countries in order to: 1) identify similarities and differences of the epidemiological situation of the main transboundary diseases, emerging diseases and zoonotic diseases, 2) identify methods and tools in data collection and data transmission that would be interesting to share between countries, 3) understand the variability of the surveillance method or tool efficacy within different population compartments to inform the implementation of One Health surveillance.

See the full paper presented in Annex 6 for details on the material and methods.

# 3. Synthesis of the various contributions of the different research studies

In Figure 5, we have summarised the different research or field studies undertaken in this work. For the evaluation section, we have described the type of tools or methods implemented (in blue) in connection with the level of evaluation implemented (global evaluation of the system or only the sensitivity – in red). For the design section we have described the tools or methods used (in blue), the component of the surveillance design that could be improved (data collection, risk-based design, training – in black) in correlation with the attribute which will be impacted (coverage, acceptability, sensitivity, specificity – in red).

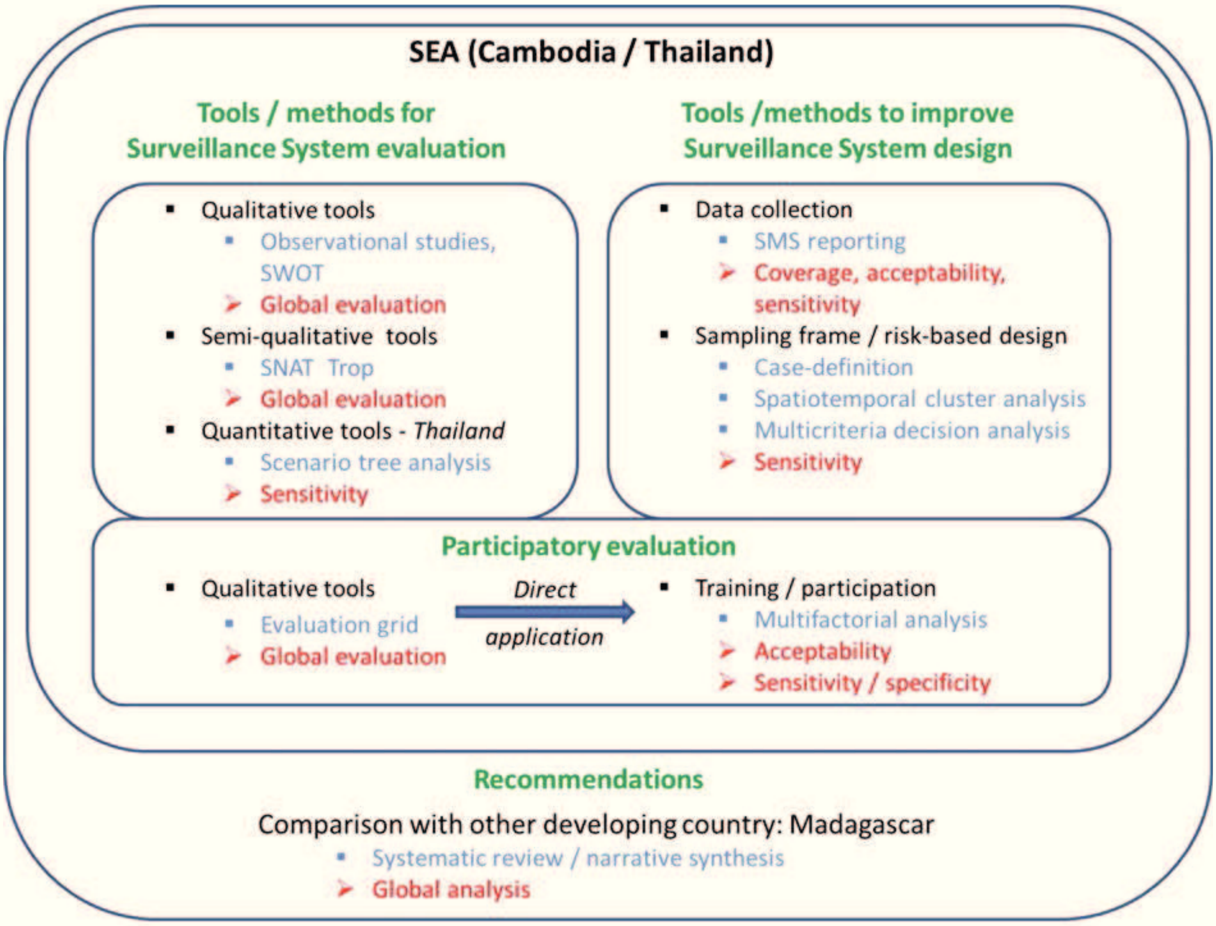



**Figure 6: Diagram illustrating the relationships among the 9 research studies done in Cambodia and Thailand, between 2010 and 2014, to improve zoonotic diseases surveillance in poor rural settings.**

# PART 4

# RESULTS

In the Part 4, we present the different results of the nine studies that were implemented during this research work. First, we describe the organisation and the functionality of the HPAI H5N1 surveillance system for animal and public health in Cambodia. We present, in detail, the different components of surveillance (passive and active surveillance activities) that were implemented at the time of the study. The VAHW and VHW system is also explained in greater detail. From this descriptive analysis, we present the results of the qualitative evaluations that were done using the SNAT Trop tool and a SWOT approach. Recommendations stemming from these evaluations are also presented. We then give some details on the results of the scenario tree analysis that was done in Thailand on the HPAI H5N1 surveillance system in backyard chickens and its possible use in passive surveillance evaluation. We also introduce the criteria grid for VAHW evaluation that was developed in Cambodia using participatory approaches.

In the section 2, we describe the results of the survey that was done in Cambodia concerning VAHW, using the criteria grid. This survey allowed us to give a score to the VAHW and to identify some factors that could influence VAHW effectiveness. We present the results of the implementation of an animal disease reporting system, based on SMS declarations, for 13 weeks in Cambodia. We also show the results of the outbreak investigation that was undertaken at the beginning of 2010 and the risk map of HPAI H5N1 human infection in Cambodia.

Lastly, we present the results of our systematic review of surveillance research conducted by CIRAD in Cambodia and Madagascar and we explain the main recommendations that can be drawn from our conclusion.

# 1. Surveillance system evaluation methods

## 1.1. Descriptive overview of the surveillance systems

### 1.1.1. HPAI H5N1 surveillance system in the animal compartment

The National Veterinary Research Institute (NaVRI) is responsible for the management of disease research, diagnosis and surveillance in Cambodia. The institution is part of the Department of Animal Health and Production (DAHP) under the Ministry of Agriculture, Forestry, and Fisheries (MAFF) (see the organisation chart in Figure 6). The HPAI H5N1 surveillance system is coordinated by the NaVRI.

The main objectives of the surveillance, as defined by the NaVRI are:

- To detect HPAI H5N1 outbreaks in poultry to enable early control, to limit the spread of the disease and to prevent transmission to humans.

-To assess HPAI H5N1 virus circulation in the country and to identify and update the evolution of HPAI virus variants.

- To demonstrate freedom from clinical disease and effectiveness of control measures when an outbreak occurs.

To achieve these objectives several components of surveillance have been implemented:

Passive surveillance: Voluntary declaration of disease suspicion based on the direct reporting of farmers/VAHW to district veterinarians during visits or monthly meetings, or by direct reporting to the Hotline that has been set up for human and animal health.

Active surveillance: This is based on specific targeted investigations of at-risk populations for evidence of infection that may be based on detecting exposure to the agent (antibody detection by serology) or the presence of the agent (virus or antigen detection). There are four components: 1) the sentinel surveillance in free-grazing duck farms, 2) the market surveillance in live ducks that are coordinated by NaVRI (with FAO funding), 3) the environmental surveillance in live-bird markets supervised by IPC (funded by FAO), and 4) the wild bird surveillance supervised by the Wild Conservation Society (WCS funded by FAO). There are also investigations following outbreak declarations that are done jointly by the MoH and the MAFF.

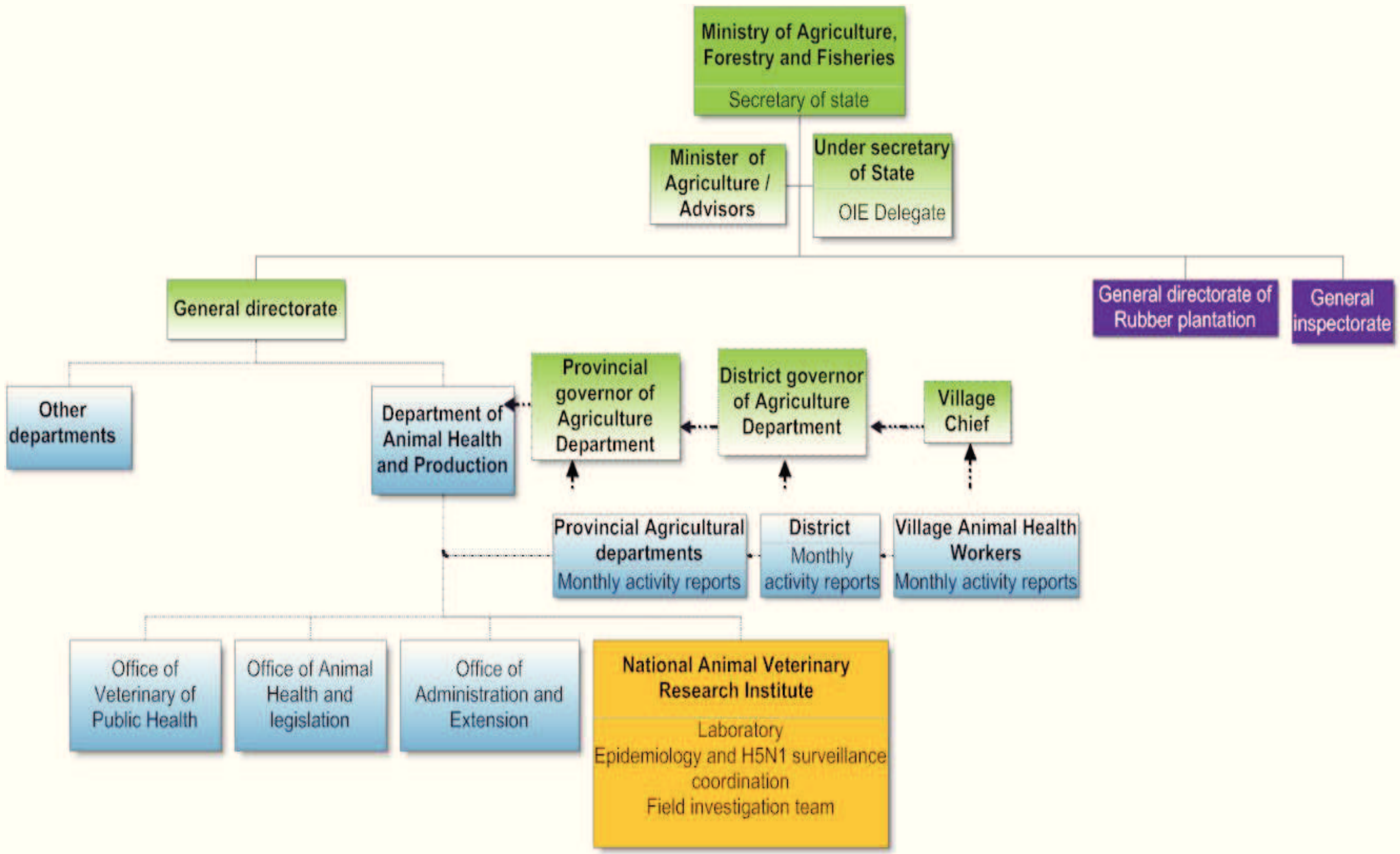



**Figure 7: Organisation chart of the Ministry of Agriculture, Forestry and Fisheries with the Department of Animal Health and Production, for Cambodia, 2012.**

#### 1.1.1.1. HPAI H5N1 case definition

The case definition which is currently used is: Poultry death >50% in several households over 4-5 days with the following clinical signs in chickens: sudden death, decreased feed intake, respiratory signs (difficult breathing, swollen head, watery eyes), neurologic signs (incoordination, twisted neck), blue (cyanotic) comb, haemorrhage of comb, wattles and leg, ruffled feathers, diarrhoea, drop in egg production; and in ducks and geese: depression, decreased feed intake and diarrhoea, swollen sinuses, nervous disorders in young birds.

#### 1.1.1.2. Passive surveillance

##### 1.1.1.2.1. Flow of animal health information

Information flows to the central level according to Figure 7. Monthly meetings are organised at the provincial level with the district veterinarians, and monthly reports are sent to the central level summarising activities: census of animals for each district, commune and village; number of vaccinations done; number of import permits issued; number of animals slaughtered; price of animals at markets.

Monthly meetings are also organised at district level for VAHW, but given that there is no budget to compensate their trip and that some of them are located far from the district office, only a small proportion of them are present at every meeting.

A specific form to report an outbreak suspicion is available at regional and district offices, but is rarely filled in according to the regional veterinarians. Only one district vet (Kong Meas, Kampong Cham Province) uses this form. The suspicions are usually declared directly by phone to the regional office and to the central office, or are reported on the note book used by the district veterinarian. Villagers can also report or ask questions about human or animal cases of HPAI H5N1 via the two Hotlines that have been set up (MoH and DAHP), the information is shared between the Center of Disease Control of Cambodia and the DAHP by SMS or direct phone calls. There is an average of 13.6 calls per month [min 6 ; max 19] through the NaVRI's Hotline. Most farmers call to ask for information about the disease (85%), in 2011 seven suspicions of HPAI H5N1 were reported via this hotline.

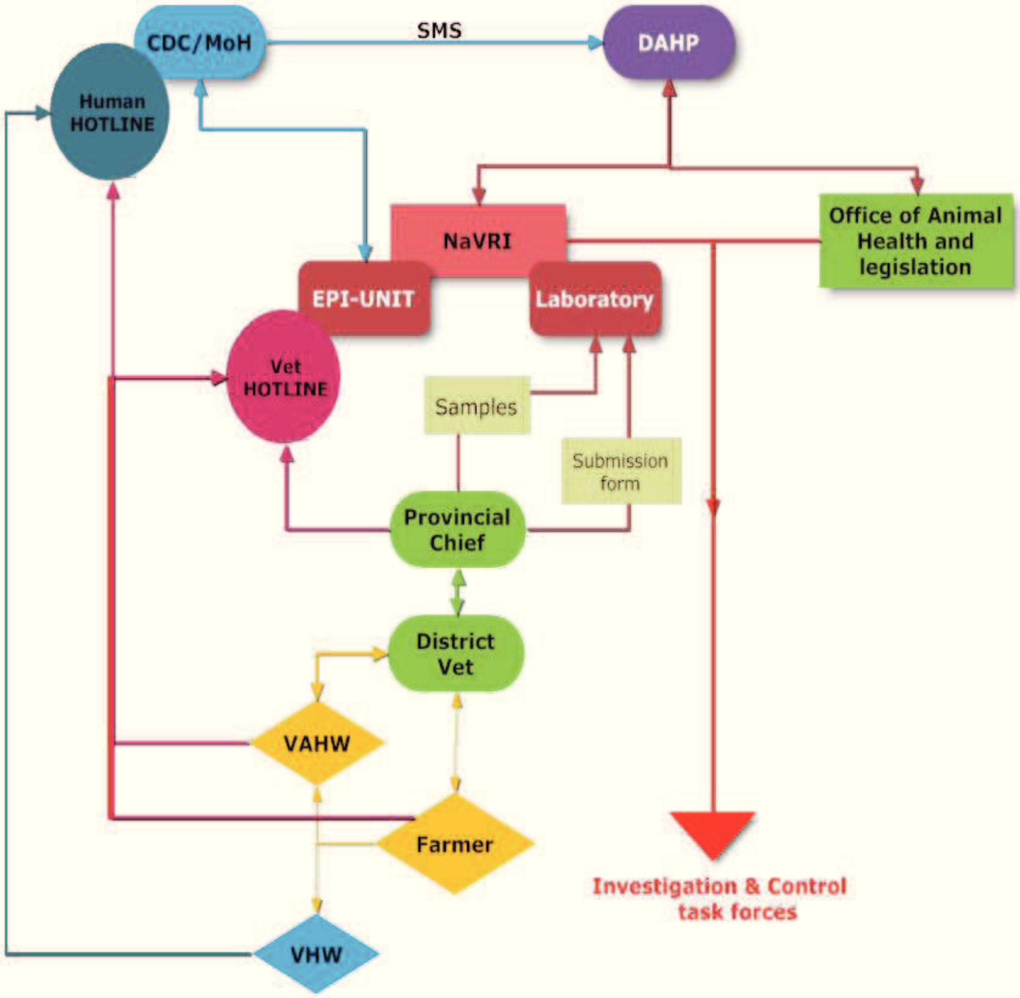



**Figure 8: Flow of animal diseases information and especially for HPAI H5N1 suspicions in Cambodia in 2012.** *DAHP: Department of Animal Health and Production; CDC: Control Disease Center in Cambodia; MoH: Ministry of Health; NaVRI: National Veterinary Research Institute; VAHW: Village Animal Health Worker; VHW: Village Health Worker; SMS: Short Message Service*

#### 1.1.1.2.2. Village Animal Health Workers

In response to the initial HPAI H5N1 outbreaks in 2004, the government decided to train one VAHW per village. Currently, a total of 12,000 VAHW have been trained. VAHW are not considered to be government staff and so do not receive any salary; however, based on the sub-decree 26 SD, they are required to report information on animal health and production to authorities and to Municipal/Provincial Services when necessary, and to cooperate with Municipal/Provincial Animal Health and Production Services when required or in case of a disease outbreak. They have been trained by different organisations (NGOs, FAO, Ministry of Agriculture and other external donors) to recognise the main diseases occurring in livestock and poultry (especially HPAI H5N1). They are in charge of the vaccination of cattle and buffaloes against haemorrhagic septicaemia. This activity is done in partnership with the district veterinarian who organises the vaccination program and obtains vaccines for the VAHW. They treat sick animals and some of them give advice on management, such as building poultry sheds or using vaccines against NCD or cholera. Only few of them seem to make a living from their activity with, for example, the sale of drugs. For the majority of them their livelihoods depend on other activities which can lead them to be away from their villages. This is not always compatible with their role in the surveillance system.

#### 1.1.1.3. Active surveillance

##### 1.1.1.3.1. Duck flock sentinel surveillance

The sentinel surveillance was only implemented in 2010, from May to October. Six provinces were involved (Takeo, Kampot, Preah Sihanouk, Battambang, Kampong Cham, Prey Veng) with 2 commercial farms each. A total of 400 birds were tagged with a ring and cloacal / tracheal swabs and serum were collected every 2 weeks. Swabs were pooled in batches of 3 to 5 and were analysed to detect the presence of avian influenza virus, through egg inoculation (HA or HI for H5) and RT PCR on positive samples. During the time of surveillance there was no viral detection but 8 flocks out of the 12 had an H5 seroconversion. These were located in 4 provinces (Prey Veng, Preah Sihanouk and Kampot) (Figure 8). The seroconversion started in June, except for Kampot which started 2 months later in August. As there was no confirmation of H5N1, it was difficult to draw any conclusions from these results as they could indicate the circulation of Highly Pathogenic H5N1, the circulation of low pathogenic H5N1 or of the H5N2 virus.

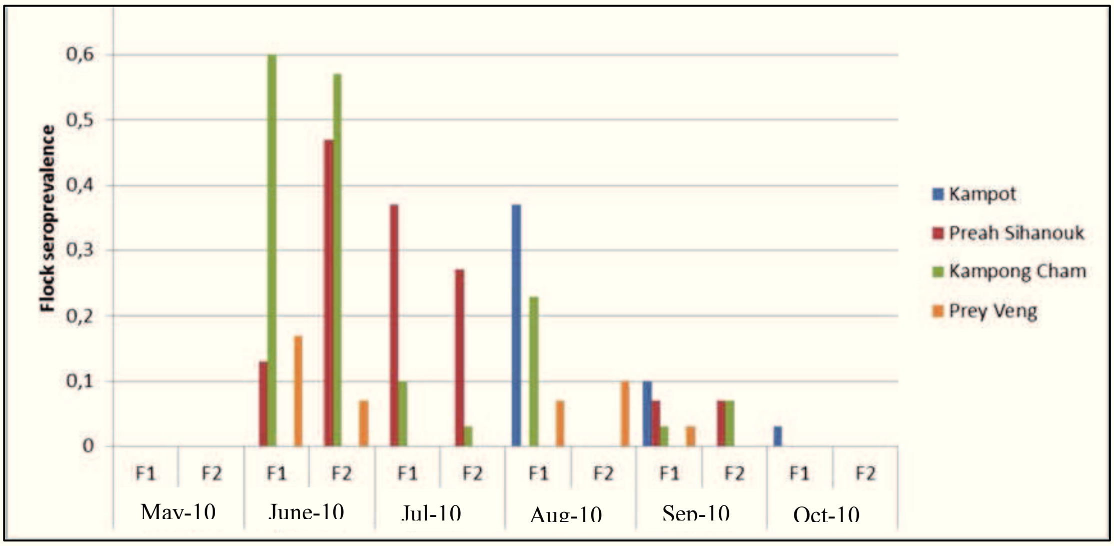



**Figure 9: Results of duck flock sentinel surveillance for HPAI H5N1 in 6 provinces of Cambodia between May and October 2010**

#### 1.1.1.3.2. Live bird market surveillance

The market surveillance started in 2007 with the follow-up of 8 markets, then was modified in 2009 with the inclusion of 4 additional markets, and again modified in 2010 to keep only 7 markets (Siem Reap, Demkor, Orussei, Takeo, Kampong Cham, Prey Veng and Kampot). The latest surveillance campaigns were implemented from March to August 2010 and from January to June 2011. Cloacal / tracheal swabs and serum were collected from 30 ducks every 2 weeks. Additional samples from the environment were also collected in 2011 in the same markets. Samples and analysis were done in collaboration with IPC. Swabs were pooled in batches of 3 to 5 and were analysed to detect the presence of avian influenza virus, through egg inoculation (HA or HI for H5) and RT PCR on positive samples.

**Table 7: Live bird market surveillance in Cambodia from October 2008 to June 2011**

| Period | Duration (month) | Number of markets | Swabs | | Sera | Positive for HI / HA + | Viral isolation |
|---|---|---|---|---|---|---|---|
| | | | Cloacal | Tracheal | | | |
| **2008-2009** | 12 | 12 | 8347 | 8347 | 8169 | 103 | 0 |
| **2010** | 7 | 8 | 4221 | 4221 | 4116 | 116 | 5 |
| **2011** | 6 | 7 | 4800 | 4800 | 4702 | 308 | 0 |

In 2010, the HPAI H5N1 virus was isolated 5 times between April and May at the Demkor and Takeo markets, but because of the lack of traceability, the use of these results was limited. The surveillance also showed regular H5 seropositivity of ducks sampled at the market, especially at Kampot market for which most of the samples were positive in 2010 and 2011.

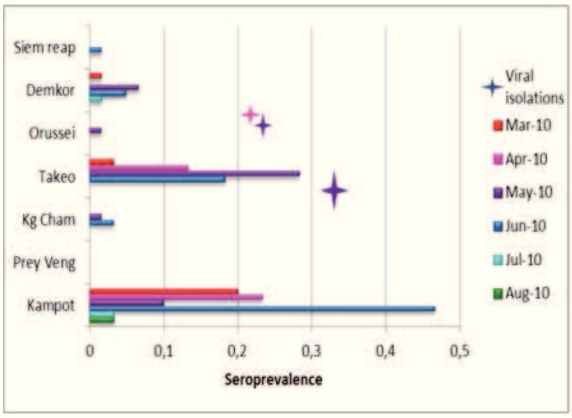



**Figure 10: Monthly distribution of live bird market HPAI H5N1 seroprevalence in 2010, in Cambodia.**

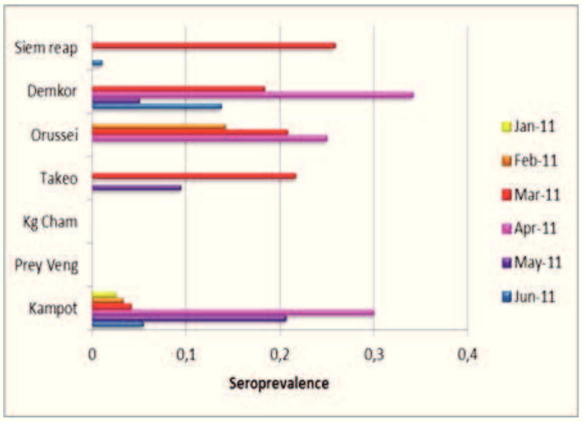



**Figure 11: Monthly distribution of live bird market HPAI H5N1 seroprevalence in 2011, in Cambodia.**

#### 1.1.1.3.3. Environmental surveillance

This component of the surveillance system was developed in collaboration with the Institute Pasteur du Cambodge. The surveillance was implemented in April 2011 for a 6 week period: before, during and after Khmer New Year. It included a weekly collection of environmental specimens in 4 markets: 2 in Phnom Penh, 1 in Kampong Cham, and 1 in Takeo provinces. Within each market and on 4 to 5 sites where poultry were gathered (cages, location…) environmental samples were collected (drinking water, water used to wash carcases after slaughtering, faeces samples, feathers and soil/mud inside the cage). From the 502 environmental samples that were collected 18% were contaminated (by qRT PCR targeting H5, M and N1 genes) with 2% of virus isolation. Water specimens were more frequently contaminated (up to 50% of cases), followed by soil/mud and feathers specimens (Horm *et al.*, 2013).

#### 1.1.1.3.4. Active surveillance of wild birds

Since 2007, several campaigns to collect samples from wild birds have been implemented with the help of Wild Conservancy Society and other donors (National Institutes of Health, Centers of Excellence for Influenza Research and Surveillance, FAO). Specimens were collected from several geographic places (Figure 11 and Figure 12) and had several types of origins: wild birds natural habitat, wild birds sold as food in restaurants, wild birds captured by trappers for human consumption or merit release birds.

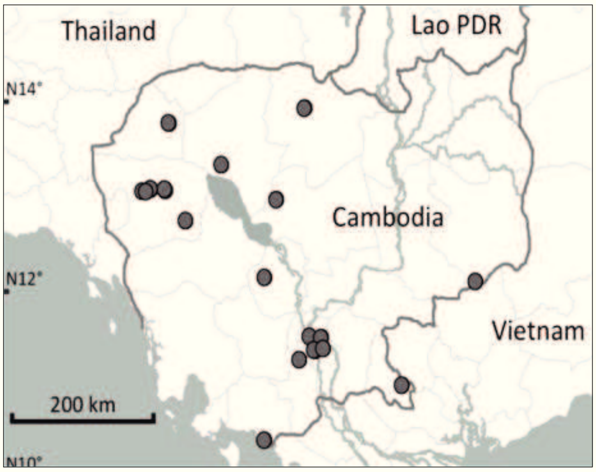



**Figure 12: Sites of wild bird sampling for HPAI H5N1 surveillance funded by NHI-CEIRS between 2007 and 2009 (WCS 2012) in Cambodia.**

**Figure 13: Sites of wild bird sampling for HPAI H5N1 surveillance funded by FAO between 2007 and 2009 (WCS 2012) in Cambodia.**

Between 2007 and 2009, 4,638 specimens were collected from 109 different species and only one bird was detected as infected with an H5 Avian Influenza virus (with sequencing suggesting a rare subtype).

### 1.1.2. HPAI H5N1 surveillance system in public health

In the section 1.1.2, we will describe the surveillance system with the different components (active and passive) that were implemented between 2009 and 2011 by the MoH in Cambodia. For the following description, we interviewed several representatives of each system as no synthetic report was available at the time of the study. We also considered that research projects on disease surveillance, coordinated by non-governmental organisations, were part of the national surveillance system.

#### 1.1.2.1. The national health system

The smallest public health facilities are the Health Center (HC) or the Health Post (HP), located at communal level and serving a population of between 8,000 and 12,000 (within 2 hours walking distance) (Chhea *et* al., 2010). With regards to the national objective, these health facilities should be able to offer the so called "Minimum Package Activities", which corresponds to basic health care for benign illnesses, injuries or stabilisation before referral. In reality, 50% of treatments are covered by private facilities (Asante *et al.*, 2011). Villagers do not trust HC/HP because of the under-qualified staff, the lack of equipment, medicines availability, and sometimes the cost of consultation. HC/HP provide primary health care to communities and are responsible for the health volunteer training. They are also in charge of reporting the diseases occurring in the villages to the Operational District (OD), on a weekly basis by mobile phone text messages, and to provide a monthly report of outbreak occurrences and demographic information to the OD.

HC/HP are supervised by Referral Hospitals (RH) (at district level), which are organised into Operational Districts (OD) that have a catchment area of 100,000 to 200,000 people. These ODs are managed by the Provincial Health Department under the Directorate General for Health located in Phnom Penh. This system is complemented by national hospitals, NGOs and private facilities. The official number of health workers in Cambodia for 2012 was 19,721, representing a density of 13 per 10,000 persons (HMIS, 2012). But that is without counting the informal health sector composed of thousands of untrained traditional healers (*Kru Khmer)* without licenses (Chhea *et al.*, 2010)

### 1.1.2.2. Health Management Information System

The national Health Management Information System (HMIS) was created in its current format in 2010, with the help of USAID. It is a web-based database system that allows health workers at OD level (in some province at HC and RH level as well) to enter monthly data directly into the system. In 2012, data were collected from the public health sector (79 OD, 83 RH, 1,024 HC, 121 HP and 8 national hospitals), from NGOs supported facilities (86) and private facilities (461) (HMIS, 2012). The flow of information is described in the Figure 13.

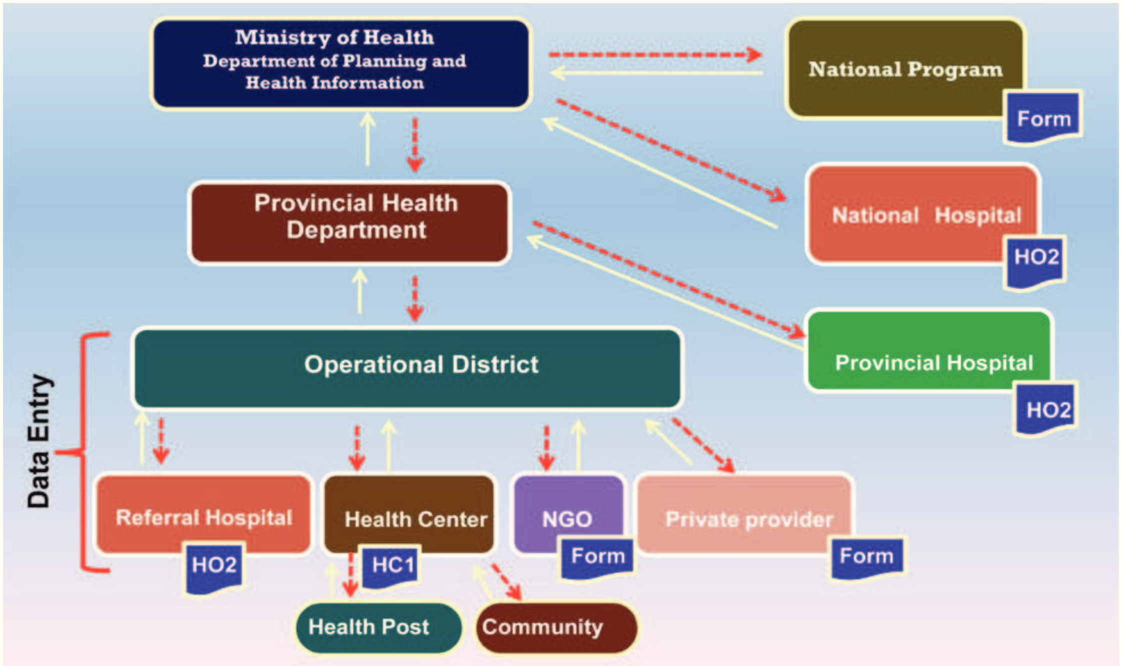



**Figure 14: National flow of public health data in Cambodia (Health Management Information System, 2014).** ***HC1 refers to the forms used by health centres; HO2 refers to the form used by hospitals (referral, provincial, national)***

1.1.2.3. HPAI H5N1 specific surveillance

The surveillance of HPAI H5N1 was based on the combination of different components which, to a large extent, mainly targeted influenza-like illnesses, respiratory infections and dengue diseases (Figure 14).

**Cambodia Early Warning and Response Network (CAM EWARN) = Zero Reporting**

- All public medical institutions

**EVENT BASED SURVEILLANCE**

- Hotline
- Public institutions
- Private institutions

**MEDIA SCREENING**

- National Websites

**SENTINEL- HOSPITAL BASED**

- Influenza-like Illness (ILI)
- Severe acute respiratory infections (SARI)
- Influenza-like Illness by the Armed Forces Research Institut of Medical Sciences (ILI AFRIMS)
- Febril Syndromic Surveillance by the US Naval Medical Research Unit (FSS NAMRU)

**SENTINEL COHORT BASED**

- AI seroconversion monitoring by NAMRU in Kampong Cham Province

**Figure 15: Components of human surveillance for Influenza in Cambodia implemented between 2009 and 2011**

#### 1.1.2.3.1. CAM EWARN = zero reporting system

Coordination: MoH at national level

Objective: All public health facilities in Cambodia reported data on 12 diseases/syndromes to the national surveillance system on a weekly basis even if no cases occurred.

Actors: It involved all government health centres and referral hospitals in the country.

Diseases or syndromes under surveillance: It was compulsory to report the following 7 syndromes which combine several diseases (for each disease a specific case definition was provided): acute neurological syndrome (acute flaccid paralysis ; meningoencephalitis; rabies), acute jaundice syndrome (hepatitis A,B,C,D and E; dengue; malaria; leptospirosis), acute respiratory syndrome (influenza, pneumococcus, legionella, RSV, mycoplasma, leptospirosis, bird flu, diphtheria), diarrheal syndrome (cholera; shigella), acute hemorrhagic syndrome (dengue fever), acute skin syndrome (measles, dengue, meningococcal disease), other syndromes (neonatal tetanus; unknown diseases occurring in cluster)

Case definition for HPAI H5N1:

1) Every case of contact with dead/sick poultry or a suspected human H5N1 case followed by: Fever (38 °C or more, or below 36°C), cough and unusual severity of difficulty breathing OR shortness of breath in a person over 5 years of age. The following samples needed to be taken in case of suspicion: nasopharyngeal swab, rectal swab, serum.

2) 1.5 more cases or a higher average than usually observed during that time of the year within the same commune or health care facility of: Fever (38 °C or more, or under 36°C), cough and unusual severity of difficulty breathing OR shortness of breath in a person over 5 years of age

Methods of data transmission: There were four reporting levels. At health center or hospital level, the information was combined with data provided by the health post present in the district. The transmission was sent to the Operational District either by text message, phone or radio. At OD level, the information was reported to the Provincial Health Department (PHD) by using a template short message (See annex 10), directly feeding the provincial and the Cambodian Center of Disease Control (CDC) Cam Ewarn database. This database was analysed weekly by the CDC staff. They issued a warning in case of too high incidence of one syndrome or if they detected abnormal cases. The CDC-Rapid Response Team was sent into the field for further investigation in the case of a warning. Not a single report of human H5N1 suspicion was transmitted to the CDC during the past year of our survey in 2011.

**Table 8: Percentage of health facilities in Cambodia having effectively transferred their report in February (2011)**

| | Census | Week 1 | Week 2 | Week 3 | Week 4 |
|---|---|---|---|---|---|
| **Health Centres** | 1003 | 949 (95 %) | 873 (87%) | 985 (98%) | 997 (99%) |
| **Referral Hospitals** | 55 | 50 (91%) | 48 (87%) | 55 (100%) | 51 (93%) |
| **Operational Districts** | 77 | 77 (100%) | 77 (100%) | 77 (100%) | 77 (100%) |

1.1.2.3.2. Event based surveillance

Coordination: MoH at national level

Objective: Immediate notification of HPAI H5N1 suspicion

Actors: Suspicions could be reported by: public medical institutions, private clinics or medical institutions, individuals through the hotline system (2 numbers, screening of calls at the call center before transfer by text message to CDC).

Case definition for HPAI H5N1: Similar to the case definition used in Cam ERWAN

Transmission of information: reports to the OD/PHD/National CDC/hotline (115, 012488981, 089669567) on clinical suspicion alone – these did not require prior laboratory confirmation.

Number of alerts in 2011, from:

- public medical institutions : 16 calls, 14 investigated
- private clinics: NA (no longer monitored)
- from hotline: 801 calls were investigated (no longer monitored)

No H5N1 detection arose from these suspicions.

1.1.2.3.1. Media-screening

In MoH-CDC, one staff is full time in charge of media screening. This function screens through radio websites and TV channel websites for information related to any abnormal health event (in terms of epidemics, and notifiable diseases occurrence, like Avian Flu). In case of suspicion of a health issue, the Rapid Response Team is sent to investigate.

No H5N1 alert was coming from media screening between 2010 and 2011.

### 1.1.2.3.2. Hospital based sentinel surveillance

**Influenza –like Illness surveillance**

Coordination: MoH-CDC.

Actors: This involved 2 national hospitals, 4 provincial hospitals, 6 HC in 8 provinces (Phnom Penh, Kampong Cham, Takeo, Battambang, Siem Reap, Kampot, Mondulkiri, Svay Rieng)

Case definition: Sudden onset of fever >= 38 °C (armpit) AND cough AND/OR sore throat in absence of other diagnosis.

The sensitivity of ILI case definition for H5N1 detection was evaluated by the MoH team at 60 % and from the literature review at 76% (Blair *et al.*, 2010)

Description: Each patient presenting ILI was examined. Ten cases per week were randomly sampled in each national hospital, and 5 cases per week in the provincial hospital and health centres. These figures were increased according to the season or context: during H1N1 outbreaks, health centres sampled 10 cases per week. Lab analyses were performed at IPC and NIPH, influenza screening by real time PCR and avian H5 and N1 tests.

**Table 9: Retrospective data about the hospital based sentinel surveillance for ILI done by the Ministry of Health in 8 provinces of Cambodia for 2011.**

| | Mean number of monthly ILI patients | Number sampled | H5N1 positive |
|---|---|---|---|
| **Phnom Penh** | 200 | 40 | 0 |
| **Kampong Cham** | 100 | 20 | 0 |
| **Takeo** | 80 | 20 | 0 |
| **Battambang** | 120 | 20 | 0 |
| **Siem Reap** | 200 | 40 | 0 |
| **Kampot** | 70 | 20 | 0 |
| **Mondulkiri** | 76 | 20 | 0 |
| **Svay Rieng** | 50 | 20 | 0 |

**SARI (Severe Acute Respiratory Infections) sentinel surveillance**

Coordination: MoH-CDC and US-CDC

Actors: This involved 4 hospitals: 2 in Phnom Penh, 1 in Kandal and 1 in Siem Reap

Case definition: Sudden onset of fever >38°C (armpit) or fever within 10 days of presentation AND cough or sore throat AND shortness of breath or difficulty breathing AND requiring hospitalisation.

Description: Each patient presenting SARI was examined. All of them were sampled, and lab analyses were performed in IPC and NIPH, influenza screening by real time PCR and avian H5 and N1 tests.

**Table 10: Retrospective data about the hospital based sentinel surveillance for SARI done by the Ministry of Health and the US-CDC in 4 hospitals in Cambodia for 2011.**

| | Mean number of SARI patients | Number sampled | H5N1 positive |
|---|---|---|---|
| **H1 Phnom Penh** | 35 | 30 | 0 |
| **H2 Phnom Penh** | 25 | 20 | 0 |
| **Kandal** | 35 | 30 | 0 |
| **SiemReap** | 30 | 20 | 0 |

**ILI sentinel surveillance AFRIMS**

Coordination: AFRIMS (Armed Forces Research Institute of Medical Sciences) is a US army medical component

Actors: This involved 2 referral hospitals and 1 HC in Battambang and Otdar Meanchey.

Case definition: The ILI case-definition was the same as for the national surveillance.

It was not possible to interview local stakeholders in AFRIMS as they did not answer our calls or demand by emails.

**Febrile syndrome surveillance by NAMRU**

Coordination: US Naval Medical Research Unit

Actors: This involved 5 provinces with one RH + one HC (Kandal, Kampong Speu, Kratie, Stung Treng and Rattanakiri)

Case definition: fever >38°C (tympanic) within the past 10 days lasting over 24 hours.

Description of the activities:

All cases were examined, and sampled (swabs and serum during the day of visit + 2-3 weeks after) for bacteriology, parasitology and virology (Influenza screening by real time PCR (CDC protocol) and Avian H5 and N1 tests + specimens sent to Institute Pasteur for confirmation). Laboratory analyses were performed at NAMRU (based in the Public Health Ministry, in Phnom Penh).

From 2006-2008, 4,233 patients were tested for influenza. One patient was found H5N1 positive.

**Table 11: Retrospective data about the hospital based sentinel surveillance for ILI done by US Naval Medical Research Unit in 4 hospitals in Cambodia for 2011.**

| | Catchment area (#districts) | Min# of patients with ILI/month | Max# of patients with ILI/month | Average# ILI/month | H5N1 case |
|---|---|---|---|---|---|
| **Rattanakiri** | 6 | 9 | 164 | 69 | 0 |
| **Kratie** | 3 | 5 | 76 | 33 | 0 |
| **Kandal** | 7 | 4 | 406 | 124 | 1 |
| **Kampong Speu** | 4 | 5 | 570 | 125 | 0 |
| **Strung Treng** | 4 | 10 | 73 | 39 | 0 |

**Cohort based- NAMRU, Avian Flu Seroconversion (2009-2011)**

Coordination: NAMRU

Actors: PH of Kampong Cham province + eight field sites (i.e., villages) were established within this province. Geographical sites where previous H5N1 transmission had been reported, detected, or suspected were selected. A total of 800 adults were enrolled in this prospective cohort study. One hundred adults with varying poultry exposure were enrolled in eight known or suspected different H5N1 endemic geographical areas (villages). For each village, systematic sampling was used to identify 100 households for enrolment. Within each household, the investigators randomly selected one adult for enrolment (≥ 20 years of age + exposure to live poultry)

Case definition: Acute onset of a respiratory illness with an oral (or equivalent from other body region) measured temperature ≥ 100.5°F (38°C) AND a sore throat, cough, shortness of breath, or respiratory distress for 4 or more hours. Designated field workers performed weekly follow-ups of all cohort subjects. If a subject was found to exhibit ILI symptoms, a healthcare worker conducted a home interview in which biological specimens were collected and an acute ILI questionnaire was completed. The objective was to assess sero-conversion and asymptomatic people. One H5N1 case in a 57 old woman was diagnosed in 2009.

### 1.1.3. Description of the health worker systems in Cambodia

There are two main documents (MoH, 2002, 2003) that define roles of health volunteers. In 2008, in the framework of the Health strategic plan 2008-2015 (Department of planning and health information, 2008) a new policy on Community participation was drafted by the MoH . However it had not been validated at the time of our survey. In these results, we compare this official framework with the information from 21 NGO workers directly in contact with health workers, in order to get a picture as realistic as possible of the real situation.

#### 1.1.3.1. Health workers at the community level

##### 1.1.3.1.1. Organisation

The first Village Health Volunteers were set up by a governmental initiative in the early 90's. They were officially recognised as a feedback group. This has now changed in Cambodia, and there are presently two kinds of health workers.

**VHSG (Village Health Support Group**): established by the MoH. This group is formed per Health Center (HC), with up to 35 members who represent all the villages of the catchment area. Each village should be represented by 2 VHSG members. They should ensure a regular flow of information between the community and HC, and cooperate with other health actors.

**VHV (Village Health Volunteers):** these belong to or have been trained by various organisations (MRD, MoH, and NGOs (Village Malaria Worker, Traditional Birth Attendant, Village Development Committee, Red Cross Volunteer …). They should be 2 to 6 according to the size of the village. They cooperate both with the VHSG, and with ministries or external institutions to facilitate contact, communication, and programs or implementation of activities in the community.

**The HCMC (Health Center Management Committee**) is a group at the Health Center level formed by 8 to 12 members, 3 HC team members (chief, vice-chief and midwife), VHSG representatives (2 to 4 per commune) and 1 Commune Council (CC) representative per commune. They provide general guidance and direction to the HC team for the management and organisation of HC activities.

##### 1.1.3.1.2. Number

According to NGOs, VHV and VHSG member are sometimes the same persons in one village. Also, the government recommends, as far as possible, that VHSG members are selected rather than new VHV, in order to increase their responsibilities in the village. This situation leads to certain confusion among users for whom the difference between VHV and VHSG is unclear. In most of the provinces (except for 5), at least one official VHSG member is present in over 65% of the villages. Nevertheless it is important to note that some NGOs can select and train their own VHSG without referring to the MoH, so the number of VHSG is certainly higher. In fact, in many provinces a majority of VHSGs are supported by NGOs.

Concerning the VHV, their real number also depends on the presence of a program or project supported by NGOs or the government (such as the Malaria Program, the Child and Mother Program). The Joint assessment of Community Health Volunteers, written in 2006 (MoH et UNICEF, 2006) mentioned that the “ratio in the study villages did not seem to follow the recommendations as set out in the official documents”.

##### 1.1.3.1.3. Income

VHSG members and VHV receive non-financial benefits and sometimes financial allowances for their activities. Their status provides them with substantial recognition within the community, in addition to the knowledge acquired through training and meetings. But this is not sufficient to sustain their commitment. Most VHSG members, if supported by NGOs, receive an incentive for transportation (only 3 NGO interviewed did not) and snacks for training. Some others receive material or equipment (a bicycle). Some NGOs provide a small incentive for each referral case (200 Riels per case). VHV also receive compensation packages which vary in terms of benefits and financial amounts (from 2 to 15 $ a month).

##### 1.1.3.1.4. Disease surveillance

Reporting diseases or outbreaks is clearly not within the scope of VHSG work. They are not formally included in the health surveillance system. But although not stipulated in official documents, all NGOs interviewed confirmed that as soon as they are active, which means that they attend meetings at the HC, VHSG in a direct or indirect way are involved in the disease surveillance through their referral activity and through their involvement in HCMC meetings. The links created between them and the HC through the bi-monthly meetings facilitate communication. Reporting can be done on a continual basis or / and after a specific request from the HC. However the promptness of their reporting is very variable.

VHV also play a role in outbreak reporting: initially they were asked to focus on the diseases related to the national program in place. But they are encouraged by NGOs to report any abnormal health related event in the village. Anyway, strengthening the links between VHV and HC through the NGO support facilitates reports of outbreaks.

#### 1.1.3.2. Challenges for efficiency

Very few studies have been carried out to investigate the efficiency of VHSGs. However, it seems obvious that there is a huge heterogeneity in their performance linked to:

- The presence of NGOs (which facilitate the meetings in HC organisations, and usually strengthen the link between the VHSG and the HC).
- The activity of the NGOs and the quality of their collaboration.
- The lack of harmonisation in the training curriculums.
- The opportunity for VHSG and VHV to receive a small incentive.
- The personal commitment of persons in charge of the HC, and of the OD.
- The involvement of HC staff volunteer programs supported by NGOs.

A feeling reported by some NGOs is that the VHVs and the VHSG members are often used as a convenience by the authorities, but they are not really recognised and supported. Even if they are volunteers and they obtain social recognition among their community, the lack of recognition through a minimum monthly incentive could lead to decreased motivation and a potential lack of sustainability.

## 1.2. Qualitative evaluation and comparison of systems (SWOT)

The SWOT analysis for the animal surveillance system was carried out retrospectively from the interviews that were implemented during the field visits with staff involved at central, provincial and district level. We first provided a table with the strengths and weaknesses of the passive surveillance systems for HPAI H5N1 as mentioned by the people interviewed (Table 9). This table was validated by the coordinator of the surveillance system. Then we have included the data that were collected during the interviews done with the people responsible for the different component of the public health surveillance system. A complete SWOT analysis of both systems (Table 10) were presented, discussed and validated during a workshop organised by FAO in Phnom Penh in Mai 2012, about Avian Influenza and Emerging Infectious Diseases surveillance and response in Cambodia. The workshop gathered 42 participants representing the different institutions working in the field of surveillance in Cambodia (MAFF, DAHP, NaVRI, MoH, IPC, WHO, WCS, USAID and FAO). The objectives of this workshop were to review the objectives of the current HPAI H5N1 surveillance strategy done in Cambodia, and to identify practical options, focusing on multi-sectoral collaboration under the One Health approach, to improve HPAI H5N1 surveillance.

**Table 12: Strengths and weaknesses of the passive surveillance for HPAI H5N1 surveillance in poultry depending on the administrative level in Cambodia**

| Strengths | Weaknesses |
|---|---|
| **Central Unit** | |
| NaVRI is the focal point for laboratory analysis and surveillance<br>Support from IPC for H5N1 confirmation<br>USAID and FAO funded project<br>Well-defined objectives of the surveillance<br>Accurate tools designed for the surveillance : notification procedures, samples collections, suspicion forms, case definition, field actors<br>Efficiency of the laboratory | No clear definition of the institutional organisation (no official coordinator)<br>Lack of specific regulation for surveillance.<br>No specific budget for surveillance<br>Not enough qualified staff and means<br>Need of relational databases between the different components of surveillance |
| **Provincial Veterinarian Level** | |
| Good awareness of PV about HPAI H5N1 and surveillance needs<br>Vehicles, sampling materials and tools for biosecurity procedure available<br>Regular management (with quarterly meetings at central level)<br>Regular training of PV | No specific budget for surveillance<br>Multiplication of tasks with few staff (no epi unit at regional level)<br>Lack of planned activities according to surveillance<br>Lack of budget for field intervention<br>No compliance on the reporting procedure<br>No means to compensate farmers (lack of trust from farmers) |

| District Veterinarian level | |
|---|---|
| Good geographic distribution<br>Good awareness on HPAI H5N1 and biosecurity<br>Regular meetings at regional level (monthly)<br>Regular contact with VAHW (monthly meetings)<br>Good communication with PV | No specific budget for surveillance<br>Alone for large superficies<br>No standardization of data collection<br>No sampling facilities<br>No planned activities regarding surveillance<br>Lack of farmer trust<br>Few connection with community health workers |
| **VAHW** | |
| Large number with good geographic distribution<br>Regular meetings at district level<br>Good communication with DV<br>Close relationship with farmers | Heterogeneity of training/knowledge<br>Disparate level of awareness for H5N1<br>Frequency of contact with the DV depending on distance (no mean of transport)<br>Not able to make a living from their activities<br>No standardized way for reporting<br>Depend on farmers' trust so reluctant to declare H5N1<br>No connection with VHW<br>Competition between VAHW |

**Table 13: SWOT analysis of the overall system and comparison between HPAI H5N1 animal and human surveillance system in Cambodia**

| | INTERNAL | | EXTERNAL | |
|---|---|---|---|---|
| | STRENGTHS | WEAKNESSES | OPPORTUNITIES | THREATS |
| Veterinary surveillance system | Well-defined objectives<br>Accurate tools designed for the surveillance (collection/suspicions forms, case definition…)<br>Efficiency of the laboratory<br>Regular management meetings at different level (Central, province, VAHW...)<br>Good geographic distribution (VAHW) | No designation of an official coordinator for the surveillance<br>Lack of compliance in the reporting procedure<br>No internal or external evaluation of the system<br>No formalised feedback to farmers<br>Heterogeneity and poor sustainability of VAHW<br>Lack of incentives for farmers or VAHW<br>Lack of specific training (analytical epi, spatial analysis) | Implementation of the Performance of Veterinary Services ( PVS) tool from OIE and of the gap analysis<br>FAO funded surveillance projects<br>USAID funded projects<br>Training opportunities (FAO, USAID, Field Epidemiology Training Programs)<br>Support from IPC for laboratory confirmation.<br>Collaboration with the MoH | Lack of recognition of NaVRI as Central Unit<br>Lack of specific and sustainable budget for the surveillance<br>Negative impact of control policy on farmers and veterinary staff<br>Lack of global approach of surveillance (no risk-based, no economic evaluation)<br>Few connection with VHW<br>No veterinary faculty<br>No compensation policy |
| Public health surveillance system | Well-defined objectives<br>Accurate tools for the surveillance (suspicions and outbreak forms)<br>SMS reporting system (standardization and timeliness of reporting)<br>Regular management meetings<br>High coverage (VHW, Health center)<br>Support of NGOs for VHW incentives and training<br>Support of international organizations (IPC, NAMRU, AFRIMS) in the surveillance of influenza)<br>Sustainable budget from the government | No internal or external evaluation of the system<br>Heterogeneity of VHW<br>Lack of trust from farmers to the public sector<br>Lack of diagnosis material at local level<br>Low sensitivity of the system for HPAI H5N1 at local level | WHO, USAID, CDC funded project<br>Collaboration with MAFF<br>Development of new guidelines for zoonotic diseases surveillance.<br>New regulation for the management of VHW<br>Medical university | No regulation system about the role of NGOs in the surveillance and in the training of VHW<br>Private sector not included in the surveillance system<br>Low sensitivity of the veterinary surveillance system to detect HPAI H5N1 cases.<br>No regulation about the private sectors<br>Lack of health insurance |

## 1.3. Semi-quantitative evaluation of animal surveillance (SNAT Trop)

### 1.3.1. Output 1

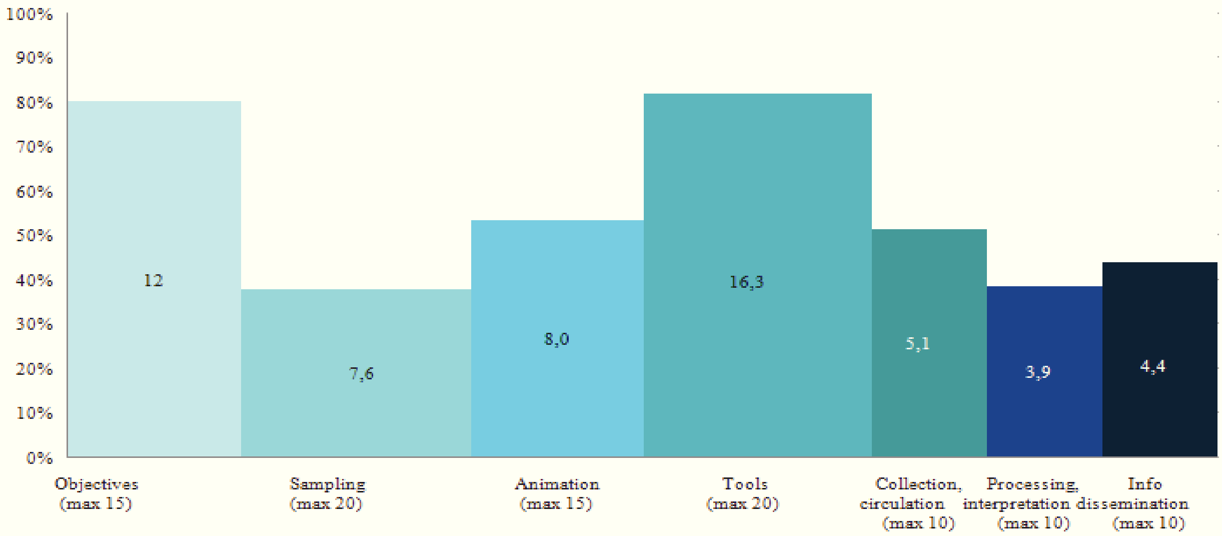
The first output is the qualitative analysis of the surveillance system. As we can see in the Table 9 section 1 (objectives and context), section 5 (surveillance tools) and section 4 (laboratory) are the most comprehensive and optimal sections with a score of 100%, 83% and 71% respectively. These are the ones that require the least improvement. In contrast, sections 6 (surveillance procedures) and 10 (evaluation) are the ones with the lowest scores (22% and 17%) and require immediate attention from the surveillance system coordination.

**Table 14: Qualitative evaluation of the HPAI H5N1 surveillance system in Cambodia done in 2011, showing the output 1 of the SNAT Trop tool.**

| Sections | Result of evaluation per each section | Percentage of satisfaction |
|---|---|---|
| Section 1: Objectives and context of surveillance | | 100% |
| Section 2: Central institutional organization | | 36% |
| Section 3: Field institutional organization | | 53% |
| Section 4 : Laboratory | | 71% |
| Section 5: Surveillance tools | | 83% |
| Section 6: Surveillance procedures | | 22% |
| Section 7: Data management | | 38% |
| Section 8 : Formation | | 37% |
| Section 9 : Communication | | 64% |
| Section 10 : Evaluation | | 17% |

### 1.3.2. Ouput 2

The second output of the tool show similar results (Figure 15). The tools used and the objectives of the surveillance have a good level of adequacy (81.5 % and 80%), on the opposite the points for dissemination of the information, data processing and sampling have the lowest score (44%, 39% and 38% respectively)

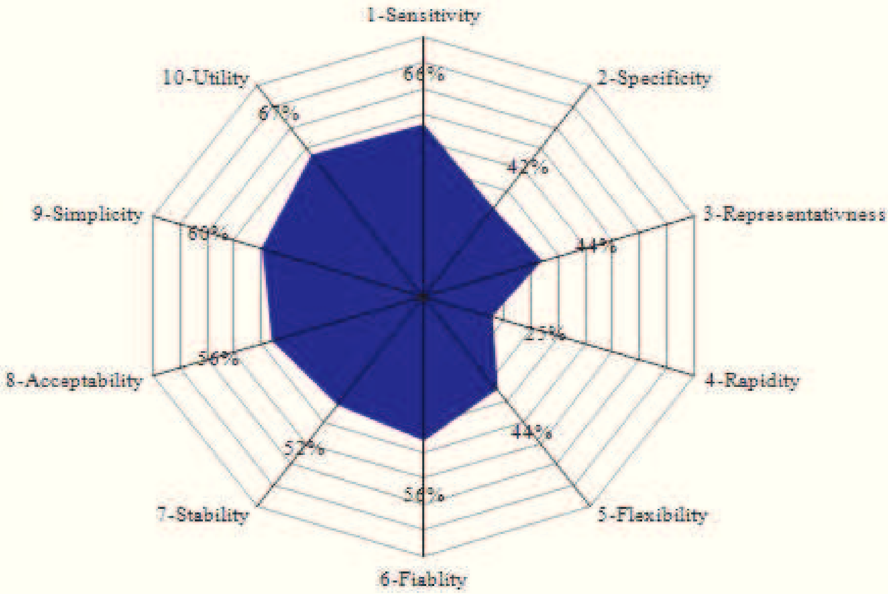



*Animation refers to the coordination of the surveillance system, tools to the diagnostic methods used at the laboratory.*

**Figure 16: Qualitative evaluation of the HPAI H5N1 surveillance system in Cambodia done in 2011, showing the output 2 of the SNAT Trop tool.**

### 1.3.3. Output 3

Most of the attributes displayed in the radar chart (Figure 16) have a medium level (from 42% to 67%) only the rapidity of the system is low, with a level at 25%




*Rapidity refers to the timeliness and the fiability to the reliability of the surveillance system.*

**Figure 17: Qualitative evaluation of the HPAI H5N1 surveillance system in Cambodia done in 2011, showing the output 3 of the SNAT Trop tool.**

### 1.3.4. Possible recommendations from the evaluation

#### 1.3.4.1. Strengths of the surveillance system

When reviewing the outputs, we identified 3 strong sections in the surveillance system organisation: the objective and context of the surveillance, the surveillance tools used and the laboratory processing. The objectives of the surveillance systems were well defined and consistent with the disease situation of the country. The notification procedures were simple, direct and adapted to the means available within the surveillance system. Surveillance system actors understood the case definition and were aware of the procedures to follow in case of suspicion. They knew how to fill in the forms. Sample collection was also properly implemented. It appeared that field workers were well trained in sampling techniques, storage and shipment of samples. The effective day-to-day operation of the diagnostic laboratory was also one of the strengths of the surveillance system. Indeed, the laboratory's diagnostic testing was accurate; they implemented good practices regarding quality assurance and successfully participated in national and international proficiency tests.

#### 1.3.4.2. Weaknesses of the surveillance system

One of the sections with the lowest scores was the evaluation process of the surveillance system. In fact, this evaluation was the first one implemented since the surveillance system was set up. Evaluation procedures for external assessment were not described anywhere and performance indicators were not used. Data analysis and communication were also assessed as unsatisfactory. The data collected through the surveillance system was stored in a separate database with no connections, making regular synthesis a complicated task. Moreover, the staff at central level did not have the required training to produce epidemiological analyses or to feed an epidemiological bulletin, resulting in poor communication about output from the surveillance system to internal and external users. The timeliness of the surveillance was also unsatisfactory. The delays between a suspicion of HPAI H5N1 case and an outbreak confirmation with sample collection and analyses, or between a confirmation and feedback to the field, were not defined and certainly not monitored, leading to extensive delays in the implementation of control measures and to an increased risk of the disease spreading. One last important point to note was the lack of sustainable financial resources experienced by all the actors of the system, whether to pay for fuel for field investigation or to renew reagents for laboratory testing. Funding depended entirely on external donors, making the surveillance system inflexible and resulting in the inability to implement long-term global actions.

## 1.4. Quantitative evaluation of HPAI H5N1 surveillance in backyard poultry in Thailand (STA Thai)

In this section we present only a summary of the most important results, the full results are presented in the paper (Annex 2).

In this study we managed to assess, through scenario tree modelling, the sensitivity of each surveillance component (especially the passive surveillance) and the overall surveillance system sensitivity (SSSe).

### 1.4.1. Sensitivity estimation

For a design prevalence of 0.05% (1,485 farms infected) all the surveillance components reached a Se of 1. When using a design prevalence of detection in 3 farms or in 1 farm (using the current definition of risk areas), the overall Se decreased to 82% and 43% respectively. For passive surveillance, the Se was 50% and 21% respectively.

### 1.4.2. Sensitivity ratio

When calculating the Se ratio, we were able to compare the components with each other. With a median Se ratio of 1.95 (95% CI [0.17-9.47]), passive surveillance showed a positive impact on the detection of HPAI H5N1 cases as compared to the surveillance component based exclusively on laboratory testing.

### 1.4.3. Disease freedom

When looking at the probability of freedom from disease over time (from January 2008 to January 2011), and considering all surveillance components, the median probability of freedom was estimated to be 99.43% (97.82 – 99.73%) for a low probability of disease introduction and 96.90% (87.25 – 98.53%) for a risk fivefold higher.

### 1.4.4. Sensitivity analysis of the model

For the passive component, the Se is mainly influenced by the probability of a poultry farm owner to notify the disease to the veterinary health authorities (Pn). For the overall surveillance, the SSSe is influenced again by the Pn, the value of the relative risk of infection attributed to a farm in an high risk area and the probability that a sick chicken will show symptoms.

## 1.5. Participatory evaluation of VAHW in Cambodia (PE VAHW)

In this section we present only a summary of the most important results, and the full results are presented in the paper in Annex 3.
In this study we managed to develop an evaluation grid to score the level of VAHW activities and their effectiveness in fulfilling their different functions, especially the functions of disease recognition and reporting to veterinary services. This tool was developed using participatory methods so that the VAHW would have ownership of the tool and so as to define specific criteria of evaluation.

### 1.5.1. Identification of the main constraints for sustainability

During the first six meetings organised with VAHW (active and inactive ones), a scenario tree was used to help characterising the mains constraints that affect VAHW sustainability. The decrease of activities over time was the main problem mentioned during the meetings. The causes for this were: fierce competition between VAHW, lack of recognition from the traditional authorities and the government and finally a range of skills that was not sufficient to really help all the farmers.

### 1.5.2. Development of the grid

A total of 8 meetings during which 67 different stakeholders were interviewed, were required to develop the grid. The final tool consisted of 5 categories describing the VAHW working environment: sustainability of their activities, the treatment function, the vaccination function, their involvement in extension services (production) and their reporting activities. To score these functions, 39 criteria were developed (with a notation system). Each criterion was linked to one or several questions. Two quizzes were also developed to first assess the diagnostic approach of the VAHW and secondly to assess their treatment capabilities. The grid was validated during a field survey, including 17 active VAHW and 19 inactive VAHW; after this phase some questions were modified or added.

Conducting an evaluation using this grid require the interview of 14 stakeholders: the VAHW himself, 10 villagers (randomly selected in the village), the village chief, a member of the village council and the district veterinarian (by phone).

### 1.5.3. Evaluating the reporting function

The reporting function was given a score of 7 out of 100 (total score for the 5 functions) in the final tool. It was interesting to note during the different discussions leading to the development of the grid, that for VAHW, disease reporting was seen mainly as a constraint, they have to report even if they recognise that there is no direct benefit for them (no compensation for reporting). They also highlighted the fact that reporting a disease like HPAI H5N1 could jeopardise the relationship of trust and confidence from the farmers that is so crucial for the VAHW.

To score the reporting function, the stakeholders selected 3 criteria: the level of involvement of the VAHW in the reporting activity, his knowledge on the diseases to be declared and the quality of advice provided to the farmers.

# 2. Surveillance system design options

## 2.1. Factors influencing the effectiveness of VAHW in Cambodia (EFF VAHW)

### 2.1.1. Descriptive analyses

From the 367 villages visited, 283 had a VAHW, 23% had none. The scoring system could give a maximum of 100 points and the mean score obtained was 44/100 [min-max: 09-77]. The score distribution is displayed in Figure 17. We arbitrarily decided that the VAHW was declared inactive below the score of 25/100, and active above 25/100. In total we classified 54 VAHWs as inactive and 229 as active. The geographic representation of the VAHWs in our study area is shown in Figure 18

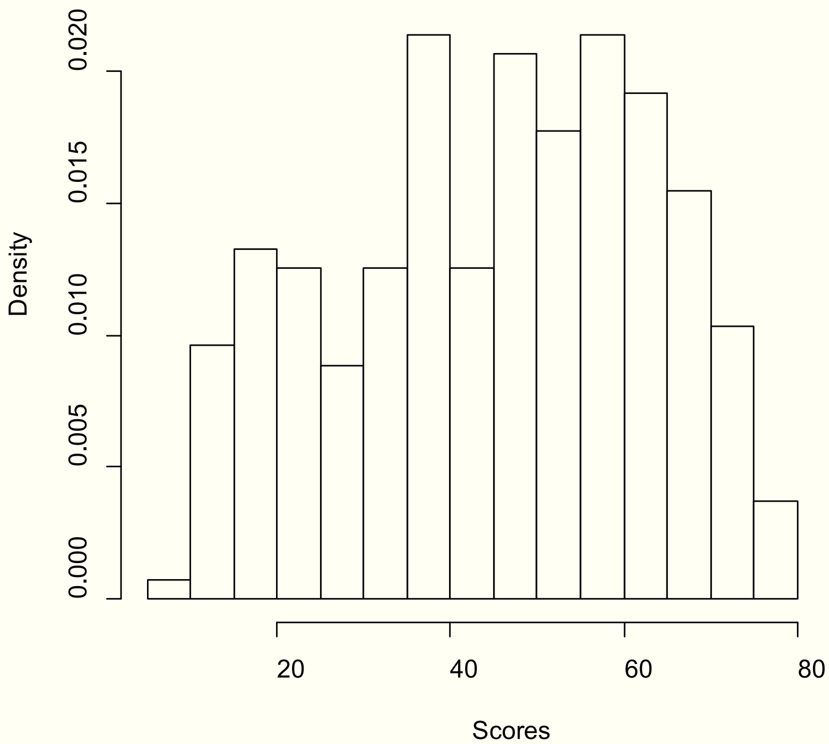



**Figure 18: Distribution of the scores obtained by the 283 Village Animal Health Workers during the evaluation done between November 2011 and January 2012 in three provinces of Cambodia.**

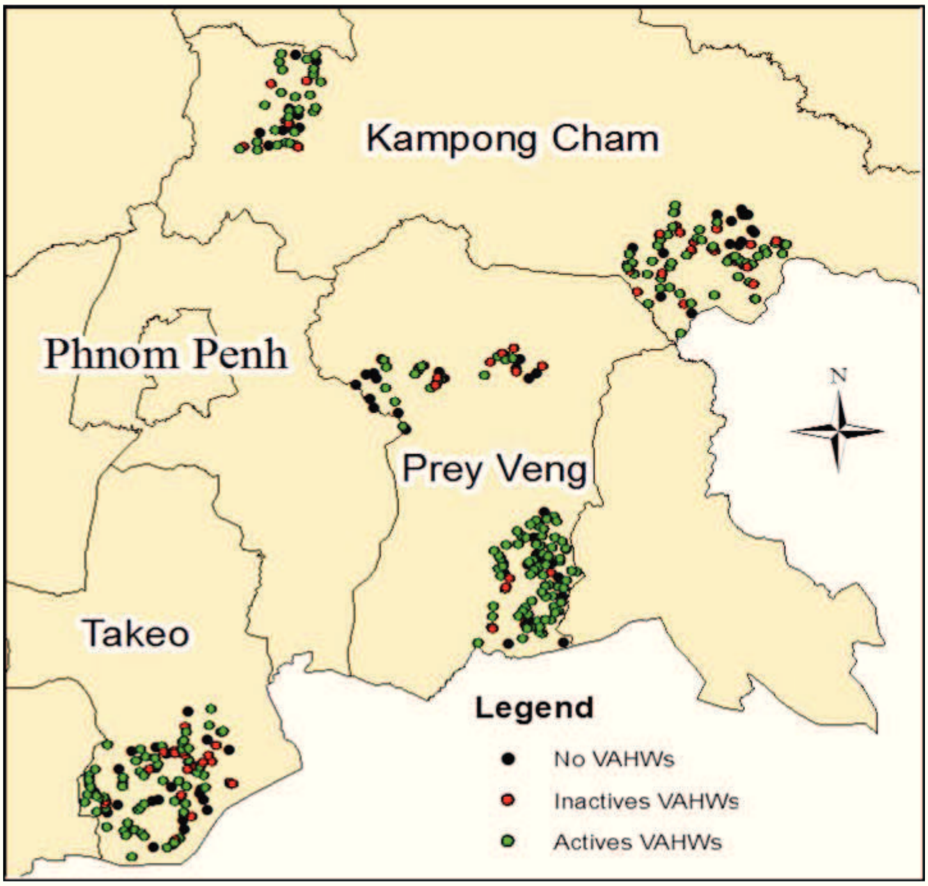


Figure 19: Map of the 367 villages included in the Village Animal Health Worker evaluation study done between November 2011 and January 2012 in Cambodia.

The score of the four categories of criteria are represented in the graph (Figure 19).

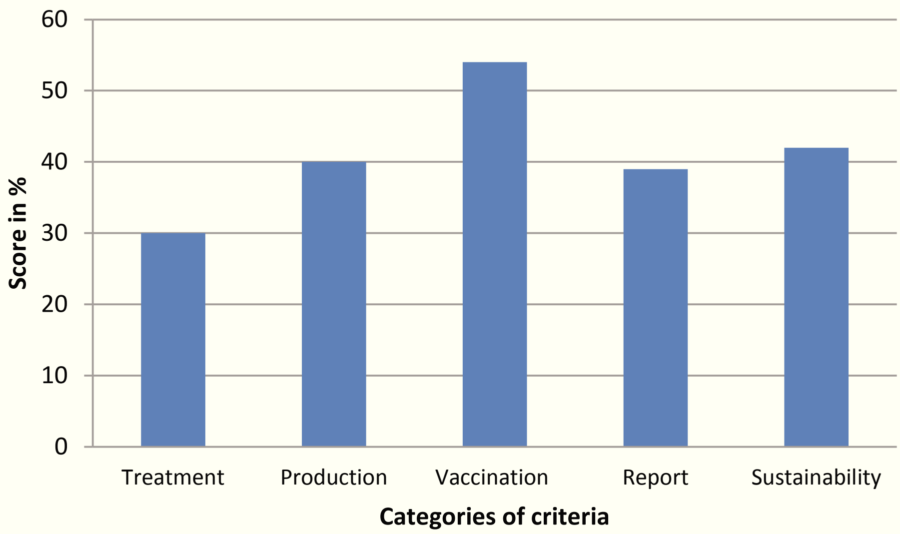


Figure 20: Score in percentage by categories of criteria obtained by the 283 Village Animal Health Workers during the evaluation done between November 2011 and January 2012 in three provinces of Cambodia.

VAHW appeared to be the most efficient in providing vaccination (53% percentage of success), then production and reporting to the veterinary services (40% and 39% success respectively). Implementation of treatment was poor (30%).

If we compare the score achieved between active VAHW and inactive VAHW (Figure 20), all the scores were significantly different ($p<0.01$), especially the treatment scores.

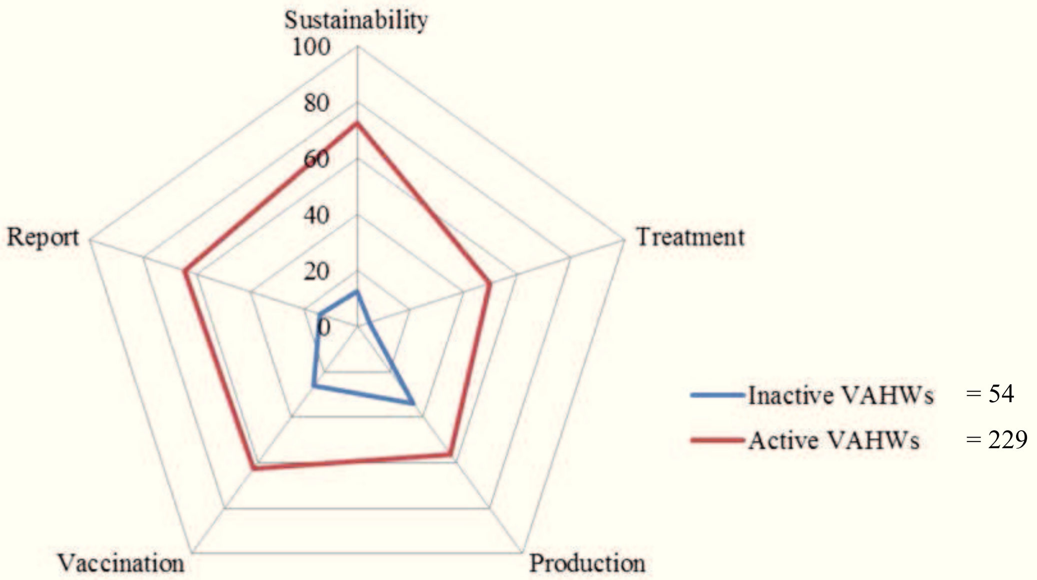



**Figure 21: Spider graph representing the score obtained by 229 Village Animal Health Workers considered as active and 54 considered as inactive during the evaluation done between November 2011 and January 2012 in three provinces of Cambodia between active and inactive VAHW**

We looked at the reporting activity by analysing the answers given to the questionnaire within the evaluation grid:

- According to villagers, more than 60% of VAHWs did not inform them about diseases in the district and did not provide any feedback based on samples taken from their farms.
- Only 2% of the VAHW knew that they were required to report any outbreak or suspicion of the 5 following diseases to local authorities (HPAI H5N1, Newcastle disease, porcine reproductive and respiratory symptom (PRRS), haemorrhagic septicaemia (HS) and foot and mouth disease (FMD)). Fifty percent of them knew about HPAI H5N1, 55% about FMD, 50% about HS and 11% about PRRS.
- Forty percent of the VAHW interviewed had received refresher training (from different organisations) about HPAI H5N but less than 40% of them responded that they “have to” report on avian flu.

### 2.1.1. Multivariable analyses of the factors associated with VAHW effectiveness

#### 2.1.1.1. Data handling

Data were checked for consistency and missing values. Thirty-two observations with more than 6 missing values were removed from the analysis. The total number of observations was 251.

The variable "number of VAHW in the commune" was removed because of too many missing values (62/270).

The types of trainers were coded into two categories: (1) Government and FAO, (2) NGOs. The year of training was coded into 3 categories: (1) before 2000, (2) between 2000 and 2005, (3) after 2005. The type of transport was coded into 2 categories: (1) none or bike, (2) motorbike. The variable "duration of the first training session" was coded into 2 categories: (1) less than 30 days (2) more than 30 days. Variables describing the number of animals in the village were coded into several categories depending on the distribution of each species (chickens, cattle, pigs, ducks and free-grazing ducks).

#### 2.1.1.2. Linear regression

The list of potential factors that were significantly associated with the VAHW effectiveness score in the univariable analysis are listed in the Table 12. These variables were selected to be included in the linear regression model.

The multivariable regression model identified 6 variables significantly associated with the VAHW score. The magnitude and direction of the associations are given in Table 13.

**Table 15: Factors significantly associated in the univariable analysis ($p<0.20$) with the Village Animal Health Workers effectiveness score (n=251) obtained during the evaluation done between November 2011 and January 2012 in three provinces of Cambodia.**

| Factor | Unit | Description |
|---|---|---|
| **Trainer** | Gov & FAO<br>NGOs | Type of organization that gave the first training |
| **Selection** | Volunteer<br>Local authorities | How the VAHW was selected for the training |
| **Duration** | <30 days<br>≥30 days | Duration of the first training |
| **Follow-up** | Field visit | Number of field follow-up visit since the first training by the trainers |
| **Refresher course** | No/Yes | If they received a refresher course since their first training |
| **Practice** | No/Yes | Presence of practical sessions during the first training |
| **Age** | Years | Age of the participant |
| **Transport** | None or bike<br>Moto | Type of transport owned by the VAHW |
| **Association** | No/Yes | Member of a VAHW association |
| **Cattle** | <100<br>100-200<br>>200 | Number of cattle in the village of the VAHW |
| **Pigs** | <100<br>≥100 | Number of pigs in the village of the VAHW |
| **Chicken** | <3000<br>≥3000 | Number of chicken in the village of the VAHW |
| **Muscovy Ducks** | <100<br>≥100 | Number of Muscovy ducks in the village of the VAHW |
| **Book keeping** | No/Yes | If the VAHW recorded his activities |
| **DV** | No /Yes | Regular meeting with the district veterinarian |

**Table 16: Factors associated with high effectiveness score of Village Animal Health workers obtained by multivariable linear regression model for the data obtained during the evaluation done between November 2011 and January 2012 in three provinces of Cambodia.**

| Factor | Coefficient | p | 95% confidence interval | VIF |
|---|---|---|---|---|
| Intercept | 12.32 | 0.002 | [4.75 – 19.89] | |
| Duration | | | | |
| <30 | baseline | . | | |
| >30 | 0.16 | 0.048 | [0.01– 0.32] | 1.04 |
| Refresher courses | 6.47 | 0.0001 | [2.97 – 9.97] | 1.06 |
| Practice | 7.02 | 0.007 | [1.97 – 12.07] | 1.06 |
| Association | 7.47 | 0.001 | [2.91 – 12.02] | 1.13 |
| Cattle | | | | |
| <100 | baseline | . | | 1.78 |
| 100-200 | 6.46 | 0.018 | [1.12 – 11.81] | 1.92 |
| 200 | 12.50 | 0.0001 | [7.77 – 17.22] | |
| District Veterinarian | 14.62 | 0.0001 | [10.67 – 18.56] | 1.17 |

F= 28.08 , $p<0.001$, n=251, $R^2$= 0.4814, Adj $R^2$= 0.4642, VIF (Variance inflation factor)

## 2.2. Pilot study for mobile phone declaration in Cambodia (SMS Reporting)

### 2.2.1. Technical characteristics of the system

The pilot study lasted 13 weeks. During week 9, the system experienced a technical breakdown, and all the data for that week were lost, leaving 12 weeks of data. During the first 2 months of the project, an automatic text message reply was sent to every participant once their text message had been received. The content was as follows: *"Hello, we have received your message. Thank you for participating."* However, once the system had been implemented at NaVRI, the automatic text message replies were not sent all the time because FrontlineSMS was not turned on for long enough during the day. It was only on for a few hours, and should have been on for the whole day. Therefore, it was decided to stop the automatic text message replies and to send a weekly text message reminder instead. This weekly text message reminder from NaVRI to participants said the following: *"Hello and thank you for participating in our study. We hope to receive your SMS this week."* In order to avoid overloading the system with messages, we had to assign a specific day during the week for each village to report.

The cost of this SMS system was estimated at 420 USD per month per 100 persons (including the phone card, and the cost of the automatic reply sent by the NaVRI, but this did not include the salary of NaVRI staff or the cost of outbreak investigation in case of suspicion).

### 2.2.2. Participation and error rates

The average weekly participation rate for the VAHW was 48.6% [min-max: 3.5-98.3], and was 45.4% [7.4-96.3] for the Village Chief (VC). The level of participation declined gradually throughout the time of the study (Figure 21).

The average weekly error rate (number of SMS sent with an error in the contents) was 10.6% [0-33.3] for the VAHW and 18.9% [0-48] for the VC (Figure 22).

Aberrant values of mortality (according to the total number of animal present within the village) were found in 5% of the SMS sent by the VCs.

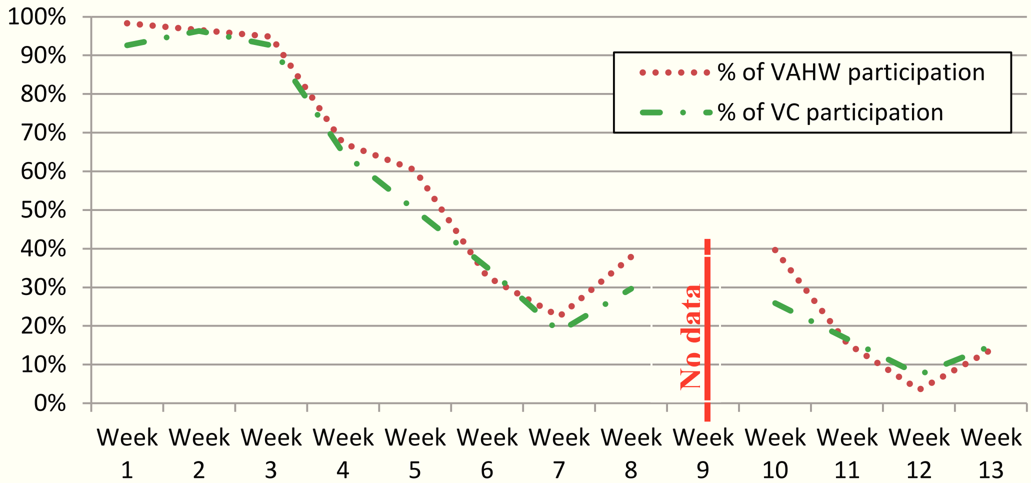



**Figure 22: Weekly participation rate of Village Animal Health Worker and Village Chief to the pilot SMS reporting system between February and June 2012 in 2 provinces of Cambodia.**

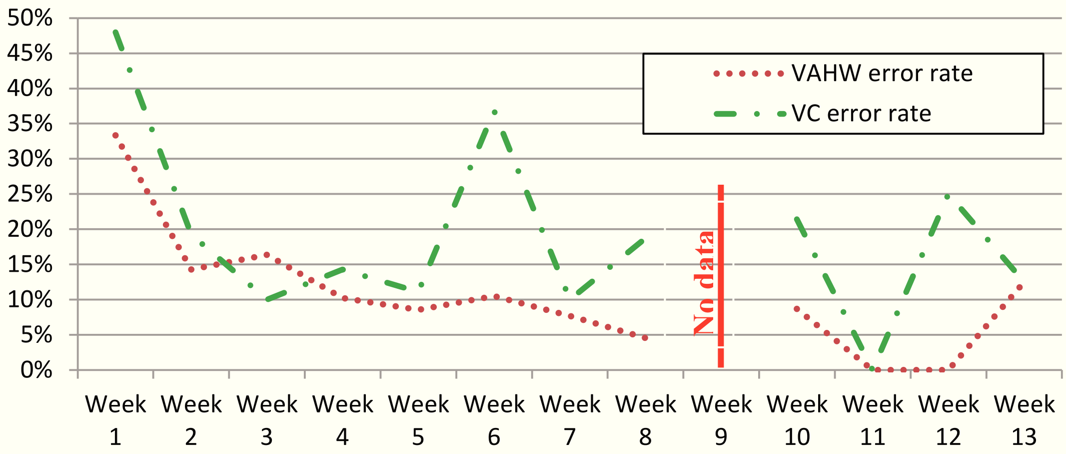



**Figure 23: Weekly error rate of Village Animal Health Worker and Village Chief to the pilot SMS reporting system between February and June 2012 in 2 provinces of Cambodia.**

### 2.2.3. Mortality declaration

Only the results provided by the VAHW are displayed in the following sections

#### 2.2.3.1. For cattle and pigs

Only one suspicion of foot and mouth disease was reported during the duration of the study, which was considered as a false suspicion by the NaVRI. Haemorrhagic septicaemia in cattle was declared by 23 villages, with a total of 145 sick animals (with 1 to 6 animals per village) and only 4 animals died. For pigs, the mean weekly mortality rate was 4.6% [0-33.4], with a 95$^{th}$ percentile at 20% (Figure 23).

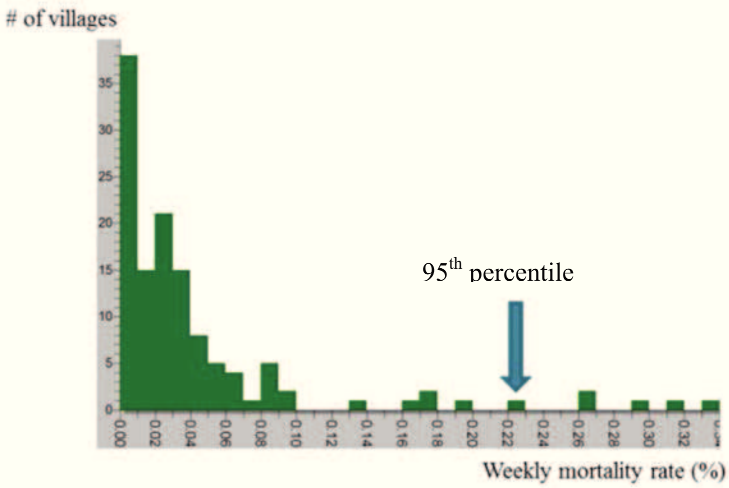



**Figure 24: Distribution of the weekly mortality rate for pigs declared by Village Animal Health Worker during the pilot SMS reporting study between February and June 2012 in 2 provinces of Cambodia**

#### 2.2.3.2. For chickens and ducks

For the chickens, the mean weekly mortality rate was 2.8% [0-35.4], with a 95th percentile at 10%. For the ducks, the mean mortality rate was 3.6% [0-50], with a 95th percentile at 13.7% (Figure 24).

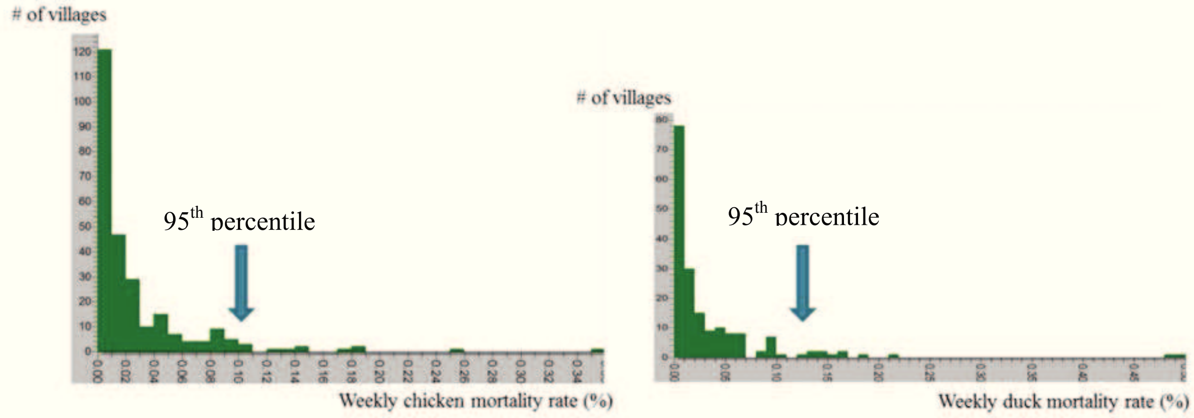



**Figure 25: Distribution of the weekly mortality rate for chickens and ducks declared by Village Animal Health Worker during the pilot SMS reporting study between February and June 2012 in 2 provinces of Cambodia**

### 2.2.4. Perceptions of participants

We managed to interview 100 participants (out of 112) for the perception survey. The majority of the participants (95%) found the text messaging easy to understand and to follow.

The automatic SMS reply from NaVRI was found useful by 94% of participants. They explained that this type of response made them feel to be part of the system and motivated them to keep on sending messages. For 3% of participants, it was difficult to remember the exact day on which they had to send their report.

A total of 48% of participants admitted that they had failed to send their report every week. Among these, 54% explained that they were too busy at the time of reporting, 13% had an issue with their mobile phones and 10% did not report because they did not receive an automatic reply from the NaVRI. The remaining participants said that there was no animal mortality to report in their village or they simply forgot to send their SMS. Only 17 participants received a phone call from NaVRI to give more information about the mortality happening in their village.

## 2.3. Spatio-temporal cluster analysis of HPAI H5N1 outbreaks in Cambodia (STC Analysis)

In order to compare the risk factors that are associated with HPAI H5N1 outbreaks in the two provinces, Takeo and Prey Veng, data from this areas were analysed separately but using a strictly similar approach.

### 2.3.1. Description of the outbreaks and the data used in the analysis

#### 2.3.1.1. Village data

Takeo province: In all 209 villages were visited and 209 VC were interviewed. One new confirmed case of HPAI H5N1 in Ponk Tuek village, in the Bourei Cholsar district (virological sample analysed by IPC, and confirmed on the 17 February 2010). Based on the inclusion criteria (see Part 3 – section 2.2.3.1.2), 115 villages were included in the analysis.

Prey Veng province: In all 229 villages were visited and 229 VC were interviewed. Based on the inclusion criteria, only 39 villages were included in the analysis.
It is important to note that after the second HPAI H5N1 confirmed in Takeo, the NaVRI no longer allowed us to take samples for confirmation.
The localisation of the villages are mapped in the Figure 25.

#### 2.3.1.2. Risk factors hypothesis

In all, 9 explanatory variables were selected for the risk factor analysis. Several variables selected for this study were those found to be significant in various countries according to a recent literature review (Gilbert et Pfeiffer, 2012a): poultry (chicken and duck) densities in the commune, presence of semi-commercial poultry farms in the commune, presence of rice paddies in a 500-m radius, distance to the closest river, distance to the closest road, human population density in a 1-km radius. In addition, maximum duration of flooding in a 1-km radius and distance to index case were also examined.

#### 2.3.1.3. Data source

In order to obtain more accurate data on the distribution of poultry in Cambodia, a survey was implemented in September/October 2010. A questionnaire on the number of chickens, ducks, free-grazing duck farms and semi-commercial chicken farms was distributed, during a monthly meeting in Phnom Penh, to every provincial veterinarian; the questionnaire was filled and returned back during the following monthly meeting. We managed to collect the census data for 1,521 communes out of 1,623, and to produce the maps that are shown in Annex 11.

A gridded human population dataset was available at a 900-m resolution for the year 2010 (http://www.asiapop.org/). From this raster layer, we extracted the mean value of human population density in a 1-km buffer around each village. A series of MODIS (or Moderate Resolution Imaging Spectroradiometer) images collected in 2005, at 500-m resolution, were processed to map water bodies and rice paddy fields. River and road data were imported free of charge from: http://www.diva-gis.org/gdata. The duration of flooding in a 1-km radius around each village was evaluated from MODIS images dating from 2006.

### 2.3.2. Spatial analysis

The index case of Takeo was detected on the 1st November 2009, 87 days before duck mortality was reported to the veterinary services. The outbreak lasted 4 months. The index case of Prey Veng appeared the 1st February 2010, 80 days before the confirmation of a human case and 83 days before any poultry mortality was declared.

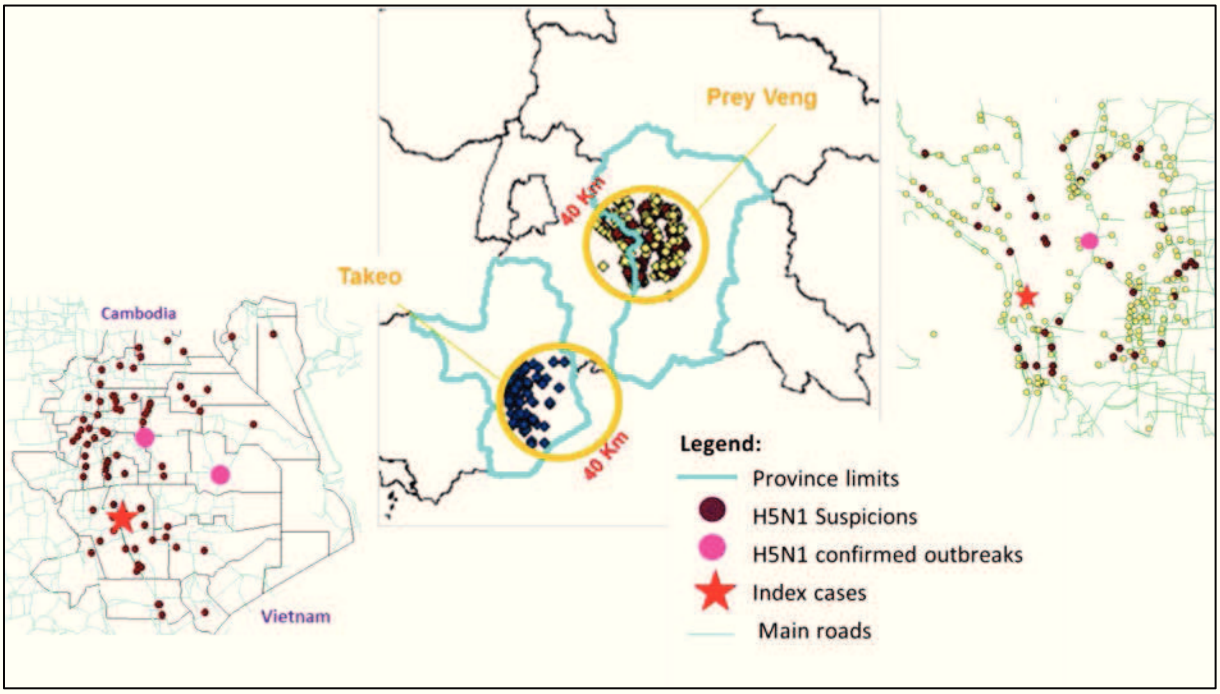



**Figure 26: Location of the villages included in the survey, the confirmed outbreaks, and the index cases for the provinces of Takeo and Prey Veng, in Cambodia 2009-2010.**

From the semi-variogram we found that the epidemic days of cases located within a distance of 7 km were correlated. The map of the spatio-temporal distribution of cases for Takeo is shown in the Figure 26. Dates of declaration were distributed over 112 days. Major roads seem to have played a role in the disease dynamic.

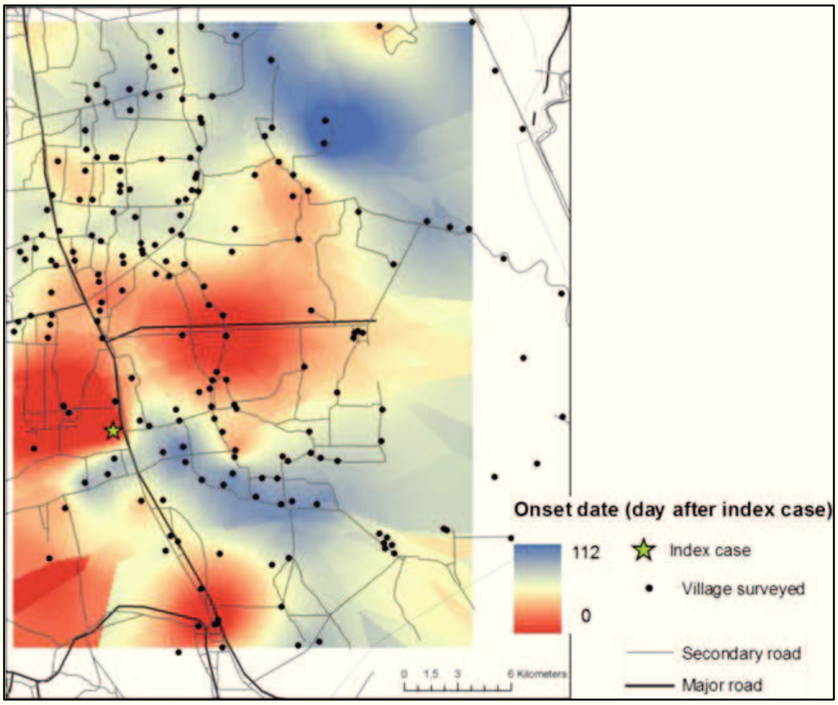



**Figure 27: Map of the spatio-temporal distribution of suspected HPAI H5N1 cases in Takeo province, Cambodia, between November 2009 and February 2010**

### 2.3.3. Spatial logistic regression model

#### 2.3.3.1. Takeo province

Out of the 9 variables screened, 8 were found to be significantly associated with the presence of HPAI H5N1 outbreaks in the univariable analysis ($p<0.25$). These variables were selected to be included in the multivariable modelling process (Table 14).

**Table 17: Variables significantly (p<0.25) associated with the presence of HPAI H5N1 outbreaks in univariable analysis of data from Takeo, Cambodia, in 2009-2010.**

| Variable | Category | OR | CI | p |
|---|---|---|---|---|
| **Distance to road** | continuous | 0.999 | 0.999 - 1 | 0.012 |
| **Distance to river** | continuous | 1.381 | 1.057 – 1.831 | 0.0207 |
| **Flooding** | continuous | 0.996 | 0.991 – 1.001 | 0.097 |
| **Rice fields** | Yes | REF | | |
| | No | 0.265 | 0.118 – 0.550 | 0.0006 |
| **Human population density** | continuous | 1.305 | 1.054 - 1.628 | 0.016072 |
| **Chicken density** | continuous | 1.395 | 1.103 - 1.778 | 0.006218 |
| **Duck density** | continuous | 1.001 | 1.000 - 1.002 | 0.024 |
| **Distance to index case** | < 10 km | REF | | |
| | 10 – 15 km | 0.777 | 0.399 – 1.506 | 0.4557 |
| | > 15 km | 0.624 | 0.316 – 1.224 | 0.172 |

Two variables were found to be significantly (p<0.05) associated with HPAI H5N1 outbreak in the spatial multivariable regression model (Table 15).

**Table 18: Multivariable logistic models for variables associated with HPAI H5N1 outbreaks data from Takeo, Cambodia, in 2009-2010.**

| Variable | Category | OR | CI | p |
|---|---|---|---|---|
| **Rice fields** | Yes | REF | | |
| | No | 0.265 | 0.118 – 0.550 | 0.0006 |
| **Duck density** | continuous | 1.001 | 1.000 - 1.002 | 0.024 |

#### 2.3.3.2. Prey Veng province

Out of the 9 variables screened, only 2 were found significantly (p<0.25) associated with HPAI H5N1 outbreaks in the univariable regression models (Table 16) . Consequently, no multivariable model was run.

**Table 19: Variables significantly (p<0.25) associated with HPAI H5N1 outbreaks in univariable analysis of data from Prey Veng, Cambodia, in 2009-2010.**

| Variable | Category | OR | CI | p |
|---|---|---|---|---|
| **Duck density** | continuous | 0.999 | 0.996 - 1.000 | 0.2135 |
| **Distance to index case** | < 14 km | REF | | |
| | 14 – 20 km | **0.30** | 0.09 - 0.70 | 0.008 |
| | > 20 km | **0.79** | 0.37 – 1.72 | 0.55 |

## 2.4. Risk mapping of HPAI H5N1 infection in human in Cambodia (MCDA)

### 2.4.1. Identification of risk factors from the literature review

Few studies have been implemented to identify factors associated with the risk of HPAI H5N1 infection in humans. Moreover, most of the factors identified are not described spatially. In our study, we therefore had to use proxy data to model these risk factors.

Table 17 shows risk factors that were found in the literature as being positively associated with the risk of human infection, together with the data that we selected as a proxy to be represented in a spatial format.

**Table 20: Risk factors found in the literature positively associated with the risk of HPAI H5N1 human infection for Cambodia, with the proxy data used in our model.**

| Data | Proxy |
|---|---|
| **Working in a farm** | % of population employed in agriculture sector |
| **Working in a slaughterhouse or in a market** | Distance to the main city |
| **Being in contact with ponds' water** | % of population using ponds' water as drinking water |
| **Being a child** | % of children in the population |
| **Level of education** | % of illiteracy |

From this list, we decided to test other factors that could also be associated with an increased risk of infection: backyard chicken density, duck farm density, free-grazing duck density, human population density, proportion of population that have access to communication, poverty rate, presence of any previous poultry outbreaks in the village, presence of any previous human cases in the village and human density to poultry density ratio. In total, 14 risk factors were submitted to our 10 experts. Only two were excluded by the experts: human population density and presence of previous human cases in the village.

### 2.4.2. Characterisation and weighting of risk factors by the experts

Each expert selected a correlation function (linear, sigmoid…) between the factors and the risk of infection. They weighted each factor using the Saatay scale. The final factor weightings are shown in the Table 18.

**Table 21: Final weighting of the risk factors of HPAI H5N1 infection in human for Cambodia combined from the elicitation of 10 experts.**

| Risk factor of human infection | Weights |
|---|---|
| **Free-grazing ducks density** | 0.326 |
| **Poverty rate** | 0.235 |
| **Presence of previous poultry case in the village** | 0.155 |
| **Backyard chicken density** | 0.075 |
| **Human density to poultry density ratio** | 0.063 |
| **% of population employed in agriculture sector** | 0.048 |
| **% of population using ponds' water as drinking water** | 0.035 |
| **Duck farms density** | 0.031 |
| **Distance to main city** | 0.01 |
| **% of children in the population** | 0.005 |
| **% of population that have access to communication** | 0.005 |
| **% of illiteracy** | 0.005 |

No correlation between the risk factors included in the model was identified by the sensitivity analysis (variance < 0.10). No risk factor seemed to have more impact than the other ones (mean <0.10).

### 2.4.3. Validation of the map

The map (Figure 27) shows the distribution of the risk of HPAI H5N1 human infection. Some small areas, orange and yellow, are more at risk than the rest of the country, where the likelihood of human infection reaches 0.59. By overlaying the human cases in this map, we noticed that the location of most cases have occurred in the areas where the predicted risk was the highest (in yellow and orange on the map).

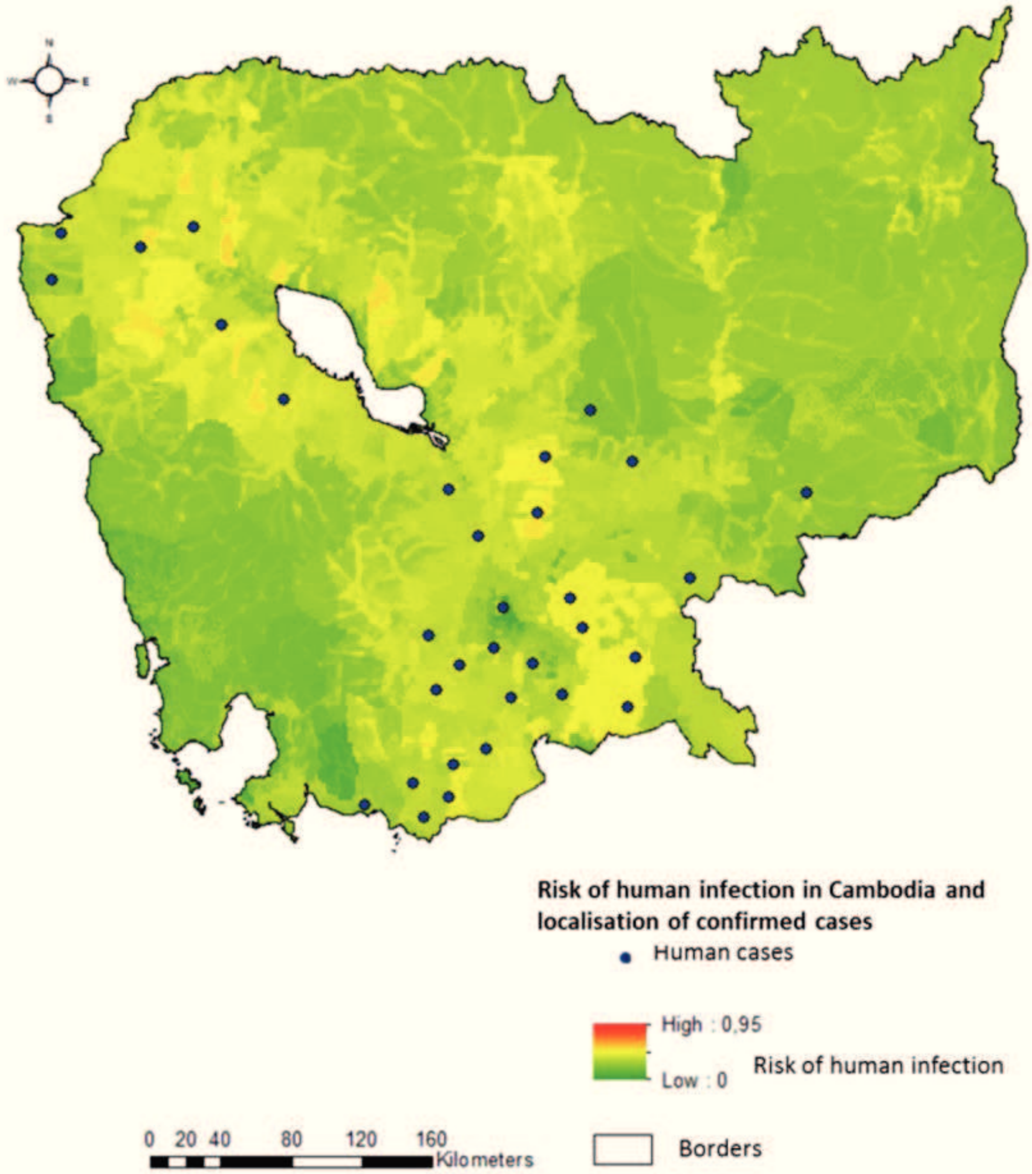



**Figure 28: Distribution of the risk of HPAI H5N1 human infection in Cambodia from the use of spatial MCDA with 10 experts in 2014 and the localisation of confirmed human cases since 2004.**

### 2.4.1. Mapping the risk of HPAI H5N1 dissemination in the poultry population in Cambodia

During this work the risk map of poultry infection in Cambodia was also produced using the same methodology (but with different risk factors and a different group of experts. All the details can be found in the master report of Florianne Roulleau (Roulleau, 2014)

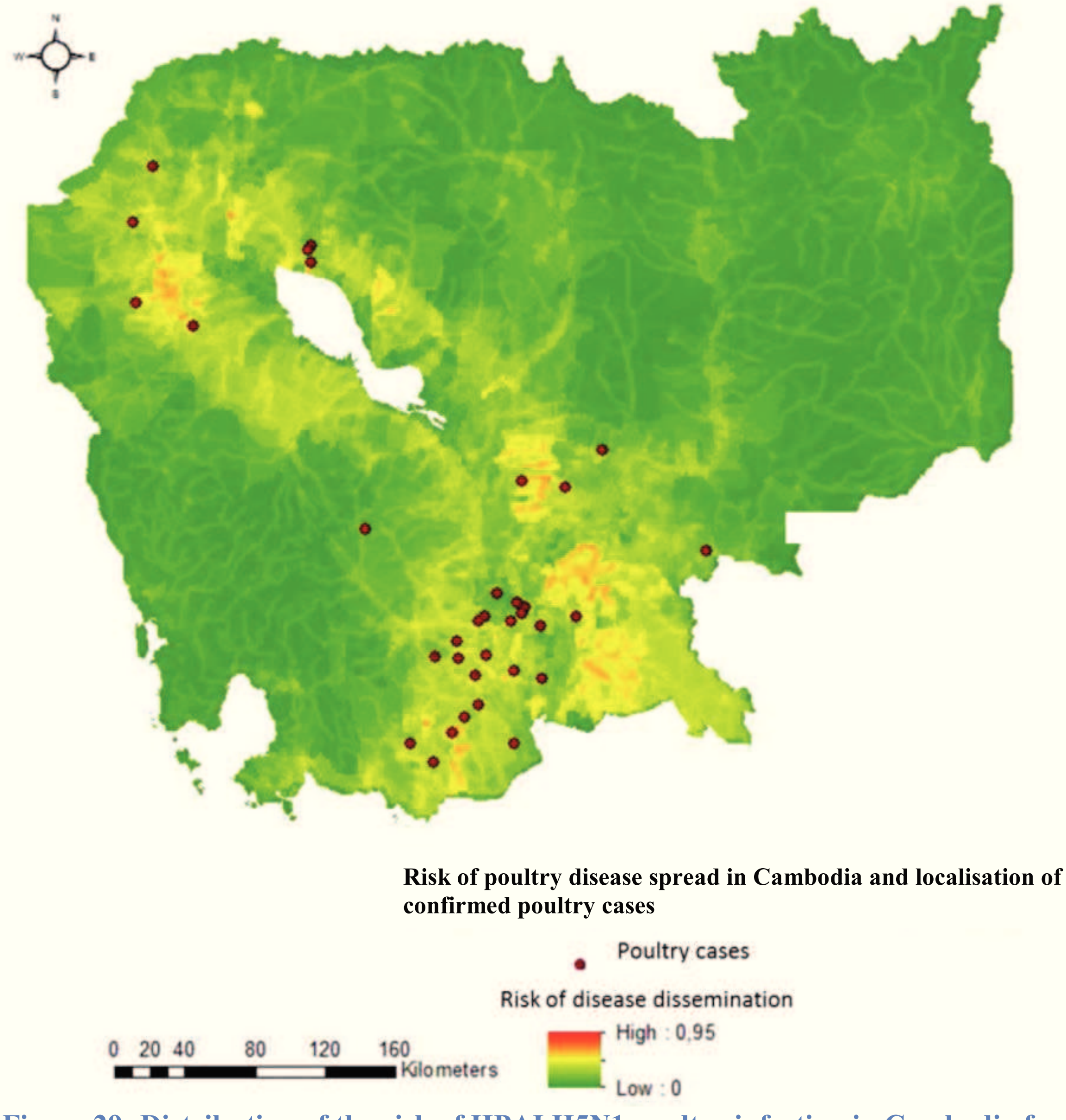



**Figure 29: Distribution of the risk of HPAI H5N1 poultry infection in Cambodia from the use of spatial MCDA with 10 experts in 2014 and the localisation of confirmed poultry cases since 2004.**

## 2.5. Lessons from CIRAD experiences in Cambodia and in Madagascar (Narrative Synthesis)

In this section we present only a summary of the most important results, the full results are presented in the paper (Annex 6).

In this study, we did a systematic review of all the research papers or documents which were published by Cirad researchers on surveillance and control options in Cambodia and in Madagascar. This was done in order to compare the different tools and methods applied in challenging countries to provide recommendations for future research.

### 2.5.1. Systematic review

A total of 148 papers were identified from Scopus and 63 from Google ScholarTM. After exclusion and verification of duplicates, 17 and 5 papers remained respectively. The additional search in the AGRITROP and CIRAD project websites identified 11 other documents. A total of 33 documents were used for this synthesis: 22 research papers, 5 conference proceedings, 4 technical reports and 2 policy briefs.

### 2.5.2. Narrative synthesis: assessing the quality of the tools and methods used

For each method or tool identified by the systematic review, a qualitative assessment of their limitations and advantages was done and summarised.

#### 2.5.2.1. Evaluation methods / tools

From the review, three types of approaches for the evaluation of surveillance systems were identified: participatory evaluation, the use of capture-recapture (CR) method (for the estimation of Se) and the use of economic evaluation (especially cost-effectiveness). Their main limitations were the lack of sustainability and representativeness for the participatory approaches and the lack of simplicity for the CR and the economical methods. On the other hand, their main advantages were the feeling of ownership on behalf of the stakeholders when using participatory approaches, the flexibility of the CR method and the usefulness, for systems, of having economic data.

#### 2.5.2.2. Design approaches

Different types of design were tested. First we identified methods or tools to better design risk-based surveillance: field surveys and epidemiological studies that had the advantages of being sensitive and flexible methods, and contact network analysis which could be a more specific tool. The main limitations for these tools were their complexity (especially for contact networks) and their lack of representativeness.

The review also identified methods or tools to design One Health surveillance, such as multi-species field surveys, or the use of syndromic surveillance. These methods were characterised by good flexibility (being able to be adapted to different contexts) and good sensitivity, but suffered from structural disadvantages such as a lack of sustainability (when combining different sectors) and a difficulty to be truly representative of the different populations.

Lastly, some methods and tools were also tested to improve passive surveillance: the use of participatory surveillance, the inclusion of non-conventional systems (private, informal) in the surveillance, specific training of VAHW and the use of mobile phones. The main advantages of these methods were the increase of ownership on behalf of the stakeholders, the increase of timeliness in the reporting system (with mobile phone reporting) and the possibility to increase sustainability by relying on informal networks. The disadvantages were a lack of specificity for the participatory approaches or informal networks, the lack of sensitivity of a system based on VAHW and the lack of sustainability of mobile phone reporting.

# PART 5
# DISCUSSION AND RECOMMENDATIONS

In the Part 5, we summarise the main results of our research work and discuss the main limitations and challenges experienced during the implementation of the field studies. Our main objective was to test and propose innovative methods to increase the involvement of rural communities in the reporting of zoonotic diseases and to improve the effectiveness of surveillance networks in human and animal health systems. We decided to focus our work on the HPAI H5N1 surveillance system in Cambodia (with the exception of one study implemented in Thailand), and to limit the tools or methods to be used. In the first part, we summarise the main results of each study presented in the previous chapters. Then, we discuss the main methodological limitations that we encountered in the field: the specific aspects and challenges of research in developing countries and the political context that may have interfered with our project. We also review the limitations regarding the quality of our data. Next, we try to place our work within the perspective of a One Health approach, explaining the advantage of such an approach, the situation in Cambodia and the challenges related to its implementation.

Finally, we look at each method or tool used within our research work, to provide a critical assessment of which actions are effective and what remains to be developed, and to attempt to provide practical recommendations for the Cambodian context.

# 1. Essential findings of the different research studies

## 1.1. Surveillance systems evaluation methods

### 1.1.1. Main outcomes of the evaluation of HPAI H5N1 surveillance in Cambodia

HPAI H5N1 is currently considered endemic in the poultry population of Cambodia, with the presence of a new virus clade (1.1A) found only in this country (Sorn *et al.*, 2013). Outbreaks occur yearly in poultry with sporadic spill-over into the human population. In many cases, the detection of the disease comes first from the human compartment, which in turn triggers investigations within the poultry population.

Both surveillance systems rely on an extensive network of volunteers at village level, VAHW for the veterinary sector and VHW (or VHSG members) for the public health sector. These volunteers are not paid by the government, but in the public health sector the majority of VHW receive incentives from NGOs to conduct their activities, in contrast to VAHW who have to generate their own income, putting them in more precarious situations. The efficacy of disease detection depends on the quality of the relationship that exists between the volunteer and the patient (or the farmer). In both systems, this link is tenuous. In public health, as highlighted during our interviews and in the literature review, patients generally mistrusted the public sector, preferring to first seek help from the private (55.5% of the patients for the first consultation) or non-medical sector (6% of the patients) (NIS, DGH et ICF Macro, 2011). As the private sector is not included in the surveillance system, this often delays the detection time (on average 9.6 days between the onset of the symptoms and the detection of the virus see Annex 12) which results in a high mortality rate. In the animal surveillance system, the control option applied by the government, i.e. slaughtering of all poultry present in the village without compensation, is feared by the farmers and the VAHW. Therefore, for the vast majority of the persons interviewed, the first strategy is to manage the outbreak locally. Some farmers use virucidal disinfectant (most often TH4+ which is a synergistic combination of glutaraldehyde and quarternary ammonium compounds) themselves, or sometimes with the help of the local veterinary service when there is a relation of trust between them. But often farmers prefer to sell their animals to other villages to spare themselves the economic loss from culling.

Another parallel between the human and veterinary surveillance systems is the presence of active components funded by external donors (live bird markets or duck farm sentinels;

febrile syndromic surveillance of humans). These components are often more sensitive in detecting virus circulation. In live bird markets, the virus is regularly detected in animals or in environmental samples (18% of the samples being positive with 2% of virus isolation (Horm *et al.*, 2013) but no actions are taken and it is not possible to trace back the origin of the animals. In humans, this active surveillance allowed the detection of 4 human cases (see Annex 12) but the actual coverage of the population is very low. Even if active surveillance methods have successfully demonstrated the presence of an active virus, they are too expensive to be maintained by the national authorities, especially with the current decline in regular funding.

Finally, one common weakness highlighted in this work was the lack of a regular internal evaluation strategy. Both systems have been assessed but only partially and as a small component of the general health services. An evaluation mission conducted by the OIE was implemented in July 2007 using the PVS instrument. The objective of this evaluation was to assess the strengths of the veterinary services and their ability to meet OIE standards (Hamilton et Brückner, 2010). This evaluation was followed by a gap analysis mission in January 2011 (Weaver *et al.*, 2011) but very few elements of this evaluation targeted HPAI H5N1 surveillance. Since then, and at the time of writing, no provision has been made for a systematic evaluation of the animal surveillance system.

For the public health sector, an overall evaluation was conducted in October 2006, by the MoH. The ministry convened several agents and stakeholders involved in the health system for three days, and asked them to complete questionnaires. The results revealed a system that had no incentive mechanism, no evaluation of the completeness or consistency of field reporting and with only 50% of the epidemics being recorded at district level. Subsequently, a second workshop was organised in 2008 to produce a strategic plan for the Health Information System (Department of planning and health information, 2008). The main objective was to define and use evaluation indicators for 2015. At the time of study this had not yet been implemented.

### 1.1.2. Quantitative evaluation methods for surveillance in backyard poultry production in Thailand

In this study, we assessed the sensitivity of complementary components of the HPAI H5N1 surveillance in the backyard poultry population in Thailand.

We applied scenario tree modelling method in a challenging environment, compensating for the lack of sufficient data by the use of expert opinion (Martin *et al.*, 2007). The method allowed us to quantify, in a transparent and structured manner, the Se of the passive component, using simulation to detect important input parameters that could have an impact on the estimate such as the probability that poultry farm owners will notify the disease to the veterinary health authorities. When we compared the three components within the risk-based design, we showed that the SSC2 and SSC1 had similar values with a mean Se of 0.49 and 0.50, respectively, and that the SSC3 had the lowest Se with a mean value of 0.25. It would appear that even as the farm Se of the SSC3 is the highest, with a mean value of 0.79 for chicken and mixed farms (compared with 0.79 for SSC2 and 0.33 for SSC1), and 0.99 for free-grazing duck farms (compared with 0.004 for SSC1), the actual difference was due to the fact that SSC2 had a population coverage 10 times greater than SSC3 with the addition of risk-based SSC2 being 3.24 times (see Annex 2) more sensitive than a representative sampling, and that SSC1 covered the entire population of farms.

SSC1's high Se might seem surprising but is doubtless the consequence of a very intensive awareness campaign undertaken by the Thai government and of the presence of VHH and LDV in every village. We are aware that this estimation remains subjective and that it should be reassessed as it is likely to change over time if the country remains free of disease (Hadorn et Stärk, 2008b).

### 1.1.3. Development of an evaluation grid for VAHW

We developed our own participatory method to collect information on the VAHW context and to build a criteria grid for their evaluation. In this framework, several participatory approaches were used such as problem trees, semi-structured interviews, pair-wise ranking and focus groups. The grid was designed with the help of relevant stakeholders involved in the animal health system in Cambodia in order to (i) identify VAHW functions; (ii) set up criteria and associated questionnaires, and (iii) score the grid with all the stakeholders. The tool was divided into five evaluation criteria: sustainability, treatment, production, vaccination and disease reporting. Our approach considered local indicators of success developed and used by VAHW themselves, which should lead to an enhanced acceptability of evaluation. This method emphasised discussion, aiming to engage decision makers and other stakeholders in a mutual learning process and could be applied to develop trust between health workers and official service representatives as well as to foster corrective actions after evaluation.

## 1.2. Design options and recommendations

### 1.2.1. Identification of factors improving the VAHW network

In the population studied, 23% of the villages were found to be without any VAHW. According to our scoring system, 23.6% of the VAHW interviewed were in a situation of inactivity. Disease diagnosis and treatment of the major diseases was the part of the assessment with the poorest score. The mandatory notification of diseases was not well understood by the majority of the VAHWs

From our multivariable analysis, several factors were identified as being significantly associated with a high score in the evaluation. Strong relationships existed between a good evaluation score and the fact that regular meetings were organised between the district veterinarian and the VAHWs. The working environment of the VAHW also seemed to be connected to a good score with the number of cattle present in the village (the more cattle, the higher the score) and the fact of being part of a VAHW association (factor associated with a higher score). Other factors linked with the training organisation were also related, such as the presence of refresher courses, the use of practical work during the initial training or the duration of the training (higher score if the training lasted at least 30 days).

### 1.2.2. Feasibility of SMS surveillance reporting in Cambodia

Throughout the 13 weeks of implementation, the VAHW participation rate decreased steadily from 98.28% to 13% (last month). The same trend was apparent in the participation rate of Village Chiefs with a greater rate of error (18.93%) and of aberrant values (5%) within their text messages. This waning of interest occurred even when there had been a visit with a group discussion two months after the start of the pilot study and despite the fact that, during this field visit, 98% of the participants expressed their willingness to continue the pilot study.

None of the SMS reports was followed by a visit from the Veterinary services, and only 17 participants received a phone call from the central services in order to check the validity of their text messages and of the clinical signs that were observed.

The distribution of the weekly mortality rates in pigs, ducks and chickens were estimated and the 95$^{th}$ percentile were calculated in order to help the veterinary services to identify abnormal mortality rates. The following thresholds were estimated: 20% weekly mortality for pigs, 3.6% for ducks and 13.7% for chickens.

## 1.2.3. Use of GIS for designing risk-based surveillance

### 1.2.3.1. Estimating the extent of HPAI H5N1 outbreaks and the local factors influencing transmission in Cambodia

Two outbreak sites were investigated following the confirmation of HPAI H5N1 outbreaks in poultry or in humans. We used a case definition based on clinical signs to look for additional cases around the village which was first declared infected. In the first investigation in Takeo, out of 209 villages surveyed, 115 villages were found to be positive within our case definition; in the second site of investigation, in Prey Veng, out of 229 villages surveyed, 39 were found to be positive. These results showed that between 55% and 17% of the villages were not declaring suspicions of HPAI H5N1 in their flocks respectively.

Using spatial analysis, we were able to detect the index cases and to calculate the time lag between the first suspicion and the first case reported to the authorities (83-87 days), and the possible duration of the outbreaks (between 2.5 and 4 months). The spatial distribution of the cases for Takeo appeared to show a correlation between the spread of the disease and the presence of main roads. Duck density and presence of rice paddy fields were strongly associated with the suspicion of HPAI H5N1 in the villages.

### 1.2.3.2. Risk mapping using spatial MCDA

Risk maps are usually produced from the spatial analysis of confirmed cases and their correlation with existing factors. In the case of Cambodia, the number of poultry cases (and certainly the number of human cases) is under-estimated due to the weak performance of the surveillance system. Despite this shortcoming, spatial MCDA allowed us to produce maps indicating the risk of HPAI H5N1 spreading in the poultry population and the risk of human infection with HPAI H5N1.

In our model, the risk factors having the higher weight for the risk of human infection were the presence of previous poultry outbreaks in the vicinity and the density of free-grazing ducks. However, it is interesting to observe that even though the population's poverty rate was estimated to be high by experts, the high-risk areas of infection were not correlated with the areas including the poorest populations. This could be certainly explained by the low density of free-grazing ducks in these areas, thus decreasing the risk of infection.

#### 1.2.4. Outlining general recommendations for developing countries

A total of 33 documents were retrieved from the systematic review of the research on surveillance done by CIRAD in Madagascar and Cambodia, and included in the narrative synthesis. The main limitations of tools or methods implemented or described within the papers were the lack of representativeness, specificity, sustainability and simplicity. The main advantages were the sensitivity, the ownership, the usefulness and the flexibility. To overcome extensive deficiencies in surveillance systems, diverse methods or tools were tested with varying degrees of success. Some of these methods (e.g., participatory surveillance) confirmed their effectiveness in practice in both countries and could be replicated in other settings. Other methods showed potential for success (e.g., SMS data transmission) but will require certain modifications or adaptations to be truly effective in such settings. This could be achieved through dialogue and sharing of experiences among researchers working in different countries and settings. Finally, some methods such as syndromic surveillance were judged to be too complex to be implemented, highlighting the need to develop new approaches tailored to resource-poor situations.

# 2. Methodological limitations

## 2.1. The economic and policy environment

### 2.1.1. Context of developing countries

Even though there is no established convention for the designation of "developed" and "developing" countries or areas in the United Nations system, the World Bank (2013) specified that developing countries are defined according to their Gross National Income (GNI) per capita per year. Countries with a GNI of US$ 11,905 and less are defined as "developing". If we compare with factors that define a developed country, developing countries host “people with a lower life expectancy; people with less education; people with less money (income)". According to these definitions, Cambodia and Thailand are developing countries and Cambodia is a low-income economy in the World Bank classification whilst Thailand is an upper-middle-income economy (http://data.worldbank.org/about/country-and-lending-groups#Low_income). In these socio-economic contexts, which are overwhelmingly rural, formal and informal information regarding infectious diseases are often less available, less reachable and poorly transmissible from the field to the official services. Indeed, in numerous developing countries, surveillance systems suffer from chronic under-budgeting or are foreign-project dependent, and this leads to a diminished field presence (Zepeda, 2011).

### 2.1.2. Political context and evaluation readiness

Evaluations of surveillance systems are essential to ensure that the system is working properly, provides relevant information and is sustainable. The main objective is an overall improvement of the system and evaluation can trigger changes in policy making, management, or implementation strategies. Nevertheless, when facing program evaluation, stakeholders may often react in a defensive manner. This resistance to evaluation is well documented (Smith, 2002). When evaluating a system, staff may believe that we are assessing their individual performance and may feel criticized. Moreover, evaluation may have negative consequences for the country or the organisation, such as the loss of potential funding or trade impacts. When we started our research work in Cambodia and in Thailand, the word "evaluation" was impossible for us to use without an adverse reaction from our partners. We had to talk about assessment or appraisal. This resistance to our work occurred throughout the project, and might have created a bias in the way people responded in several of the interviews that were implemented.

Due to the potential consequences of declaring an outbreak or a new epidemic, farmers, medical staff and policy-makers are frequently reluctant to communicate on health events: famers because of potential decisions regarding culling without incentive, rumours and social concerns; governments because of fear of political embarrassment, economic, touristic or trade repercussions, or concern that it may make the government look ineffectual (Morse, 2007). However, new forces at work in an electronically inter-connected world are beginning to break down the traditional unwillingness of countries to report diseases (Heymann et Rodier, 2001).

During the two outbreaks of 2010 that we investigated, our intention was to collect blood samples and swabs from ducks in villages that met our selection criteria, to validate our case definition. The first sample we took from Ponk Tuek village in the Bourei Cholsar district was found to be positive by PCR on 17/02. From this point on, the MAFF did not allow us to take further samples in more villages as they could not afford more villages to be declared to the OIE and therefore more poultry to be slaughtered. They had already culled thousands of poultry without any compensation and were implementing movement restrictions and awareness campaigns. It was detrimental for their image and worse for their relationship with farmers. They justified their position by explaining that it was part of the same outbreak, so it was not necessary to detect all the cases and even less so to report them.

## 2.2. Specific limitations of our data

### 2.2.1. Data availability

In our studies, the main constraint that we faced during the first evaluation phase was the access to surveillance data, especially from the MoH. Face-to-face meetings with the persons in charge of data management and data analysis were possible but not the direct access to data, which were considered as sensitive data by the government. For the MAFF, access to surveillance data was facilitated by my position as an "external evaluator" contracted by the FAO, which was the main donor for veterinary and agricultural research projects in Cambodia. But access to data was made difficult due to the lack of standardisation at central level. Data from different sources are reported in an isolated manner with no common identifier; moreover, a great deal of information is paper-based and written in Khmer. Surveillance activities are described in a fragmented manner, in fact there was no official document either for the MAFF or the MoH describing, in detail, the whole organisation of the HPAI H5N1 surveillance systems, the roles and duties of actors, the different components of surveillance, the connections between the different stakeholders (government staff, volunteers, private sectors, NGOs, international organisations) and the regulations they have to follow. Moreover, at the time of the evaluation, only a first draft on animal health laws was still under revision by the Ministry of Agriculture of Cambodia in collaboration with members of international organisations.

We experienced the same constraints in Thailand with no direct access allowed by the DLD and with most of the documents available being in Thai. One difficulty was to obtain the latest accurate description of the Thai surveillance system, as the surveillance system was continuously adapted to new constraints and was thus very dynamic. The definition of high-

risk areas was challenging. When doing field interviews, we detected discrepancies between what was described in official documents and what was really done at local level.
Another limitation was limited availability of baseline data such as livestock numbers and density. Census data were only available at district level and were not regularly updated. Maps of poultry density were extrapolated on the basis of human population density. In order to obtain more accurate data, we implemented a survey between September and October 2010. A questionnaire about the number of chickens, ducks, free-grazing duck farms and semi-commercial chicken farms was distributed during a monthly meeting in Phnom Penh to every provincial veterinarian. We managed to collect the census data for 1,521 communes out of 1,623, and to produce the maps that are shown in Annex 11. The database was handed over to the veterinary services.

## 2.3. Data quality

### 2.3.1. Representativeness

Because of financial and logistical constraints, we had to limit the size and the representativeness of the group of people that were interviewed in the different studies. It is therefore possible that we did not capture the opinions of all relevant actors.
When using the SNAT Trop tool, the choice of who to include in the interviews remained with the coordinator or the persons in charge of the surveillance system. This choice may have been biased, with the selection of people more involved in the surveillance or with a more positive attitude. For the public health sector, unfortunately, it was not possible to spend enough time visiting VHW and staff from health centres. We managed to interview 4 VHW and 2 HC (in Kampong Cham and in Takeo). Our study population was mainly composed of agents from the central level or members of NGOs.
Because participatory methods are more time-consuming than conventional processes, we involved VAHW from only two districts of two provinces when we developed our evaluation grid. Moreover, as no complete list was available of VAHW in the target areas with their accurate status (active or inactive) at the time of the study, the selection process may have induced a lack of representativeness and so may have had an influence on the accuracy of the tool.
In the survey evaluating the efficiency of VAHW in Cambodia, the selection of the provinces was made by the FAO (project sponsor) based on the past occurrence of HPAI H5N1 and on the fact that they shared borders with Vietnam. These provinces were heavily supported by

different projects by international organisations and hosted a great number of NGOs working on animal health. This may have influenced our results, with an overestimation of the number of VAHW still active and their scores.

### 2.3.2. Validity

The validity of data can be defined as the degree to which the estimated value reflects the true value of the variable in the reference population that it is intended to measure. In our work, the validity of our data was a significant challenge.

In scenario tree modelling, the estimation of relative risks is often a challenging task (FAO, 2014b). In the study in Thailand, relative risks were estimated from data of the outbreaks observed, and thus may have been influenced by the under-reporting that might have occurred in Thailand, especially at the beginning of the epidemic in 2004 (Kanamori et Jimba, 2007), interfering with our results.

The data that we used in the spatial MCDA model were also a source of uncertainty in our results. Indeed, one of the principles of the analytic hierarchy process is to weight the risk factors by classifying them against each other, using the scale of Saatay (Chen *et al.*, 2013). But this step can introduce subjectivity, as it can be difficult to compare risk factors two by two by placing them on a scale. In fact, the calculation of the consistency ratio is supposed to help to identify errors of judgment; if the ratio obtained for a matrix is greater than 0.2, it should be reconsidered (Hahn, 2003). However, because of time considerations, it was not possible to ask experts who obtained a consistency ratio that was too low for a new comparison matrix. So we decided to attribute less weight to them at the time of aggregation, but this may have induced bias. Secondly, the quality of such a model depends on the quality of the data used to build it. For example, the poverty rate used for mapping the risk of human infection is an estimate for 2009 made from a statistical model (HMIS, 2012). In addition, some factors such as risk behaviours (Paul *et al.*, 2013) are difficult to represent geographically. To address this issue, we used the proportion of people without communication access as a proxy for the exposure of people to awareness messages and therefore the exposure to risky behaviours. This option can be arguable.

In our pilot study on SMS reporting, our main constraint was the validity of the information contained in the SMS. It was impossible to verify all mortality rates with a field visit, only extreme mortality rates were double checked by phone calls from the NaVRI. However, the data sent from the VAHW over the 13 weeks were consistent with those sent by the VC (the

VAHWs had the tendency of reporting a slightly higher mortality rate). The weekly mean mortality rate of 2.8% [0-35%] was consistent with previous studies done by the NaVRI in Cambodia.
Another source of information bias may have been introduced during the fourth technical workshop conducted in the process of developing our evaluation grid. During this workshop, representatives from all the sectors were present. From our interviews it appeared that VAHW felt they were poorly understood by decision makers and had conflicting interests. Then, during the workshop, some of them may have been somewhat reluctant to provide information when confronted with persons associated with government authorities. These biases were certainly limited thanks to the previous meetings that were organised with only the VAHW. Biases may also have been introduced due to the translation process, affecting the understanding of stakeholders despite the efforts of the research team.

## 2.4. The One Health challenge: complexity to work across sector

In countries where HPAI H5N1 is endemic, and where occasional human cases occur, the early detection of outbreaks often comes from human reporting (Scoones et Forster, 2008). Although it is a well-known fact that the early monitoring of virus circulation is crucial in both sectors to prevent the emergence of future pandemic strains, it is not uncommon for the virus to circulate in the poultry component over an extended period of time before detection. In order to strengthen efforts undertaken for the prevention, detection and control of zoonotic diseases, such as HPAI H5N1, a novel, more system-based approach is currently advocated by international organisations, the "One Health" (OH) approach (One Health Commission, 2014). This refers to a holistic approach promoting inter-sectoral and multidisciplinary actions, in order to improve the cooperation between animal, public and environmental health, and enhance their capacity to deal with complex problems. Numerous actions labelled "One Health" are being developed worldwide and especially in developing countries, with a high concentration in Asia (Gongal, 2013).
Surveillance of zoonotic diseases should be enhanced by OH principles. This could be achieved by systematic and integrated observations of disease events in both sectors and by shared analyses and dissemination of results to guide interventions to control diseases in humans and animals (Karimuribo *et al.*, 2012). Linking human and animal health surveillance data can offer a number of advantages (Rabinowit *et al.*, 2010; Wendt *et al.*, 2014): i) animals

can serve as sentinels to prevent human cases; ii) predictive models in humans can be developed from animal data; iii) the magnitude and the spread of the disease can be assessed using both sets of information; iv) and human data can help to identify gaps in animal disease control and reporting systems. In developing countries this cooperation would contribute to economies of scale in both sectors. Yet, despite these potential benefits, surveillance data from human and animal systems are still rarely combined.

The Cambodian government, under the pressure of international agencies (FAO, WHO) organised the development of joint committees between the MoH and the MAFF. In 2006, a Cambodia National Comprehensive Avian and Human Influenza Plan was prepared jointly to combine plans for animal health, human health, communication and inter-ministerial cooperation. In 2007, three task forces were set up under the responsibility of the MoH and the MAFF with the financial support of FAO, WHO and UNICEF: (1) Investigation; (2) Information; (3) Culling and disposal.

For national policy decisions regarding implementation of the National Comprehensive Avian and Human Influenza Plan, Cambodia established the Inter-ministerial Committee for the Control and Prevention of Avian Influenza, composed of the following members: MAFF (chair), MoH (vice chair), Ministry of Commerce (vice chair), Ministry of Interior (vice chair), Council of Ministers, Ministry of Finance and Economics, Customs Department Provincial, Municipal Governors and DAHP. However, competition for resources among ministries was an ongoing issue, with MoH blaming the MAFF for not detecting animal cases before human fatalities occurred (Ear, 2009). The HPAI H5N1 crisis did improve the communication between the different Ministries, but this was achieved under the monetary perfusion of external donors and has not yet been institutionalized. The government remains uncommitted to engagement in joint planning or budgeting (Ear, 2011a).

At operational level, there remains little collaboration. The information collected from the two hotlines (MoH and DAHP) is shared between the CDC and the DAHP by SMS or direct phone calls. When an outbreak occurs, response teams from both ministries are sent to the infected area and work closely to determine the public health risk. However, there is no local mechanism to improve the collaboration between VHW and VAHW.

In this research, one of my primary objectives was to implement tools or methods that could be shared between both sectors. The purpose was to propose methods for the joint evaluation of surveillance in order to identify critical points and to propose collective actions targeting the improvement of performance. In the time frame of this research and in view of the difficulties I faced in gaining access to human surveillance data, only a partial evaluation was completed and few recommendations have been developed.

# 3. Appraisal of the tools: what's working and what's not

## 3.1. Evaluation methods and tools

### 3.1.1. Qualitative methods

The first specific objective of this work was to use qualitative and semi-quantitative methods to jointly evaluate the human and animal surveillance of HPAI H5N1 in Cambodia and to review their feasibility in our context.

Several institutions have developed guides for conducting evaluations of surveillance systems. From a systematic review that we performed within the framework of the RISKSUR project (EU FP7 project: http://www.fp7-risksur.eu/), we found that 15 different guidelines are used (10 from the public health sector; 3 from the animal health sector, 1 from the environmental health sector and 1 covering animal and public health sectors). Most of these guides highlight four common stages in the evaluation process: *(i)* defining the surveillance system under evaluation, *(ii)* designing the evaluation process, *(iii)* implementing the evaluation, and *(iv)* drawing conclusions and recommendations. However, even if some of these guides provided information on which attribute to assess, only one provided detailed methods and a ready to use tool to perform this assessment: the OASIS tool (Hendrikx *et al.*, 2011). This was the main reason why we selected SNAT Trop which is the modified English version of OASIS (Peyre *et al.*, 2011).

This tool is easy to understand and use. It can be used by either the coordinator alone, for an internal evaluation, or with the participation of external evaluators for a more in-depth evaluation. The tool provides easy-to-read outputs, and gives an overview of the main weaknesses and strengths of the surveillance system. In the new version that we applied, evaluators can identify the priority corrective actions which they must implement if they want to improve their system. A few comments should be made on the tool itself and the outputs. Firstly, in SNAT Trop the weight attributed to each section is the same as the one used in

OASIS. This weighting scale originated from an expert elicitation workshop organised in Europe and represents a form of “gold standard” of surveillance systems, which may be far from the situation in developing countries. Another important point is the score provided in the outputs. This could be misleading and should be used more as a way of ranking the different sections and not as a quantitative value. At the time of implementation, the module on economic considerations (e.g. sustainability of the system, allocation of funds) had not yet been developed, but it is now available in the new version (Faverjon, 2011).

Although this tool was developed to evaluate surveillance systems in animal populations, it could easily be adapted to the human surveillance systems. This adaptation was not conducted within the framework of this research work due to a lack of time, but it could be undertaken within the foreseeable future.

The SWOT analysis was selected for its simplicity and the fact that it is easy to use. This method is usually implemented in a participatory manner, according to which groups of informants are brought together to discuss and identify the different factors influencing the performance of a system. In our work, the SWOT analysis was carried out retrospectively, after having interviewed the different stakeholders involved in both surveillance systems. The final results were presented during a workshop with the different representatives of the HPAI H5N1 surveillance system in Cambodia, discussed and validated before appearing in the official report for the FAO.

The SWOT method is simple and easily understood by different stakeholders. It is flexible and can be applied to different types of organisations. This method is best used in a participatory way, to promote the exchange of information, better communication and the development of a joint consensual view of the situation. However, the method is subjective. The adequacy and effectiveness of the tool depends on the capacity of the contributors to be as objective as possible in the way they represent reality.

This method could be included as an evaluation tool within the surveillance system, to enhance cohesion and the feeling of ownership by the different stakeholders.

### 3.1.2. Quantitative methods

Our second specific objective was to evaluate the feasibility to use scenario-tree modelling methods in resource-scarce environments, by evaluating the HPAI H5N1 surveillance system in backyard poultry populations in Thailand. During this study, we managed to evaluate the different components of the surveillance system, and especially that of passive surveillance.

The scenario tree approach was originally conceived to help developing countries with the process of disease freedom declaration, which was the case of Thailand at the time of implementation. Furthermore, the approach is more suitable to evaluate the sensitivity of risk-based surveillance. In our experience, the main difficulties of the method were first the complexity of the concept in relation to statistical data analysis and modelling. The implementation of the method still needs the evaluator to possess prior knowledge on probabilities and distributions even if a new methodological guide was recently produced by FAO (FAO, 2014b) to make the process more accessible. Another limitation of the method is the need to have some prior knowledge on risk factors, to be able to quantify their impact on disease distribution and also to be able to quantify factors that could influence the detection process (such as the probability that farmers will declare a suspected animal case). Often, such data are not available and when they are, we need to elicit expert opinions to estimate their value.

During this research, we managed to collect enough data to estimate the distribution of key parameters such as the probability of chicken farmers reporting an outbreak to DLD officers or the value of relative risk attributed to high-risk areas. We were therefore able to demonstrate the usefulness of scenario-tree modelling to demonstrate disease freedom in countries with non-conventional surveillance systems.

Another objective, however, was to implement the same tool to evaluate the HPAI H5N1 surveillance system in Cambodia. The initial context was different, with disease being endemic in the animal population. We attempted to implement the method for the evaluation of the CAM EWARN component and the event-based surveillance in human populations. We managed to describe the components through a scenario tree with a combination of infection, detection and category nodes. Some parameters were available as the percentage of monthly reports submitted by the health centres or the referral hospital, an estimation of the sensitivity of the case definition used by the clinicians in the field, the probability of medical consultation or the catchment areas of an operational district (see abstract of the oral presentation done during the ISVEE conference in Maastricht 2012 in Annex 13). But data for the probability of detection by the different actors of surveillance did not allow for an estimation. We therefore used the probability that a suspected case would be referred to the provincial hospital as a proxy. However, this value was estimated from a panel of experts that was too small to be valid. In conclusion, the scenario-tree modelling was less adapted to the Cambodia situation for the evaluation of the surveillance system.

### 3.1.3. Participatory evaluation

In this study, the objective was to develop a participatory method for evaluation in order to demonstrate the value of participation in the process of surveillance evaluation.

VAHWs in Cambodia are the cornerstone of passive surveillance. A total of 12,000 have been trained, but no systematic evaluation of their capacity and performance has ever been done (Burgos *et al.*, 2008). In fact, no specific method for their evaluation was planned by the organisations responsible for their training, besides the observation and reporting of their activities by the district veterinarian responsible for their village. We decided to use participatory evaluation in order to achieve a better acceptability of the evaluation process by the VAHW. This method leads to stakeholder empowerment in the process, which could improve the sustainability of health interventions (Lahai, 2009). The method helped stakeholders to form judgments by describing the system, identifying the criteria and giving value to these criteria. The process enabled key decision makers, funders and program beneficiaries to be in the same room, giving them the rare opportunity of exchanging points of view. The development of our evaluation tool presents certain limitations. Indeed, the different steps were time consuming but they are essential to avoid the potential influence of some stakeholders (such as government representatives) on the opinions of the VAHW at the beginning of the process. Our method of evaluation provides more than just a description of the current situation; it leads to quantitative scores. It can be used to identify the strengths and weaknesses of the system, to propose better refresher training courses and estimate the survival rate of VAHW after training. However, our tool could be improved by including economic criteria in the evaluation, focusing on economic viability and financial sustainability (Riviere-Cinnamond, 2005). A full impact assessment would be useful to evaluate the cost-benefit of such a system at community level but also at national level.

One option for future research would be to adapt the criteria grid to the VHW evaluation. The preparatory phase of this step was already initiated by us through the different contacts made with the various NGOs involved in VHW training. From these interviews, we could describe, in detail, their roles and responsibilities, the compensation framework and the organisation of the management structures and supervision.

## 3.2. Design options

### 3.2.1. Appraisal of VAHW network

In this section, our first objective was to validate our criteria grid with a practical field survey. Before the field survey, we organised the training of the three research assistants, one per province, who were hired to implement the evaluation grid. A brief guideline was produced in order to explain the process and how to fill in the criteria grid. The use of the grid was found to be simple and easy. For each VAHW, the objective was to have a face-to-face interview with 10 farmers of his village (customer or not of the VAHW), the village chief and the VAHW himself. The interviews of the DV and of the member of the communal council were done by phone. On average, the full evaluation lasted 3 hours, but sometimes two visits to the village were necessary where some of the interviewees were absent on the day of the visit. The criteria grid provided valuable information on the percentage of villages without VAHW, or with inactive VAHW. The scoring highlighted the need to provide more refresher courses on disease diagnosis and treatment and enabled us to identify geographic areas where the VAHW score were the weakest.

The additional questionnaire allowed us to propose recommendations on VAHW training to ensure that the quality of VAHW activities complies with a minimum set of standards. Our findings showed that selecting a VAHW from a village with at least 100 heads of cattle, the use of practical activities during training, training duration longer than 30 days and the organisation of refresher courses were factors that ensured a better score for the VAHW once they were active.

The most important factor was the presence of regular contact between the DV and the VAHW. This point is related to the need of constant networking activities in the surveillance system to ensure that field staffs do not feel isolated. This factor is similar to the fact that VAHW are more efficient when they are a member of an association. In fact, these associations allow VAHW to exchange experiences and knowledge, and assist them in buying medicines. Some of these findings could be used as a prerequisite for continued participation in refresher training activities.

### 3.2.2. Use of mobile phones in surveillance

During this pilot study our objective was to test the feasibility of the use of mobile phone text messages by VAHW to declare village animal mortality.

Many projects and studies are developing mobile phone surveillance networking in public health or veterinary health sectors (Déglise *et al.*, 2012). Most of the research papers describing these projects stressed the advantages of this type of reporting system for developing countries. The approach is low cost, reduces the transmission delays, enhances early warning, enables the health sectors to monitor the trend of diseases and can strengthen local capacities and trust in the relationship between stakeholders (Robertson *et al.* 2010; Soto *et al.*, 2008). This type of reporting technology worked well for itinerant herders and pastoralists in Africa (Vreni *et al.*, 2014). But the use of this technology is not without limitations, especially in resource-poor countries. Even if the method is inexpensive, most of the current projects where it was applied were externally funded, creating a problem of self-sustainability once the projects are over. This emphasises the need for a strong political support. There are also some issues with the accuracy and the consistency of the data sent by mobile phone. Its validation is sometimes difficult, and requires involvement and a strong relationship between the field and the central level. Also, training and education on basic epidemiology remains necessary.

In Cambodia, OD weekly reports are sent via a template text message to the central level with a participation rate of 100%. However, this report is still fed by data sent from HC or RH, using traditional channels of information transmission and with a compliance rate between 87 and 100%. In an official MoH report, it was mentioned that only 50% of the epidemics were being recorded at district level.

In our pilot study with VAHW, the participation rate progressively declined over the 13 weeks of study, starting at 98% to end at a value below 10%. From the second week of the survey, the SMS error rate was below 15%. These results were inconsistent with the group interview that was implemented at the mid-term of the survey, where 96% of VAHW were satisfied and wanted to keep the system of SMS texting. Several factors may have influenced these results. First, the use of text message is unusual in rural areas in Cambodia. Most of the mobile phones handsets do not offer Khmer font, so people prefer to use voice-based communication which is very cheap. In our survey, none of the participants had ever sent an SMS before the training session. In the pilot survey that was implemented at the International Vaccination Center of the Institut Pasteur du Cambodge, the participation rate was high

(71.7%), but the participants were mainly young, urban with a higher level of education and certainly more familiar with sending text messages (Baron *et al.* 2013).

Another important issue was with the utilisation of the FrontlineSMS Software. The system was slow, and could only send or receive one text message after the other, requiring the computer to be switched on all day, which was not the case at the NaVRI office. Even with three trained members of staff, people were often out of the office and the computer was regularly off. This clogged the system, interrupting the sending of the automatic reply to participants and lead to loss of data. To solve this problem, we removed some functionality and introduced specific time slots for sending for each village.

Finally, the level of participation probably reflected the level of VAHW activity, as the SMS pilot study was implemented in the four districts concurrently with the evaluation revealing that 18.7 % of the VAHW were inactive. Moreover, the NaVRI did not have the budget to implement follow-up field missions, thus discouraging VAHWs from reporting. As stressed by Halliday et al. (2012), if the people in the field are not enough trained or are reluctant to report, the use of SMS reporting will not solve the problem of underreporting.

### 3.2.3. Risk based design

In this section, our objectives were to improve our understanding of risk associated with the local spread of zoonotic diseases leading to human infection, in order to produce a risk map for risk-based surveillance design.

The first study included the outbreak investigations done in Takeo and Prey Veng. We used a case definition that was developed from previous studies done in Cambodia (Conan *et al.*, 2010), with a specificity of 76 % and a sensitivity of 62 % for duck flocks and a specificity of 80 % and a sensitivity of 63 % for chicken flocks. Our first objective was to validate these two case definitions by collecting samples from the suspected villages. Unfortunately, after the first confirmed case, it was not possible, due to political issues, to continue sampling, and we had to keep our villages as suspected cases and not confirmed cases.

This will certainly have biased our spatial analysis at local level, and the evaluation of the risk factors associated with a village outbreak. However, the results relative to the presence of rice paddy fields and duck density as risk factors were consistent with the literature (Gilbert et Pfeiffer, 2012b). In view of these limitations, the village prevalence that we found must be considered with caution, and does not reflect the real prevalence of HPAI H5N1 cases in the two provinces at the time of the outbreaks. Nevertheless, all the suspected villages would have been in a situation to report the high level of mortality that was happening in their flocks, but none of them did, which clearly illustrates the lack of reporting by VAHW or local authorities.

Risk-based surveillance is defined as the use of prior information on the health hazard under surveillance (probability of occurrence, magnitude, consequences) to design, plan or interpret surveillance systems (Hoinville *et al.*, 2013b). The principle is to define populations where the risk of disease is the greatest or where the consequences of diseases will be the most critical. This approach requires a good understanding of the local risk factors and of how the disease is distributed spatially but also among the different husbandry sectors (Stärk *et al.*, 2006). Spatio-temporal analysis is the preferred method to determine spatial risk factors and to produce risk maps. But in this type of method, the quality of data is crucial and different data sources may result in conflicting outputs (Zhang *et al.*, 2010). The validity of the confirmed case distribution of disease is essential to be able to evaluate the correlation between potential risk factors and the presence of disease. As seen in the previous section, underreporting of HPAI H5N1 suspicion in Cambodia is very frequent, making the data on disease distribution in the country highly unreliable. In this situation, the spatial MCDA method appeared to be really useful, as its allowed us to produce risk maps without the need to use data on disease distribution in Cambodia.

We managed to produce two risk maps, the risk of HPAI H5N1 infection in humans and dissemination among the poultry population in Cambodia. These maps could be a starting point to define risk-based surveillance in Cambodia. High risk areas could be targeted with specific activities, either with active surveillance (such as sentinel flocks) or with the implementation of participatory surveillance in sentinel villages (Desvaux *et al.*, 2006). The risk map of human infection will need further validation from medical sector experts, with a second round of elicitation, and could be discussed between human health and veterinary sectors.

Other data could be used for the implementation of risk-based surveillance in Cambodia. Surveys at live bird markets have been done, showing a very high level of environmental contamination by the virus (Horm *et al.*, 2013) and identifying some main risk factors associated with virus circulation, such as the high proportion of sellers with surplus poultry (Fournié *et al.*, 2012). These factors could be used for surveillance strategies and also for risk mitigation strategies; resting days, hygiene measures and culling of unsold birds could be a solution to decrease the level of virus circulation at the market. Risk-based surveillance can also be defined according to the period of surveillance during the year. It is known that the anticipation of seasonal holidays (e.g., Khmer New Year) often results in increases in the population density of domestic poultry and in poultry trafficking (Durand *et al.*, 2015). Thus the intensity of surveillance could be modulated according to the month.

The design of risk-based surveillance can also be facilitated by the use of scenario tree analysis (Lowder *et al.*, 2014). Different scenarios of surveillance design, including the different risk factors identify previously, can be modelled, and performance of each scenario can be estimated (sensitivity, predictive value). In addition, the economic efficiency of each scenario can be estimated to propose the most cost-effective design.

## 3.3. New approaches in surveillance

In this last section, the objective of the systematic review was to provide generic recommendations for improving surveillance methods in a context of resource poor settings, by comparing research work done by Cirad in Cambodia and in Madagascar.

The inclusion of different approaches in the surveillance design could help to overcome some of the constraints inherent to developing countries for the surveillance of zoonosis. Risk based surveillance must be advocated, but with a One Health design in which risk factors for human and animal sectors are included and where decisions about planning, execution and budget are made jointly. By sharing and pooling means and human resources, the One Health approach allows a more cost-effective design. According to (Barboza *et al.*, 2013), One Health surveillance allows the coalition of expertise from human and animal surveillance systems, and could increase the detection of HPAI H5N1 cases in humans from 57% to 93% and epizootics from 40% to 53%. However, there is still some research to be done. We need (i) to demonstrate the feasibility of integrating human and animal surveillance for avian influenza and other zoonotic diseases and (ii) to assess the impact of the One Health surveillance. While many people agree that OH adds value compared to traditional single disciplinary and sectoral approaches, there is limited evidence available to demonstrate this added value. Some studies in pastoralist populations in Africa describe the multiple benefits of OH, such as the reduced risk of zoonotic disease emergence, better access to primary health care and an overall improvement of animal and human health (Greter *et al.*, 2014). In fact, there is no clear methodology defined for the quantitative evaluation of OH activities. This shortcoming is currently addressed within the new COST action (European Cooperation in Science and Technology), NEOH (Network for Evaluation of One Health), coordinated by the Royal Veterinary College in London, in which we have been involved since November 2014 (http://www.cost.eu/COST_Actions/TDP/Actions/TD1404 ). Its main objective is to develop a framework to assess the effectiveness and economic efficiency of existing One Health initiatives and to investigate the factors that influence performance.

To overcome the shortcoming of underreporting, the data sources in a low-income economy should be more based on farmers' knowledge, with the use of participatory approaches. These approaches explore community-based information networks and use a range of methods and tools (semi-structured interviews with key informants, scoring and visualising techniques) to enable communities to share their traditional knowledge about the clinical and epidemiological features of local diseases and to understand disease patterns leading to control decisions (Jost *et al.* 2007). Community involvement is a pre-requisite for the sustainability of a surveillance system. Animal owners should feel the direct effects of their participation in the surveillance system. At the end of the day, they should experience an improvement in the health of their animals and an improvement in their livelihood.

New technologies such as mobile phones or personal digital assistants are promising and have already, in many contexts, shown their efficiency. The main problem will be to set up the right incentives to keep stakeholders involved. Beyond individual relationships with farmers involved in outbreaks, routine communication procedures should be established.

Modelling is increasingly used in the field of epidemiology and public health. Besides the use of classical epidemiological modelling, including social network analyses or scenario tree modelling, new methods have been proposed and assessed by Cirad researchers: loop analyses (Collineau *et al.*, 2013) and companion modelling (Etienne, 2011). In 2001, (Barreteau *et al.*, 2001) proposed to jointly use multi-agent systems and role-playing games for purposes of research, training and negotiation support in the field of renewable resource management. The 'companion modelling' (Barreteau *et al.*, 2003) directly involves stakeholders in the design of the agent-based model and simulation. Such participatory approaches allow stakeholders to test their management scenario and facilitate their appropriation of the simulation results. In the domain of surveillance, companion modelling seems promising but still remains to be tested in the field. Comparing experiences from a range of less-developed countries allows new knowledge to be generated, supports development and fuels the debate among scientists and policy-makers on how to improve animal health surveillance

In conclusion, as shown in the Figure 29, we believe that combining the proficiencies of multiple surveillance systems (public health, animal, several strategies and options etc.) can increase the detection rate of diseases.

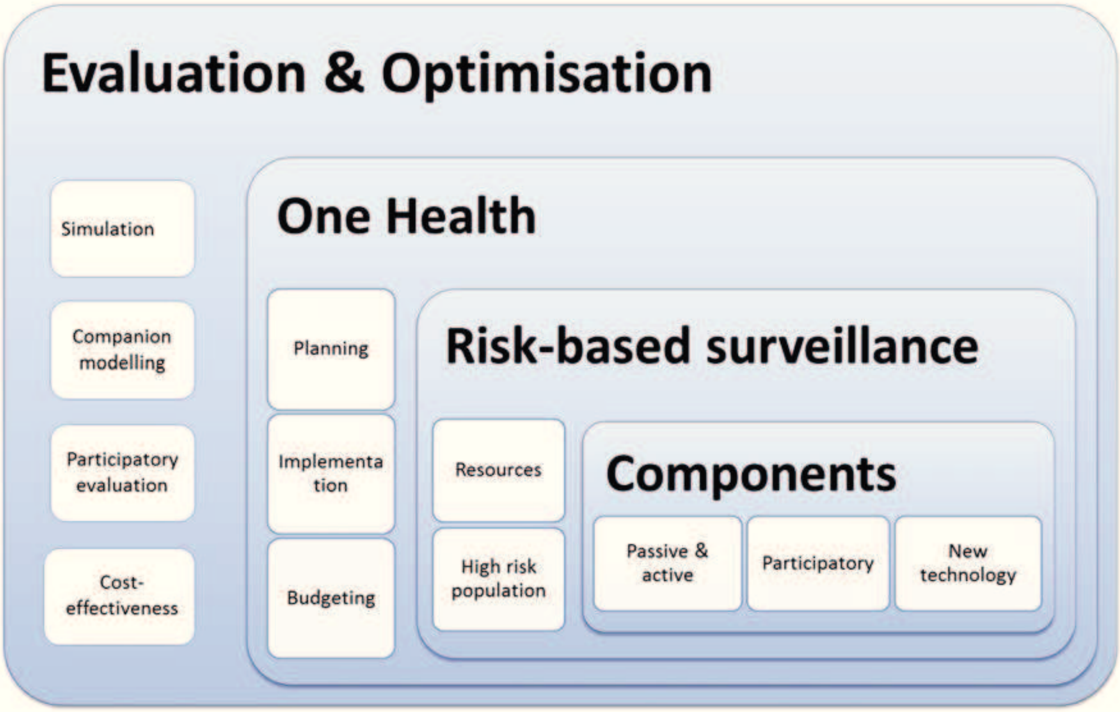



**Figure 30: Essential elements to take into account when designing surveillance systems for zoonotic diseases.**

# PART 6
# CONCLUSION AND PERSPECTIVES

Cambodia is among the top 10 recipients worldwide of Avian Influenza funding with, in 2011 a total of $34 million provisioned for the Cambodia government to fund prevention and preparedness strategies (Ear, 2011b). However, in spite of this effective monetary mobilisation, the resources made available were not enough to mitigate the risk associated with HPAI H5N1. In 2014, Cambodia was still declaring 5 poultry outbreaks, 9 human cases with 4 fatalities. The reasons for this are many, and the responsibilities are shared among the different sectors, the national decision-makers and the international donors. Anyhow, the poor performance of the surveillance systems in poultry may have played a major role in the persistence of the disease within the population.

> *"Following the recent spread of HPAI H5N8 virus in Asia and Europe, the World Organisation for Animal Health (OIE) warns of the need to strengthen surveillance and early detection systems for diseases of domestic and wild animals throughout the world and recommends making this a major objective of official health policies. [...]. The existence of competent, well-organised national Veterinary Services, irrespective of a country's level of development, is a precondition for early detection of animal disease outbreaks and a rapid, transparent response*." (OIE, 2015, Press com).

This statement from OIE confirms the need of robust animal health services as the foundation of efficient surveillance systems, whatever the socio-economic situation of the country. But in an aid-dependent country like Cambodia, where more than half of the national budget comes from foreign aid, official services are still suffering from an undersupply of human and financial resources. In this perspective, besides the compulsory strengthening of the education and training of veterinary staff, including Veterinary Officers, and the support of the national infrastructures, health management in challenging environments needs innovative methods and tools built in close connection with rural populations and stakeholders. The priority should be placed on the use of cost-effective methods and on the integration of disciplines (biology, social and modelling sciences) and sectors (veterinary, medical and environmental).

One of the major issues in surveillance implementation is the existence of conflicting interests between international donors, national officers, and local people. In fact, if we look at the risk associated with HPAI H5N1, the main concerns are fundamentally opposed (Ear, 2011b). Farmers are more concerned about how to preserve their livelihood and health, whereas national decisions-makers are more concerned about maintaining their economic status and international donors about how to mitigate the risk of the emergence of a pandemic strain of HPAI H5N1. Unfortunately in developing countries, the interests of the poorest are often ignored, seriously undermining the basic quality of life of this part of the population. Moreover, the real (economic losses in cases of culling) or assumed (losses in social influences) penalties following disease suspicion at grass root level often discourage farmers from reporting. We therefore propose to shift from a top-down approach, in which no consultation processes are used, to more participatory approaches. This process should enable discussion, communication, negotiation, knowledge sharing and should provide a strong basis for the common identification of socially acceptable solutions. Participatory surveillance could definitely complement a surveillance system by filling the gaps which should be identified by a well-organised evaluation process.

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# ANNEX 1

# Evaluation of surveillance systems in animal health: the need to adapt the tools to the contexts of developing countries, results from a regional workshop in South East Asia.

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**Keywords:** evaluation, evaluation tool, surveillance, developing countries

**Summary**
A central issue in disease management is how to construct permanent surveillance networks that are capable of promptly detecting the emergence of an epizootic to enable a rapid reaction. The capacity of surveillance networks to detect a real emergence in a cost effective way has to be evaluated. Standard evaluation methods are generally qualitative or semi-quantitative and are often subjective and the tools developed to counterpart their subjectivity are not adapted to the specific contexts of developing countries. The objective of this work is to evaluate the needs for each country and the possibility of using SNAT (Surveillance Network Analysis Tool) as the first standardized tool to evaluate the avian influenza surveillance networks in Southeast Asia. There are great needs for developing countries to evaluate their surveillance systems either to identify the critical points for improvement or for presentation to the donors. However SNAT under its current format is not yet applicable to developing countries. The tool should be further developed to integrate each country needs and to identify and prioritize the means of action for improvement according to specific socio-economical contexts.

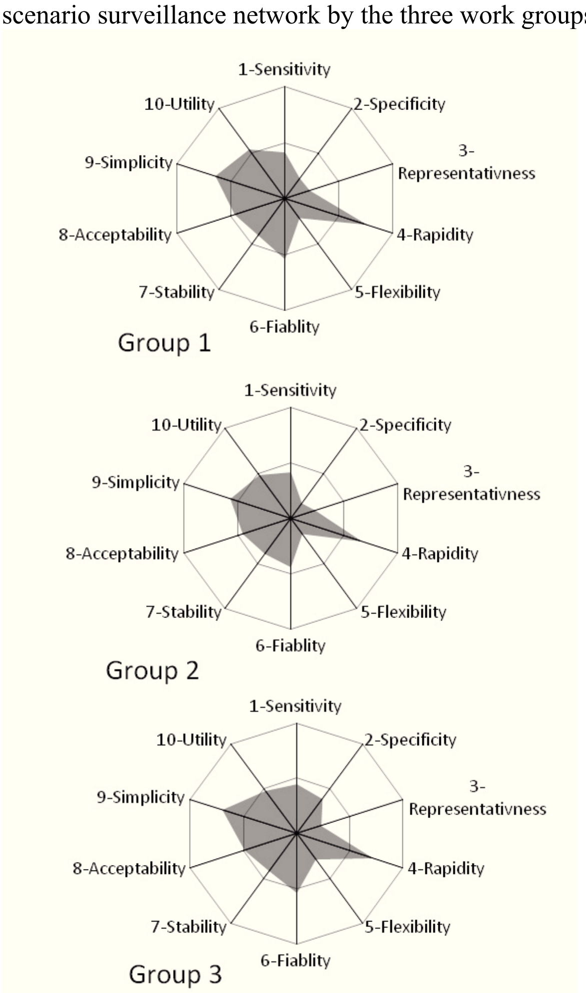
**Introduction**
The avian influenza (AI) panzootic caused by highly pathogenic H5N1 subtype, the risk of new highly pathogenic strains emerging on an intercontinental level, and the risk that a pandemic strain may develop require the reinforcement of controls at the animal level in priority in countries where the disease is recurrent or enzootic, particularly in Southeast Asia (SEA). A central issue in disease management is how to construct permanent surveillance networks that are capable of promptly detecting the emergence of an epizootic to enable a rapid reaction. This issue is even more important in developing countries where human and financial resources are limited and geographic access and communications are sometimes very restricted. Surveillance networks must be evaluated in terms of their sensitivity and predictive value -- their capacity to detect a real emergence within a defined spatial and temporal framework – and their desired cost effectiveness. Standard evaluation methods are generally qualitative or semi-quantitative and are often subjective. Under the framework of the research programme for the Evaluation of Avian Influenza Surveillance in South East Asia (REVASIA) the quality and operational efficacy of the surveillance systems of AI in SEA countries need to be evaluated. The results of these evaluations will be used as a basis of comparison with the methods for evaluation developed within the framework of the project. A Surveillance Network Analysis Tool (SNAT or OASIS in French) based on qualitative and semi-quantitative evaluation methods has been developed in Europe by a group of expert from ANSES (French agency for food, environmental and occupational health safety) (1,2). The objective of this work was to identify the needs and the potential of this tool to evaluate AI surveillance networks in SEA.

**Materials and methods**
Several meetings were organized to identify the needs and gaps in the evaluation of AI surveillance networks within the different countries (Cambodia, Lao, Thailand and Vietnam). A regional workshop was organized in Hanoi in November 2010 to discuss the acceptability of the tool to be used in the evaluation of the surveillance networks in the field and to draw recommendations for adapting the tool accordingly. The meeting gathered 30 participants from national Veterinary Services, laboratory experts and University researchers from Cambodia (National Veterinary Research Institute), Lao (National Animal Health Center), Thailand (Department for Livestock Development and Kasetsart University) and Vietnam (Department of Animal Health & National Center for Veterinary Diagnostic; National Veterinary Research Institute; Hanoi Agriculture University and National Institute for Hygiene and Epidemiology); international experts from United Nations organizations (FAO,WHO) and international institutes (CIRAD, CDC). The main objectives of the workshop were 1) to present the tool to the actors of the surveillance in SEA; 2) to have an overview of the AI surveillance systems existing in SEA and 3) to discuss and adapt the tool to the AI surveillance networks and to the socio-economical context of SEA countries. Specific group discussions had to review the questionnaire and the scoring method by evaluating a scenario surveillance system created for the purpose of the workshop. Each group had to consider the issues of 1) adequacy of the tool to the context of AI disease in SEA countries; 2) simplicity and understanding of the tool; 3) needs and recommendations for improvement.

**Result and Discussion**
There was a general consensus on the need for an evaluation of the surveillance systems in animal health as a critical part of the surveillance process. A better understanding of the weaknesses of the system is required

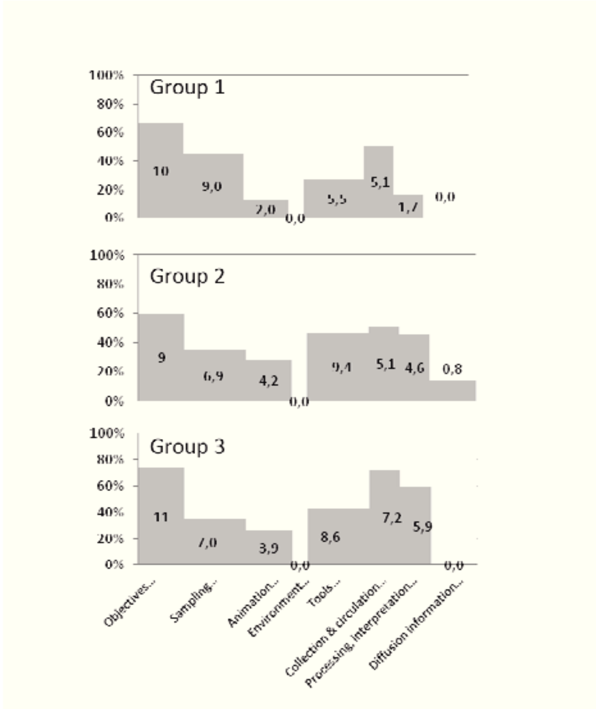
to identify the gaps for improvement. However, the methods currently used for evaluation (including the methods used in SNAT) are highly subjective and rely on the evaluator background and level of expertise. SNAT was recognized as the first standardized tool trying to reduce some of this subjectivity by relying on closed questions and precise scoring criteria. Results from the scoring exercise clearly demonstrated this subjectivity. Only limited variability was observed when looking at the qualitative assessment results: 1) satisfactory level of the process (results not shown) and 2) strength/weaknesses of the systems according to defined quality criteria (2) (Figure 1). The variability between experts was greater when looking at the results from the semi-quantitative assessment. Different trends in ranking the critical points of the system according to the margins for improvement were observed between the experts (Figure 2).

**Figure 1**. Results from the quality assessment of the scenario surveillance network by the three work groups.




The tool was originally developed for the evaluation of surveillance systems in industrialized countries. Under its current format the tool is not yet applicable to South East Asia contexts: it is too long, too complex or not straight forward enough and would need to be simplified (both the questionnaire and scoring method) to be applicable in SEA. One recommendation was to adapt the outputs of the tool to the different objectives of each country in the evaluation of their surveillance systems (e.g. internal use for improvement; argument for donors etc…). This will have an impact on the number of criteria required to evaluate the system and its prioritization could help reducing the complexity of the tool (Table 1).

**Figure 2**. Results from the semi-quantitative assessment of the scenario surveillance network by the three work groups.




Under its current development, the tool only highlights the strengths and weaknesses of the system organization. However, the purpose of evaluation is also to help decision makers and any tool should be easy to use to ensure its implementation in the field. This means easy way of identification of corrective measures to be implemented to improve the system. Highlighting and prioritizing the components where the measures should be applied to improve the system, including a cost-efficacy approach, is a priority.

**TABLE 1**. Number of scoring criteria involved in the assessment of each of the quality components.

| Quality components | Number of scoring criteria involved |
|---|---|
| Sensitivity | 12 |
| Specificity | 5 |
| Representativeness | 6 |
| Rapidity | 10 |
| Flexibility | 10 |
| Reliability | 48 |
| Stability | 24 |
| Acceptability | 19 |
| Simplicity | 7 |
| Utility | 13 |

Within the “one health” approach bridges between animal and public health surveillance are needed to reinforce the strengths of the systems. The issue of cross-cutting with public health and wildlife surveillance needs to be accounted for within any evaluation tool.

SNAT is a potential efficient tool to address the needs in evaluating animal health surveillance systems. All the representatives from the countries along with the international organization recognize the importance of such a tool and the needs for its development. Some countries such as Vietnam and Thailand have already included evaluation indicators within their systems. However they acknowledged the interest for a more generic and standardized approach to improve the accuracy of their evaluation. The need to involve a third party (an external expert) to increase the objectivity and credibility for presentation to the donors was highlighted.

SNAT is an evolving tool that needs be developed with the government of the SEA countries for its implementation in the field. Pilot field studies to further develop the tool are already planned in Cambodia and Lao. This development will take into consideration the epidemiological and socio-economical specific contexts of each country.

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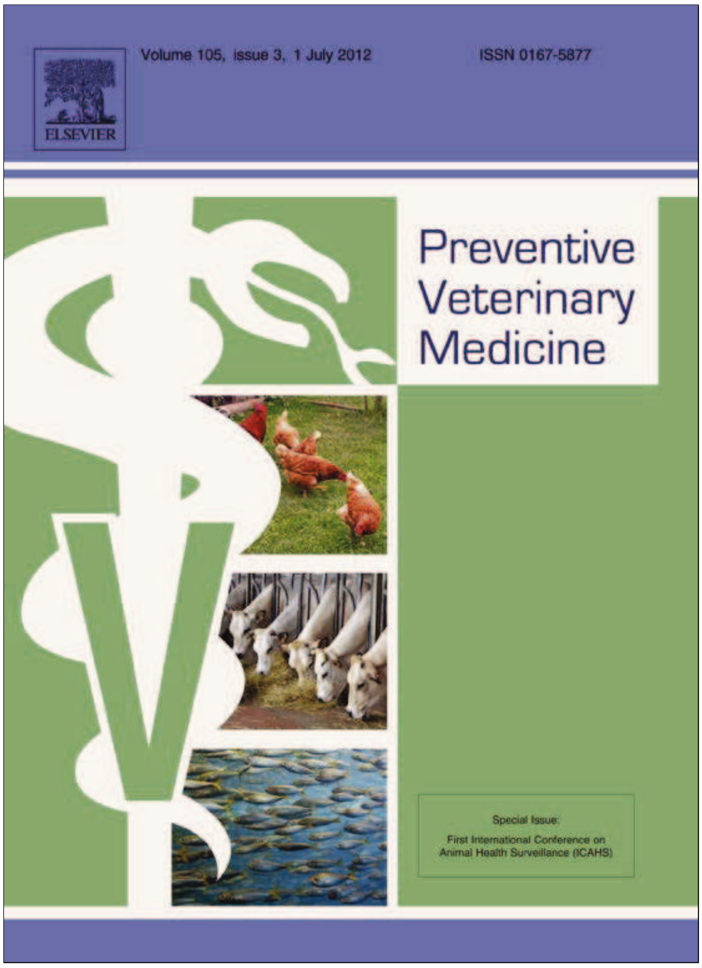
# ANNEX 2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# Optimizing early detection of avian influenza H5N1 in backyard and free-range poultry production systems in Thailand

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ABSTRACT

For infectious diseases such as highly pathogenic avian influenza caused by the H5N1 virus (A/H5N1 HP), early warning system is essential. Evaluating the sensitivity of surveillance is a necessary step in ensuring an efficient and sustainable system. Stochastic scenario tree modeling was used here to assess the sensitivity of the A/H5N1 HP surveillance system in backyard and free-grazing duck farms in Thailand. The whole surveillance system for disease detection was modeled with all components and the sensitivity of each component and of the overall system was estimated. Scenarios were tested according to selection of high-risk areas, inclusion of components and sampling procedure, were tested. Nationwide passive surveillance (SSC1) and risk-based clinical X-ray (SSC2) showed a similar sensitivity level, with a median sensitivity ratio of 0.96 (95% CI 0.40–15.00). They both provide higher sensitivity than the X-ray laboratory component (SSC3). With the current surveillance design, the sensitivity of detection of the overall surveillance system when the three components are implemented, was equal to 100% for a farm level prevalence of 0.05% and 82% (95% CI 71–89%) for a level of infection of 3 farms. Findings from this study illustrate the usefulness of scenario-tree modeling to document freedom from diseases in developing countries.



## 1. Introduction

Since its emergence in China in 1996, the highly pathogenic avian influenza virus H5N1 (A/H5N1 HP) has spread to many countries, leading to the culling of millions of poultry and the death of hundreds of human beings (Yee et al., 2009). Currently, in South East Asia (SEA), the disease is considered endemic in Cambodia, Vietnam, Indonesia and China (FAO, 2011; Naughtin et al., 2011). By contrast, Thailand, which was seriously affected by the epidemics of 2004–2005, managed to control the disease with massive culling and prohibition of vaccination (Buranathai et al., 2007) and declared its last outbreak in 2008 (OIE, 2011a). In February 2009, in accordance with section 10.4.4 of the

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OIE Terrestrial Animal Health Code, the country authorities declared Thailand free of H5N1 infection. However, demonstrating A/H5N1 HP free status remains challenging for Thailand. Even if Hong-Kong, South Africa, Bahrain and Russia lifted the ban on Thai uncooked frozen chicken meat in 2010, the European Union has continued to ban importations of fresh poultry meat from Thailand since 2004 (McSherry and Preechajarn, 2005; Orestes and Preechajarn, 2010).

The Department of Livestock Development (DLD) is the division within the Ministry of Agriculture and Cooperatives in charge of A/H5N1 HP surveillance and control in Thailand. Since the first wave of epidemics, the poultry surveillance system has been repeatedly modified, to adjust surveillance strategies to disease progression and new scientific development (Buranathai et al., 2007). Backyard and free-ranging farms are of primary importance as the majority of outbreaks in Thailand were reported in outdoor poultry systems and as the low level of biosecurity in such farming systems may increase the risk of outbreak occurrence (Gilbert et al., 2006; Tiensin et al., 2007). Surveillance of HPAI for backyard and free-grazing systems is particularly challenging due to the large population of holdings concerned (Otte et al., 2006), the reluctance of backyard farmers to report outbreaks (Kanamori and Jimba, 2007) and the frequent movement of free-grazing ducks which are transported over short and medium distances depending on rice harvest seasonality (Gilbert et al., 2006; Tiensin et al., 2007). Thai authorities therefore strengthened the surveillance of H5N1 virus for backyard chickens and free-grazing ducks: at the start of the epidemic, intensive active surveillance was used, with thousands of volunteers visiting every single farm to look for clinical signs of HPAI and to take samples of poultry (Gilbert et al., 2006); as the number of outbreaks decreased, the surveillance design was modified to focus on those areas at greater risk (Tiensin et al., 2007).

Given the endemic situation of A/H5N1 HP in neighboring countries, the high sensitivity of the Thai surveillance system is crucial in order to detect, from the onset, any new incursion of the disease and to provide reliable information to efficiently prevent the spread of the virus to a large proportion of the poultry population. According to a recent report (FAO, 2011), A/H5N1 HP eradication is assumed to take at least a decade in endemic countries. Therefore, to be sustainable, the surveillance system in Thailand will require cost-effective strategies.

The objectives of this study were to quantitatively evaluate the different surveillance activities conducted in low biosecurity poultry systems, as well as the resulting confidence in freedom from A/H5N1 HP in Thailand. A useful secondary objective was to improve surveillance system design to increase the probability of case detection.

## 2. Methods

A stochastic scenario tree model (Martin et al., 2007) was developed to estimate the probability that the Thai surveillance system for A/H5N1 HP would detect the disease if present at a defined level of prevalence in outdoor poultry systems.

### 2.1. Reference population

According to the National Statistics Office (NSO) 72,335 villages located in 7410 sub districts (SDs) are recorded in Thailand. Islands were removed because data were missing for one of the tested scenarios (scenario III). Islands contribute to only 0.2% of the overall poultry population in Thailand and islands have reported no A/H5N1 HP outbreak so far. For these reasons, it was assumed that islands play a minor role in disease distribution, and that removing them would not affect the results of the study. This resulted in a geo-database of 7366 SDs. The reference population considered throughout the study incorporated all poultry farms listed in the DLD database (2005 farm census) as raising either backyard chickens (2,589,342 chicken farms), backyard chickens and ducks (365,358 mixed farms), or free-grazing ducks (12,753 farms). The number of farms per SD and the proportion of mixed farms and chicken farms per village were computed and are presented in the supplementary material. The surveillance unit for our analysis was the farm and each farm was considered as made up of a single flock.

### 2.2. Surveillance system components (SSCs)

Three SSCs were identified and are described individually below. A common time period (TP) of one month was used for the accumulation of data produced by each SSC. All the components involve laboratory diagnostics, performed by the National Institute of Animal Health of Thailand (NIAH). H5N1 confirmations are first obtained by egg inoculations and hemagglutination assay (HA) (Keawcharoen, 2011) based on the World Health Organization (WHO) methodology (WHO, 2008). Positive HAs are further processed by reverse transcription PCR (RT-PCR). A positive outcome for surveillance was thus considered when a single animal or a single pooled sample of five animals was tested positive in RT-PCR. Since all confirmatory steps are always applied whenever a positive sample is recorded, it is reasonable to assume perfect specificity of the surveillance process.

#### 2.2.1. Passive surveillance (SSC1)

This component relies on voluntary notifications of any clinical A/H5N1 HP suspicion from backyard or free-grazing duck farm owners to DLD field officers. Clinical suspicions are based on the DLD case-definition. Operating nationwide and all year long, passive surveillance was considered to cover all farms in the reference population, with varying probability of declaration.

#### 2.2.2. Intensive active surveillance (X-ray campaigns)

Active surveillance, or 'X-ray campaigns', consists of two components that both run every six months, over a one-month period each time. Since the first X-ray campaign, the months have been selected according to risk factors of disease introduction into Thailand (Auewarakul, 2008): period of past outbreaks occurrence or of increased poultry movement (Chinese New Year period). For the sake of simplicity, the same months (January and June) were considered throughout the study. According to the DLD regulation, active surveillance for A/H5N1 HP for outdoor poultry production systems is built on a risk-based approach, depending on areas or species. Active surveillance for backyard farms is restricted to 'high-risk areas' which are sub districts with past outbreaks. For free-grazing ducks, active surveillance is carried out nationwide.

*2.2.2.1. Clinical X-ray surveys (SSC2).* In the last decade, health authorities in Thailand recruited and trained more than 750,000 village health volunteers (VHVs) to serve as a primary interface with communities (WHO, 2007). During the X-ray campaigns, these VHVs visit every backyard farm in high-risk areas, actively searching for illness in humans or clinical cases in poultry matching the DLD case-definition. Highly pathogenic H5N1 avian influenza virus is suspected when any of the following events occur: (i) mortality rate of at least 5% in two days; (ii) sudden death; (iii) symptoms of respiratory tract, such as difficulty breathing, swelling face; (iv) neurologic symptoms such as seizures, neck twisting; (v) depression, diarrhea, ruffled feathers, reduction of feed consumption and egg production (DLD, 2006). Swabs are collected from suspicious poultry.

*2.2.2.2. Laboratory X-ray surveys (SSC3).* This second active component is based on the active collection of virological samples by the DLD. In high-risk areas, four backyard farms are selected in each village using convenience sampling, and one pooled sample of five cloacal swabs of chickens is collected per farm. Free-grazing duck farms are visited nationwide and 12-pooled cloacal swabs of five ducks are collected per farm (Tiensin et al., 2007).

### 2.3. Model description

Scenario trees represent the whole process of disease detection and take into account the main factors influencing the probability that a randomly selected farm would be infected and subsequently detected. Their analysis provides an estimation of the probability of obtaining at least one positive surveillance outcome, for a predetermined threshold of prevalence or design prevalence of disease in the population. Each SSC is described through a scenario tree, a combination of infection, detection and category nodes (Martin et al., 2007): each event in the surveillance process appears as a detection node; infection nodes indicate the level of design prevalence targeted for the analysis, while risk category nodes divide the population under surveillance into several groups (i.e. branches) for which the probability of being infected is homogenous. The nodes for each SSC are summarized in Tables 1a and 1b.

To take into account uncertainty and variability into account for most input parameters, probability distributions were used and a stochastic process was generated using @RISK5.5® (Palisade Corporation) with Microsoft® Excel 2007. Latin Hypercube sampling was used, with 10,000 iterations and an initial seed chosen randomly. Input values and data sources for the probability distributions are described in Tables 1a and 1b.

#### 2.3.1. Design prevalence

Depending on the SSC, design prevalences were associated with infection nodes at animal level and/or at farm level. A within-farm prevalence ($P^*_A$) of 0.5 was used (for SSC3 only), consistent with a high level of infectiveness of avian influenza in naive chicken and duck populations. Regarding farm status, three different levels of infection ($P^*_F$) were considered: (i) a value of 0.05%, representing a level of infection similar to what Thailand experienced in 2004 for outdoor systems (Tiensin et al., 2007); (ii) a value of $P^*_F$ corresponding to one infected farm; (iii) a value of $P^*_F$ corresponding to three infected farms.

#### 2.3.2. Detection process

Five steps were identified for passive surveillance (SSC1), three for clinical X-ray (SSC2) and two for laboratory X-ray (SSC3). Two detection nodes are common to all three components: the results of the diagnostic tests (HA and RT-PCR) used by veterinary laboratories, characterized by their sensitivities ($Se_{HA}$ and $Se_{PCR}$ respectively). It was assumed that there was no difference between ducks and chickens regarding the test sensitivities.

The tree for SSC2 includes one additional node: the presence of noticeable clinical signs (with a probability of occurrence $P_{CS}$) in chickens and in ducks. For the passive surveillance component (SSC1), the probability of detection also depends on: (i) the probability of clinical signs to be notified to DLD officers by farmers ($P_N$), with backyard and free-grazing ducks owners having a different probability of reporting; (ii) the probability that DLD will send a team to collect samples ($P_{DLD}$) at the suspected farm site. The latter two probabilities were estimated through expert opinion elicitation, for high-risk and low-risk areas. To select our experts we considered persons with at least several years of experience working in Thailand in the field of avian influenza surveillance. Six experts agreed to participate: one staff member from the central bureau of epidemiology of DLD in Bangkok, two officers from the sub-regional office of OIE in Southeast Asia (SEA) and three French researchers based in SEA working on Avian Influenza for an international research institute (CIRAD). A web-based questionnaire was sent to them in March 2011 with questions about the probability of farmer declaration and probability of samples collection from DLD staff (depending on type of farm and area). The ellicitation process was based on a modified Delphi approach where no consensus was expected. Instead we combined the individual distribution given by experts to provide a single probability distribution for each parameters (Table 1b).

#### 2.3.3. Risk categories

Two risk category nodes were included in the model. First the *Risk Area* node, with two branches: '*High-risk Areas*' and '*Low-risk Areas*'. Under the current surveillance system, high-risk areas are defined as all SDs where at least one A/H5N1 HP outbreak was laboratory-confirmed between January 2004 and December 2008. Secondly, the *Farm Type*

**Table 1a**

Description of the series of events in the surveillance systems implemented in Thailand for the detection of A/H5N1 HP for different zoning scenarios per risk area and farm type with the inputs description, values and distributions used in the model.

| Node name | Type | Outcome | | Input name, proportion (PrP) and risk relative (RR) | | Input values | | | Source(s) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Scenario I | Scenario II | Scenario III | |
| Area category | Risk | HRA = 1 | LRA = 2 | $PrP_1$ | Proportion of free-range farms in HRA | 11.99% | 44.21% | 26.69% | DLD census |
| | | | | $PrP_2$ | Proportion of free-range farms in LRA | 88.01% | 55.79% | 73.31% | |
| | | | | $RR_1$ | Relative risk for HRA | Exp(Normal($\mu$, $\sigma$)) | | | |
| | | | | | | $\mu = 2.11$ | $\mu = 2.00$ | $\mu = 2.47$ | DLD outbreak data |
| | | | | | | $\sigma = 0.25$ | $\sigma = 0.27$ | $\sigma = 0.52$ | DLD census |
| | | | | $RR_2$ | Relative risk for LRA | 1 | | | |
| Farm category | Risk | Chicken = 1 | Mixed = 2 FGD = 3 | $PrP_{11}$ | Proportion of chicken farms in HRA | 10.83% | 13.99% | 10.61% | DLD census |
| | | | | $PrP_{12}$ | Proportion of mixed farms in HRA | 88.29% | 85.04% | 88.75% | |
| | | | | $PrP_{13}$ | Proportion of FGD farms in HRA | 0.89% | 0.97% | 0.64% | |
| | | | | $PrP_{21}$ | Proportion of chicken farms in LRA | 12.51% | 10.98% | 12.93% | |
| | | | | $PrP_{22}$ | Proportion of mixed farms in LRA | 87.12% | 89.02% | 86.71% | |
| | | | | $PrP_{23}$ | Proportion of FGD farms in LRA | 0.37% | 0.002% | 0.35% | |
| | | | | $RR_{11} = RR_{21}$ | Relative risk for chicken farms | 1 | | | DLD census |
| | | | | $RR_{12} = RR_{22}$ | Relative risk for mixed farms | Exp (Normal(0.79, 0.31) | | | DLD outbreak data |
| | | | | $RR_{13} = RR_{23}$ | Relative risk for FGD farms | Pert (5% 3.90, 12.40, 95% 40.10) | | | Henning et al. (2009) |
| Farm status | Infection | Infected | Not infected | $P_F^*$ | Farm-level design prevalence | 0.0001, 1 farm, 3 farms | | | |
| Animal status | Infection | | | $P_A^*$ | Within-farm design prevalence | 0.5 | | | |
| Clinical signs | Detection | Detected | Not detected | $P_{CS1} = P_{CS2}$ | Probability to have noticeable clinical signs in chicken and mixed farms | Pert (0.5, 0.99, 1) | | | Paul et al. (2011), unpublished data |
| | | | | $P_{CS3}$ | Probability to have noticeable clinical signs in FGD farms | Beta (2, 100) | | | Songserm et al. (2006) |
| HA test | Detection | Positif | Negatif | $Se_{HA}$ | HA sensitivity | Pert (0.957, 0.992,0.999) | | | Yamamoto et al. (2007) |
| RT-PCR test | Detection | Positif | Negatif | $Se_{PCR}$ | RT-PCR sensitivity | Pert (0.8,0.85,0.95) | | | Alba et al. (2010) |

HRA: high-risk area, LRA: low-risk area, FGD: free grazing ducks; Scenario I: current surveillance system with HRA based on past outbreaks; Scenario II: surveillance system with HRA based on free-grazing duck farms; Scenario III: surveillance system with HRA based on previous study (Paul et al., 2010).

**Table 1b**
Description of the series of events in the surveillance systems implemented in Thailand for the detection of A/H5N1 HP per risk area and farm type with the inputs description, values and distributions used in the model.

| Node name | Type | Outcome | Input name | | Input values | | Sources |
|---|---|---|---|---|---|---|---|
| | | | | | $\tilde{x}$ | 95% CI | |
| Farmer call DLD | Detection | Notified<br>Not notified | $P_{N11} = P_{N12}$ | Probability that clinical signs are notified by chicken or mixed farms' owner in HRA | 0.54 | 0.01–0.95 | Expert opinions[a] (Rojanasthien, 2010; Siengsanan et al., 2009) |
| | | | $P_{N13}$ | Probability that clinical signs are notified by FGD farms' owner in HRA | 0.31 | 0.01–0.87 | |
| | | | $P_{N21} = P_{N22}$ | Probability that clinical signs are notified by chicken or mixed farms' owner in LRA | 0.32 | 0.01–0.78 | |
| | | | $P_{N23}$ | Probability that clinical signs are notified by FGD farms' owner in LRA | 0.33 | 0.02–0.87 | |
| DLD collect samples | Detection | Collected<br>Not collected | $P_{DLD1}$ | Probability that DLD collects samples in HRA | 0.81 | 0.57–0.98 | Expert opinions[a] |
| | | | $P_{DLD2}$ | Probability that DLD collects samples in LRA | 0.72 | 0.29–0.96 | |

$\tilde{x}$ median; CI: confidence interval; HRA: high-risk area, LRA: low-risk area, FGD: free grazing ducks.
[a] Distribution probability used to illicit expert opinions and to combine them: Discrete $(\{X_1, X_2, X_n\},\{p_1, p_2, p_n\})$ with $X_n$ = Pert (min, ML, max) and $p_n$ = weight allocated to experts with $p = 2$ for experts from DLD or OIE and $p = 1$ for other experts.

node, with three categories defined as *Free-Grazing Duck Farms*, *Mixed Farms* and *Chicken Farms*.

### 2.4. Scenarios for risk-based surveillance

In order to compare the current surveillance system sensitivity to alternative surveillance options, several scenarios were generated and evaluated. While scenario I represents the current surveillance system, scenarios II and III correspond to different zoning strategies, with high-risk areas defined this time as all SDs with free-grazing duck farms (scenario II) or all SDs that were estimated at higher risk of infection in a previous study (Paul et al., 2010) (scenario III). For each zoning, relative risk estimates were obtained at SD level from univariate logistic regressions, using R 2.9.2 (R Development Core Team, 2009). For the three scenarios, the outcome variable was the presence or absence of A/H5N1 HP outbreaks in SD from 01/06/2005 (binary variable), as recorded in the DLD outbreak database. The explanatory variable varied according to the scenario tested: scenario (I) presence (yes/no) of HPAI outbreak in the SD during first and second wave of influenza (from 01/01/2004 to 31/05/2005); scenario (II) presence (yes/no) of free-grazing duck farms in the SD; scenario (III) relative risk in the SD > 1 (yes/no), according to the model published in Paul et al. (2010). Each univariate logistic model produced an estimate ($\mu$) and a standard error ($\sigma$). For high risk areas (HRAs), a distribution of relative risk were generated with @RISK5.5, using the exponential of normal laws of mean $\mu$ and standard error $\sigma$ (Table 1a). The low risk areas (LRAs) were considered as the reference and their relative risk was set at the value of 1. High risk and low risk areas were mapped at the SD level for each zoning strategy (scenario I–III) using the ArcGIS software v.9.1 (ESRI Inc.). Maps are presented in Fig. 1. Two other alternative scenarios were simulated to assess the effect of changes in sampling procedures: reducing the number of pooled cloacal swabs collected from ducks from 12 to 4 (sampling II) and targeting only free-grazing duck farms for sampling (sampling III).

### 2.5. Calculation of SSCs sensitivities

Each SSC sensitivity was estimated separately for each month during which the SCC was operated between January 2008 and January 2011.

#### 2.5.1. Adjusted risks

The model requires data on the proportions of farms falling into each branch of risk category nodes. For each corresponding category a specific value for the relative risk (RR) of infection is assigned. These risks must further be adjusted to ensure the reference population has a total risk of 1 (Eqs. (1) and (2)). This process leads to $AR_z$ and $AR_t$, the adjusted risks respectively for the *Risk Area* categories and the *Farm Type* categories, calculated as:

$$AR_z = \frac{RR_z}{\sum_{z=1}^{z=2}(RR_z \times PrP_z)} \quad (1)$$

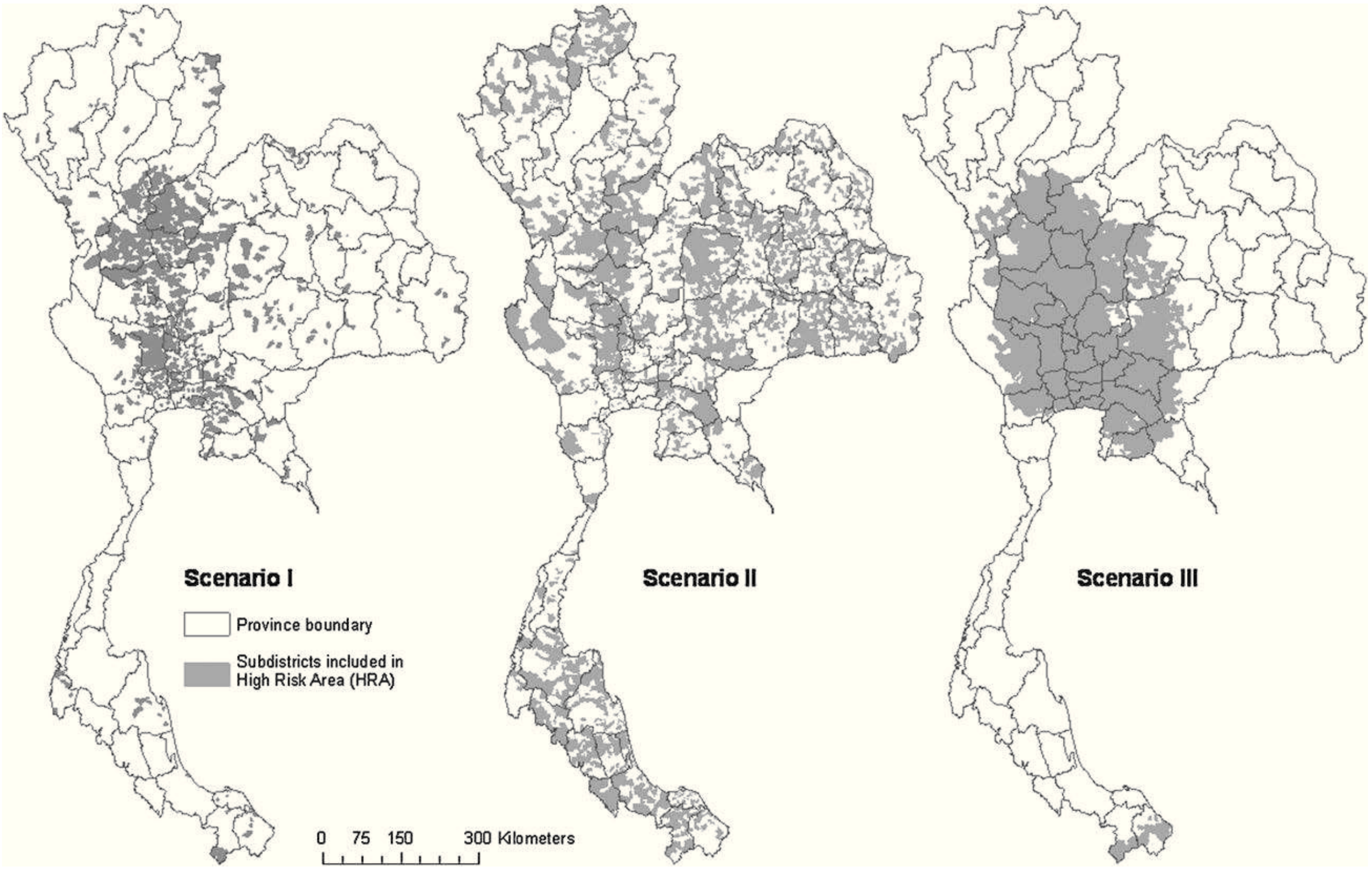


**Fig. 1.** Spatial distribution of high-risk areas for the three scenarios of surveillance tested in Thailand, for the detection of A/H5NA HP (scenario I: 923 SDs; scenario II: 2828 SDs; scenario III: 2480 SDs). Scenario I: current surveillance system with HRA based on the presence (yes/no) of HPAI outbreaks recorded since January 2004; scenario II: surveillance system with HRA based on presence (yes/no) of free-grazing duck farms in SD; scenario III: surveillance system with HRA based on the level of risk modeled in a previous study (Paul et al., 2010).

$$\mathrm{AR}_{zt} = \frac{\mathrm{RR}_{zt}}{\sum_{z=1}^{z=3}(\mathrm{RR}_{zt} \times \mathrm{PrP}_{zt})} \tag{2}$$

where $z = 1$ for *High-risk Areas*, $z = 2$ for *Low-risk Areas*, $t = 1$ for *Chicken Farms*, $t = 2$ for *Mixed Farms*, $t = 3$ for *Free-Grazing Duck Farms*; $\mathrm{PrP}_z$ and $\mathrm{PrP}_{zt}$ are the proportions of farms from the reference population falling into each branch; $\mathrm{RR}_z$ and $\mathrm{RR}_{zt}$ are the relative risks applied to each category (with *Low-risk Areas* and *Chicken Farms* being the reference categories, i.e. $\mathrm{RR}_2 = 1$ and $\mathrm{RR}_{z1} = 1$).

The adjusted risks are then multiplied by the design prevalence $P_F^*$ to obtain the effective probability of infection (EPI) at the farm level in each section of the population (Eq. (3)).

$$\mathrm{EPI}_{zt} = \mathrm{AR}_z \times \mathrm{AR}_{zt} \times P_F^* \tag{3}$$

### 2.5.2. Farm sensitivity (SeF)

For each SSC, the probability for each infected farm to be detected (farm-specific sensitivity of detection $\mathrm{SeF}_{zt}$) was calculated by multiplying the different probabilities of detection as follows:

$$\text{For SSC1} \quad \mathrm{C1SeF}_{zt} = P_{\mathrm{CS}t} \times P_{\mathrm{N}zt} \times P_{\mathrm{DLD}z} \times Se_{\mathrm{PCR}} \times Se_{\mathrm{HA}} \tag{4}$$

$$\text{For SSC2} \quad \mathrm{C2SeF}_t = P_{\mathrm{CS}t} \times Se_{\mathrm{PCR}} \times Se_{\mathrm{HA}} \tag{5}$$

where $P_{\mathrm{CS}t}$ varies according to the type of farm, $P_{\mathrm{N}}$ depends on both areas and farm types, and $P_{\mathrm{DLD}}$ is dependent on the area. Both $P_{\mathrm{N}}$ and $P_{\mathrm{CS}t}$ were considered identical for chicken and mixed farms.

For the third component, we referred to the equation from Christensen and Gardner (2000) to estimate herd sensitivities from pooled samples.

$$\text{For SSC3} : \mathrm{C3SeF}_t = 1 - ((1 - (1 - P_A^*)^k) \times (1 - (Se_{\mathrm{PCR}} \times Se_{\mathrm{HA}})) + (1 - P_A^*)^k)^{r_t} \tag{6}$$

where $r$ is the number of pooled samples per farm with ($r_1 = r_2 = 1$) for chicken and mixed farms ($r_3 = 5$) for free-grazing farms and k is the number of animals per pooled sample ($k = 4$ in all instances).

### 2.5.3. Component sensitivity (CSe)

The sensitivity of each surveillance system component was estimated as its probability to give a positive outcome for at least one infected farm when the disease is present at the design prevalences. This is equal to 1 − Pr (all farms will give a negative outcome) and can then be expressed using the following formulas:

$$\mathrm{SSC1Se} = 1 - \prod_{z=1}^{2} \prod_{t=1}^{3} (1 - (\mathrm{EPIL}_{zt} \times \mathrm{ClSeF}_{zt}))^{n_{zt}} \tag{7}$$

$$\mathrm{SSC2Se} = 1 - \prod_{t=1}^{2} (1 - (\mathrm{EPI}_{2\mathrm{t}} \times C2\mathrm{SeF}_t))^{n_{2t}} \tag{8}$$

$$\mathrm{SSC3Se} = 1 - \left[\prod_{z=1}^{2}(1-\mathrm{EPI}_{z3}\times \mathrm{C3SeF}_3)^{n_{z3}} \times (1-\mathrm{EPI}_{11}\times \mathrm{C3SeF}_1)^{n_A}\times(1-\mathrm{EPI}_{12}\times \mathrm{C3SeF}_2)^{n_B}\right] \quad (9)$$

where $n_{zt}$ denotes the number of farms of type $t$ processed in the area $z$, $n_A$ and $n_B$ are the number of chicken farms and mixed farms sampled under SSC3.

### 2.6. Calculation of SSCs sensitivities

#### 2.6.1. Lack of independence

During the months, when the three SSCs are run in parallel (twice a year), some farms are processed by more than one SSC, and this potential overlap between SSCs must had to be corrected because, in reality, this would not occur. To take into account this lack of independence between the components, a posterior probability of infection ($\mathrm{PostPInf}_F$) as calculated for all farms in SSC1 using equation 10 below, and for those farms also processed in SSC2, values of $\mathrm{EPI}_{zt}$ were replaced by $\mathrm{PostPInf}_F$ in the calculation of SSC2Se (and a similar process was adopted for the calculation of SSC3Se for those farms having been processed in SSC1 and/or SSC2).

$$\mathrm{PostPinf}_{\mathrm{Fztu}} = 1 - \frac{1-\mathrm{EPI}_{zt}}{1-\mathrm{EPI}_{zt}\times FSe_{zti}} \quad (10)$$

#### 2.6.2. Combining component sensitivities

Once the overlap between components is taken into account, the sensitivities from all three components can be combined to obtain the overall sensitivity of the complete surveillance system for the months of January and June (for the rest of the year SSSe = SSC1Se):

$$\mathrm{SSSe} = 1 - ((1-\mathrm{SSC1Se})\times(1-\mathrm{SSC2Se})\times(1-\mathrm{SSC3Se})) \quad (11)$$

### 2.7. Sensitivity ratio (SeR)

Sensitivity ratio (SeR) can be calculated to (i) evaluate the surveillance sensitivity between components by calculating the ratio of SSC and (ii) assess the usefulness of using risk-based surveillance instead of surveillance based on representative samples by calculating the ratio of the actual surveillance sensitivity (SSSe) over that of a hypothetical surveillance system of the same design but using representative sampling from the entire reference population.

### 2.8. Probability of freedom

The negative predictive value of the surveillance system (i.e. the confidence that one can have in A/H5N1 HP freedom), was estimated at the end of January 2011 (posterior probability of freedom (*PostPFree*). The probability of country freedom has actually been calculated at the end of each month (Eq. (12) below) since the last outbreak in Thailand in December 2008 thereby taking into consideration the accumulation of data from the ongoing surveillance.

$$\mathrm{PostPFree}_{\mathrm{tp}} = \frac{1-\mathrm{PriorPInf}_{zt}}{1-(\mathrm{PriorPInf}_{\mathrm{tp}}\times \mathrm{SSSe})} \quad (12)$$

The prior probability of infection ($\mathrm{PriorPInf}_{\mathrm{tp}}$) for each month was calculated as:

$$\mathrm{PriorPInf}_{\mathrm{tp}+1} = \mathrm{PIntro} + \mathrm{PostPInf}_{\mathrm{tp}} - (\mathrm{PIntro}\times \mathrm{PostPInf}_{\mathrm{tp}}) \quad (13)$$

where $\mathrm{PriorPInf}_{\mathrm{tp+1}}$ is the prior probability of infection for the following month before analysis of data obtained and $\mathrm{PIntro}_{\mathrm{tpi+1}}$ represents the probability of disease introduction in the country during $\mathrm{TP}_{i+1}$.

To estimate the prior probability of infection at the start of our analysis, a conventional approach was followed with the selection of a neutral prior ($\mathrm{PriorPInf}_{\mathrm{tp+1}} = 0.50$). The probability of disease introduction, in the absence of available data, was arbitrarily tested at two levels: (i) a value of 2% during January and June, and 1% for the remaining months; (ii) considering a scenario with greater risk with these probabilities of introduction respectively set to 10% and 5%.

### 2.9. Sensitivity analysis

Regression analysis were performed using @RISK advanced sensitivity analysis, to evaluate the influence of input distributions on the passive surveillance sensitivity (SSC1) and on the overall SSSe under the current surveillance scenario. Normalized regression coefficients associated with each input parameter were calculated. Inputs with the most impact were plotted in a Tornado graph, which shows the minimum and maximum values of the median SSSe when the values of the input vary between the 10th percentile and the 90th percentile. In addition, a scenario analysis was performed in @Risk to identify the input variables which were significant to reach a median SSSe equal to 90%.

## 3. Results

### 3.1. Surveillance system component sensitivities (SSCSe) and overall sensitivity (SSSe)

The median, 2.5 and 97.5 percentiles of the estimated distribution of the sensitivity of detection of each component and of the combined surveillance system are displayed in Table 2, for each scenario. Results are presented for each level of design prevalence considered. For a farm-level prevalence of 0.05%, the sensitivity of detection of each component and of the overall surveillance system was equal to 1.00, regardless of the zoning scenario.

When reducing the level of infection to be detected to a minimum of 3 farms or 1 farm, the median sensitivity of the system decreased to 82% and 43% respectively. For both these levels of design prevalence, scenarios II and III appeared similar and provided a higher sensitivity than the current system. Passive surveillance (SSC1), which is the only component in place for 10 months of the year, had low median sensitivity ranging from 50% with the current design to 58% for scenarios II and III, and when reducing

**Table 2**
Sensitivity of each surveillance system component (SSCSe) and of the overall surveillance system (SSSe) implemented in Thailand for the detection of A/H5N1 HP according to the level of infection to be detected and for each scenario I, II and III, calculated using Eqs. (7)–(11) described in Section 2.

| | Scenario I | | | | Scenario II | | | | Scenario III | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 Farm | | 3 Farms | | 1 Farm | | 3 Farms | | 1 Farm | | 3 Farms | |
| | $\tilde{x}$ | 95% CI | $\tilde{x}$ | 95% CI | $\tilde{x}$ | 95% CI | $\tilde{x}$ | 95% CI | $\tilde{x}$ | 95% CI | $\tilde{x}$ | 95% CI |
| SSC1Se | 0.21 | 0.01–0.37 | 0.50 | 0.04–0.75 | 0.25 | 0.01–0.42 | 0.58 | 0.04–0.80 | 0.25 | 0.01–0.42 | 0.58 | 0.04–0.80 |
| SSC2Se | 0.20 | 0.11–0.34 | 0.49 | 0.28–0.71 | 0.30 | 0.17–0.47 | 0.66 | 0.43–0.85 | 0.30 | 0.16–0.47 | 0.65 | 0.41–0.85 |
| SSC3Se | 0.09 | 0.02–0.18 | 0.25 | 0.06–0.45 | 0.11 | 0.03–0.21 | 0.39 | 0.08–0.51 | 0.09 | 0.03–0.18 | 0.25 | 0.07–0.45 |
| SSSe | 0.43 | 0.33–0.52 | 0.82 | 0.71–0.89 | 0.54 | 0.47–0.58 | 0.90 | 0.85–0.93 | 0.53 | 0.44–0.58 | 0.90 | 0.82–0.93 |

$\tilde{x}$: median; CI: confidence interval; SSC1Se: passive surveillance; SSC2Se: clinical X-ray surveys; SSC3: laboratory X-ray surveys; SSSe: system surveillance sensitivity; Scenario I: current surveillance system with HRA based on past outbreaks; Scenario II: surveillance system with HRA based on free-grazing duck farms; Scenario III: surveillance system with HRA based on previous study (Paul et al., 2010).

the level of infection, ranging between 21% and 25% respectively.

### 3.2. Change of sampling procedures

Fig. 2 shows that there is no difference in the sensitivity of the system between the three sampling strategies for a given scenario. The number of samples to be collected for the different sampling strategies and the associated sensitivity of the surveillance system are plotted in Fig. 2, for each zoning and for a level of infection to be detected to a minimum of 3 farms.

### 3.3. Sensitivity ratios (SeRs)

Table 3 shows a comparison of the different components by calculating their SeRs for January and June. Table 4 illustrates the relative sensitivity of the current surveillance system and its different components compared to a representative design. Under the current surveillance design, a median SeR of 1.36 demonstrates the benefit of a risk-based approach to detect the disease as opposed to surveillance based on random sampling only, with SSC2 gaining the most advantage with a median SeR of 3.24. Scenario II and III showed a median SeR close to 1.00 for the overall surveillance system, indicating that this zoning design would be equally effective when using representative sampling.

### 3.4. Probability of freedom

Fig. 3 shows the development of the combined estimated probability of disease freedom over time since the last outbreak in January 2008 under the current surveillance system and a design prevalence of 3 infected farms. When considering a low probability of disease introduction, the median probability of freedom at the end of January 2011 was 99.43% (97.82–99.73%); for a fivefold

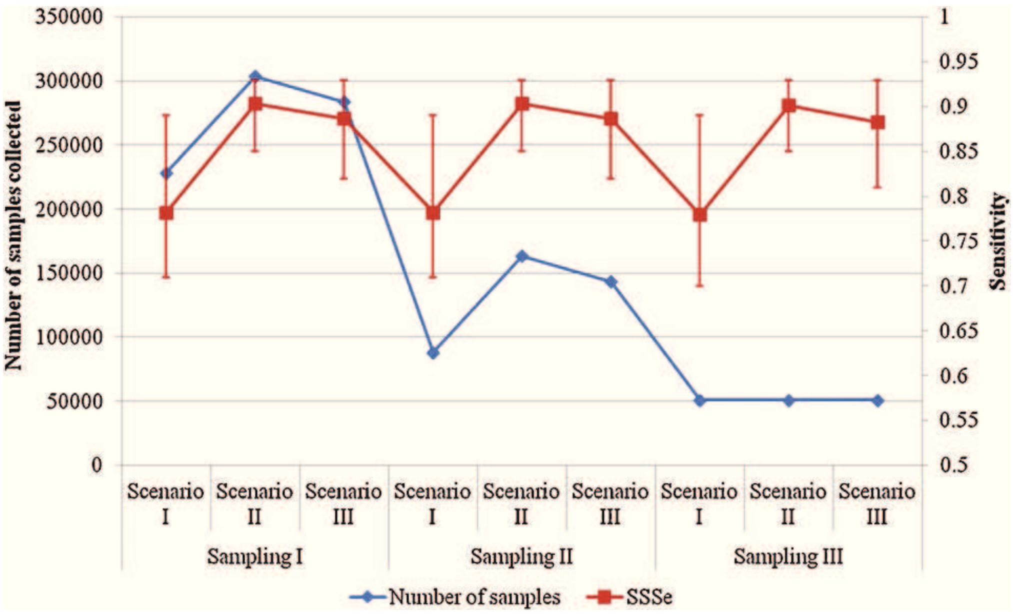


**Fig. 2.** Number of samples collected for various designs of the surveillance system implemented in Thailand for the detection of A/H5N1 HP (zoning scenario and sampling strategy for SSC3) and associated overall sensitivity of detection for 3 farms infected (SSSe). Scenario I: current surveillance system with HRA based on past outbreaks; scenario II: surveillance system with HRA based on free-grazing duck farms; scenario III: surveillance system with HRA based on previous study (Paul et al., 2010); sampling I: 5 birds in 4 chicken and/or mixed farms per village in high-risk area + sampling in every free-grazing duck farm with 12-pooled cloacal swabs of 5 birds; sampling II: 5 birds in 4 chicken and/or mixed farms per village in high-risk area + sampling in every free-grazing duck farm with 4-pooled cloacal swabs of 5 birds; sampling III: sampling in every free-grazing duck farm with 12-pooled cloacal swabs of 5 birds.

**Table 3**
Sensitivity ratios between the three surveillance components implemented in Thailand for the detection of A/H5N1 HP Thai in outdoors systems, for a design prevalence of three infected farms, and for each scenario I, II and III.

| | Scenario I | | Scenario II | | Scenario III | |
|---|---|---|---|---|---|---|
| | 3 Farms | | 3 Farms | | 3 Farms | |
| | $\tilde{x}$ | 95% CI | $\tilde{x}$ | 95% CI | $\tilde{x}$ | 95% CI |
| SSC1Se/SSC3Se | 1.95 | 0.17–9.47 | 1.80 | 0.14–8.33 | 2.17 | 0.16–9.28 |
| SSC2Se/SSC1Se | 0.96 | 0.40–15.00 | 1.15 | 0.60–19.10 | 1.13 | 0.50–18.20 |
| SSC2Se/SSC3Se | 1.99 | 0.80–8.50 | 2.26 | 1.00–9.05 | 2.67 | 1.19–9.38 |

$\tilde{x}$: median; CI: confidence interval; SSC1Se: passive surveillance; SSC2Se: clinical X-ray surveys; SSC3: laboratory X-ray surveys; Scenario I: current surveillance system with HRA based on past outbreaks; Scenario II: surveillance system with HRA based on free-grazing duck farms; Scenario III: surveillance system with HRA based on previous study (Paul et al., 2010).

**Table 4**
Sensitivity ratios of the actual surveillance components and overall surveillance system implemented in Thailand for the detection of A/H5N1 HP against equivalent systems using representative sampling, for a design prevalence of three infected farms, and for each scenario I, II and III.

| | Scenario I | | Scenario II | | Scenario III | |
|---|---|---|---|---|---|---|
| | 3 Farms | | 3 Farms | | 3 Farms | |
| | $\tilde{x}$ | 95% CI | $\tilde{x}$ | 95% CI | $\tilde{x}$ | 95% CI |
| $SSC1Se/SSC1Se_{Rep}$ | 1.00 | 0.10–11.90 | 0.99 | 0.10–12.30 | 1.01 | 0.10–11.20 |
| $SSC2Se/SSC2Se_{Rep}$ | 3.24 | 1.70–5.70 | 1.10 | 0.70–1.49 | 1.54 | 0.95–2.12 |
| $SSC3Se/SSC3Se_{Rep}$ | 1.04 | 0.23–5.77 | 1.02 | 0.23–4.91 | 1.09 | 0.26–5.43 |
| $SSSe/SSSe_{Rep}$ | 1.36 | 0.88–2.87 | 1.06 | 0.83–1.61 | 1.24 | 0.90–2.22 |

$\tilde{x}$: median; CI: confidence interval; SSC1Se: passive surveillance; SSC2Se: clinical X-ray surveys; SSC3: laboratory X-ray surveys; $Se_{Rep}$: sensitivity of an equivalent surveillance system using representative sampling; Scenario I: current surveillance system with HRA based on past outbreaks; Scenario II: surveillance system with HRA based on free-grazing duck farms; Scenario III: surveillance system with HRA based on previous study (Paul et al., 2010).

higher risk of introduction, the median was still at 96.90% (87.25–98.53%).

### 3.5. Sensitivity analysis

The probability of notification by a chicken farm owner in high-risk areas ($P_{N11}$; coefficient of normalized regression of 0.76) and in low-risk areas ($P_{N21}$; coefficient of 0.49) were the parameters which influenced the most the sensitivity of the passive surveillance. Concerning the overall sensitivity of the surveillance system, critical parameters with their coefficient were: $P_{N21}$ (0.66), the relative risk of infection assigned to the farms located in high-risk areas $RR_1$ (0.48) and the probability that an infected chicken will show symptoms $P_{CS1}$ (0.32). The Tornado graph of the sensitivity analysis (Fig. 4) shows that the median SSSe ranged from 75% to 86% when the value of $RR_1$ varied between the 10th percentile and the 90th

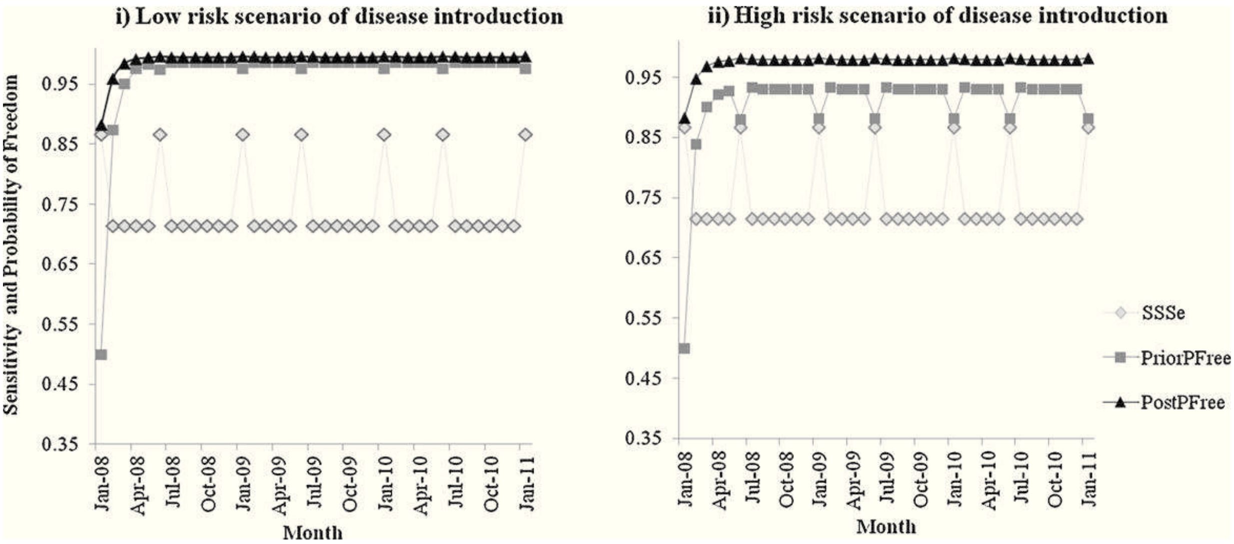


**Fig. 3.** Probability of disease freedom (PostPFree) over time given surveillance system sensitivity (SSSe) implemented in Thailand for the detection of A/H5N1 HP and for two scenarios regarding the probability of disease introduction (PIntro) of A/H5N1 HP in Thailand with i) a low-risk scenario with PIntro equal to 2% in January and June and equal to 1% the remaining months and ii) a high-risk scenario with PIntro equal to 10% in January and June and equal to 5% the remaining months.

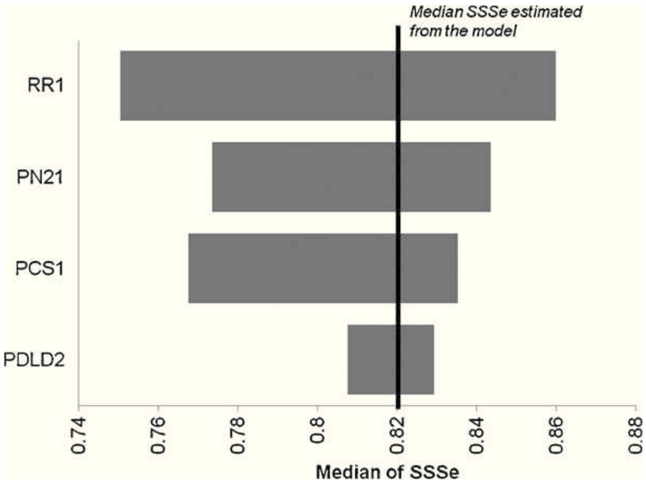


**Fig. 4.** Tornado Graph showing the minimum and maximum values that the median surveillance system sensitivity (SSSe) acquires, as the values of the different inputs vary with $P_{N21}$ for the probability of notification by a chicken farm owner in low-risk areas; $RR_1$ for the relative risk of infection assigned to the farms located in high-risk areas; $P_{CS1}$ for the probability that an infected chicken will show symptoms; $P_{DLD2}$ for the probability that DLD will send a team to collect samples.

percentile. In addition, the scenario analysis showed that the overall SSSe would be over 90% with a model combining high values of $P_{N21}$ and of $RR_1$.

## 4. Discussion

The use of probability-based sampling, which is recommended in the OIE Terrestrial Animal Health Code (OIE, 2011b) to prove freedom from disease, is often too expensive and unworkable in large backyard poultry population. The scenario tree approach was originally conceived to help developing countries with the process of disease freedom declaration (EUFMD, 2007). The present study, focusing on backyard poultry in a developing country, is one of the very few that used a scenario tree model to assess the sensitivity of a complex surveillance system in a challenging environment. Despite potential limitations, our results show that the current surveillance strategy designed for free-range poultry farming systems is very sensitive, and therefore tend to support the freedom declaration of H5N1 made by Thailand in February 2009.

During the two months of high-risk period, when X-rays are implemented, the current surveillance system has a high probability (82%) to detect the disease in early stage of infection when only three farms are affected. Results show that among the three surveillance components implemented simultaneously, the most efficient activity is the active search of clinical signs in chicken and mixed farms in high-risk areas. This result is directly linked to the case-definition used by the DLD to detect A/H5N1 HP suspicion, which is very wide and so highly sensitive. On the other hand, the poor specificity of case-definition increases the risk of false positive as many poultry diseases can have similar clinical symptoms (Elbers et al., 2005; Spickler et al., 2008). This lack of specificity could create farmers' mistrust in the DLD since control measures are often implemented before any confirmation comes from the laboratory (Executive Committee for Prevention and Control of Avian Influenza and Preparedness for Influenza Pandemic, 2007) and could be one explanation for the lack of sensitivity of passive surveillance. An additional shortcoming of this case-definition is the 5% level of mortality which is used as a trigger for A/H5N1 HP suspicion. Baseline mortality is difficult to estimate for backyard flocks of small size with a number of deaths being frequently unobserved (Henning et al., 2008).

Outside the X-ray period, when only passive surveillance is implemented, the current surveillance sensitivity for the same level of infection drops to 50% with a very large confidence interval (95% CI 0.04–0.75). This low sensitivity could result from different reasons. First the high level of uncertainty of the data we used to estimate model input, especially the distributions estimated through expert opinions used to estimate probability of reporting by farmers and sample collection, could have influenced the estimation of the SSe of passive surveillance. However, it is recognized that surveillance based only on clinical signs and voluntary notifications may have a poor sensitivity with high variability, in relation to level of farmers' knowledge, seriousness of disease and types of enforcement measures (with or without compensation) (Hadorn and Stärk, 2008). In the case of A/H5N1 HP in Thailand, the control measures based on the massive culling of the poultry population in suspected farms with only partial compensation (Auewarakul, 2008) may have discouraged farmers from reporting the disease to DLD. Whatever the case, this result needs to be put into perspective. Sensitivity was estimated for the detection of only three infected farms over a total of 2,967,453 farms with free-range poultry systems. It is worth considering that the sensitivity of the passive surveillance system is close to 1 when taking a design prevalence of 0.05%.

The sensitivity analysis indicated that the probability of chicken farmers reporting an outbreak to DLD officers in low-risk areas and to a lesser extent in high-risk areas had a high impact on the SSSe. These probabilities were estimated from expert opinions with median values of 54% and 32% which may appear rather high but are consistent with the study implemented by Rojanasthien (2010). These high probabilities of farmer reporting could reflect the joint efforts of the DLD and the Ministry of Public Health to improve farmers' access to the reporting system by the presence of volunteers in each village (WHO, 2007) and by a constant effort to raise public awareness. This is fully described in the Second National Strategic Plan for Prevention and Control of Avian Influenza and Preparedness for Influenza Pandemic (2008–2010), which highlighted the role of livestock volunteers, public health volunteers, sub-district headmen and village headmen who act as focal points for HPAI surveillance in the poultry and human populations. This plan also mentioned the importance of communication and training of community leaders and village volunteers.

When taking into account historical data from ongoing surveillance and assuming the worst case scenario of introduction, the present probability of freedom, for the open-range poultry production system of Thailand, computed by our model is high with a median of 96.9%.

Interpretation of these results should be taken with caution because of potential bias in our inputs but could provide some evidence regarding the implementation of compartmentalization with a safety standard acceptable to international organizations (Executive Committee for Prevention and Control of Avian Influenza and Preparedness for Influenza Pandemic, 2007) and therefore to regain trust from international trading partners.

It is worth noting that, in the SSC3, reducing the number of pooled cloacal samples in free-grazing duck populations from 12 to 4, or targeting only free-grazing ducks for sampling had no impact on the current SSSe. This result should be read in regard to the low sensitivity level of SSC3 compared with the two other components. As a result reducing the number of samples has no effect on the performance of the surveillance system but would have saved budget on laboratory expenses as shown in Fig. 2.

On the other hand, the type of factor used to define the "*high-risk areas*" turned out to have a substantial impact on SSSe. Zoning based on SDs with free-grazing duck farms was the most effective with the best sensitivity and smallest confidence interval, but with the most samples to be collected and thus the most expensive.

Some limitations of the study also need to be highlighted. One difficulty was to obtain the latest accurate description of the Thai surveillance system, as the surveillance system was continuously adapted to new constraints and was thus really dynamic.

At national level, the main criteria to target the surveillance are the presence of confirmed past outbreaks (since 2004) in the SDs. However, at the local level and from our field observation, it seems that not all the villages of targeted SDs are included in the surveillance system, leaving the final decision to provincial DLD authorities. This may influence the total number of chicken and mixed farms targeted by the surveillance system.

In the sensitivity analysis, the value of relative risk attributed to high-risk areas, was one of the inputs with the most effect on SSSe. This is consistent with the principles of "risk-based" surveillance where surveillance activities are driven by the probabilities of an adverse event occurring (Stärk et al., 2006). In the present study, relative risks were estimated from data of the outbreaks observed, and thus may have been influenced by the under-reporting that could have occurred in Thailand, especially at the beginning of the epidemic in 2004 (Kanamori and Jimba, 2007). The estimation of relative risks is often a sensitive task in the framework of scenario tree modeling and further research is needed on the methods for quantifying and accounting of relative risks (Willeberg et al., 2011). Finally, no data were available concerning the probability of the introduction of H5N1 virus into Thailand. As a result, we arbitrarily set different values of disease introduction to test scenarios, considering the monthly probability of disease introduction between 1% and 5%, with double the risk during a high-risk period. However, as A/H5N1 HP outbreaks have been regularly reported in the neighboring countries, there is a need for a quantitative risk assessment of the probability of disease introduction in Thailand. This is of great interest as these systems show permanent risk for the persistence and spread of H5N1. However, this study did not examine the other components of H5N1 surveillance in Thailand. The health monitoring program that is implemented in layer and breeder poultry populations and pre-movement, pre-slaughter testing for broiler or fighting cocks (Buranathai et al., 2007), as well as the surveillance of wild birds (Siengsanan et al., 2009) could be included in further work as they currently contribute to increasing the sensitivity of the overall system of detection of H5N1 virus.

## 5. Conclusion

The scenario tree modeling approach made it possible to evaluate the overall sensitivity of H5N1 surveillance for backyard and free-range poultry production systems in Thailand, demonstrating that this sector has a high probability to be free of A/H5N1 HP virus. This illustrates the usefulness of scenario-tree modeling for demonstrating disease freedom in countries with non-conventional surveillance systems and limited resources.

## Conflict of interest statement

We further state that we are free of any financial and personal relationships with other people or organizations that could inappropriately influence the article submitted.

## Acknowledgement

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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.prevetmed.2011.12.020.

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# ANNEX 3

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# Development of a participatory tool for the evaluation of Village Animal Health Workers in Cambodia

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ABSTRACT

In countries with a lack of primary care systems, health workers are of crucial importance to improving the delivery of health and animal health services at community level. But somehow they are rarely evaluated and usually with a top–down approach. This is the case in Cambodia, where thousands of Village Animal Health Workers (VAHWs) have been trained by the government, and where no standardized evaluation tool is available to accurately assess the situation.

Based on methodology developed by the French NGO *Agronomes et Vétérinaires Sans Frontières* (AVSF) in Madagascar for farmers' association evaluation, we developed our own participatory methods to collect information about the VAHW context and build a criteria grid for their evaluation. In this framework, several participatory approaches were used such as problem trees, semi-structured interviews, pair-wise ranking and focus groups. The grid was built with the help of relevant stakeholders involved in the animal health system in Cambodia in order to (i) identify VAHW functions; (ii) set up criteria and associated questionnaires, and (iii) score the grid with all the stakeholders. The tool was divided into five categories of evaluation criteria: sustainability, treatment, production, vaccination and disease reporting.

Our approach looked at local indicators of success developed and used by VAHWs themselves, which should lead to better acceptability of evaluation. This method gave priority to dialog aiming to engage decision makers and other stakeholders in a mutual learning process and could be applied in other countries to develop trust between health workers and official service representatives as well as to foster corrective action after evaluation.



## 1. Introduction

Agriculture represents the most important economic sector for Cambodia, with the livestock sector accounting for around six per cent of gross domestic product (GDP) (Harding et al., 2007). Most of the livestock is produced in the smallholder farming system (Harding et al., 2007). However this sector is characterized as a low income-generating activity with a high level of morbidity and mortality of animals due to the farmers' poor feeding resources, lack of efficient local veterinary services, limited technical skills and access to medicine (Chheng, 2009a). To overcome these challenges, in the early 1990s the Cambodian government started training volunteer farmers to provide animal health services at village level: Village Animal Health Workers (VAHWs) (Burgos et al., 2008). The farmers are selected within their own community and trained in the basic techniques of veterinary medicine. They are in charge of

*Abbreviations:* AVSF, Agronomes et Vétérinaires Sans Frontières; CV, communal veterinarians; DAHP, Department of Animal Health and Production; DV, district veterinarians; FAO, Food and Agriculture Organization; FO, Farmer Organizations; GDP, gross domestic products; MAFF, Ministry of Agriculture Forestry and Fisheries; NaVRI, National Veterinary Research Institute; NGO, Non-Governmental Organization; PAHP, Provincial Animal Health and Production; PE, Participatory Evaluation; VAHW, Village Animal Health Worker; VRC, Vétérinaires Ruraux du Cambodge.

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providing advice, technical assistance and animal healthcare services, including vaccination, treatment and husbandry practices (Burgos et al., 2008; Chheng, 2009b). The first wave of training was largely implemented with the help of external support (NGOs and FAO). Development objectives were targeted through solid theoretical training and practical exercises (Benzerrak et al., in press) in order to improve livestock production (CelAgrid, 2007) but no formal evaluation was carried out afterward.

After the H5N1 Highly Pathogenic Avian Influenza crisis in Cambodia in 2004, a second wave of training was introduced. These sessions targeted public health security and were undoubtedly implemented in response to international pressure. The government objective was to have at least one trained VAHW per village to improve poultry disease surveillance and ensure early detection (vice-chief of the Department of Animal Health and Production, DAHP, personal communication, 2011). To reach this objective, the government delegated training to diverse NGOs such as *Agronomes et Vétérinaires Sans Frontières* (AVSF), Heifer International or Care International, within specific projects funded by the FAO (CelAgrid, 2007). This strategy has led to a massive training period, with marked heterogeneity in regard to training contents, participant selection processes and training session duration. Up to now most VAHWs have received training (or refresher training sessions) focusing on AI (Wilsmore et al., 2010). This strategy has diverted attention away from other diseases (Wilsmore et al., 2010).

In Cambodia most VAHWs are men, with an average educational level grade of 7.8 (CelAgrid, 2007). Their only source of income as VAHWs comes from the farmers who pay for their services, although most VAHWs practice other activities at the same time (e.g. rice production) (CelAgrid, 2007). They work in close collaboration with village chiefs to implement animal health campaigns and activities recommended by the Ministry of Agriculture Forestry and Fisheries (MAFF), and NGOs (Burgos et al., 2008). They are not government agents, but are regarded as representatives of the DAHP at village level and it is mandatory for them to report suspected outbreaks of notifiable diseases, even if they receive no compensation for their involvement (Wilsmore et al., 2010). This task is made difficult by the fact that there is no compensation scheme for farmers after major outbreaks (Wilsmore et al., 2010).

So far 12,000 VAHWs have been trained (http://www.fcfd-cambodia.org/avsf/avsf_successes_en.html) but according to the French NGO AVSF several issues within the system remain: the heterogeneity of their skills, due to (i) the high number of trainers, (ii) the diversity of organizations providing training, (iii) the inconsistent selection criteria for VAHWs and (iv) training contents (AVSF, personal communication, 2011) and the fact that each year more and more VAHWs cease their activities. Indeed, 7.5% ceased activity in 2010 (vice-chief of the DAHP, personal communication, 2011) and probably even more. However, the term 'activity' remains unclear and there is no information about the kind of activity the VAHWs have ceased: livestock and poultry production (first training wave), and/or animal disease reporting (second training wave). The status and definition of VAHWs also remains unclear.

The main objective of VAHWs is to help the veterinary services (SV) to achieve the priorities of national government by improving animal health and welfare, as well as global human health (OIE, 2013). These services should be regularly evaluated in order to gage their current level of performance and identify any gaps and weaknesses in the system to make recommendations for improvement. Evaluation basically refers to the collection, analysis, interpretation and reporting of information, in order to judge the success or failure of an intervention or a project (Rice and Franceschini, 2007). Most evaluation processes are conducted by external stakeholders, yet the project participants, who are directly concerned by the evaluation outputs, are not taken into consideration either in the process of question formulation or in data collection (Rubin, 1995). Bradley et al. (2002) recommends using participatory evaluation (PE) as this facilitates mutual learning, it helps participants evaluate their own needs and analyze their own priorities and objectives thus leading to better acceptability. PE can be defined as applied social research that implies interactions between stakeholders (Garaway, 1995; Lahai, 2009), focusing on the understanding of local realities and on continuous learning (Rice and Franceschini, 2007). This method leads to stakeholder empowerment in the process, which could improve the sustainability of health interventions. The use of such developmental evaluation (DE) has been recognized as a way of supporting adaptive learning, leading to a deeper understanding of the stakeholder's problem/opportunity, resources, and the broader context (Dozois et al., 2010). Moreover, a key principle of DE is to 'help stakeholders surface and test their assumptions, articulate and refine their models, extend their understanding and cultivate a culture that supports learning' (Dozois et al., 2010).

One example of the development of a PE tool was initiated by AVSF in Madagascar for the assessment of Farmer Organizations (FO) and then adapted in Cambodia in the framework of the Komrong Daikou project (Gennet and Martin, 2012). This tool is implemented in four stages: (i) define evaluation criteria through workshop(s), (ii) finalize criteria in guidelines and communicate these to farmers, (iii) evaluate and score criteria in the field and (iv) link scoring results with suitable and available technical and financial supports (Gennet and Martin, 2012).

Through this experience, AVSF highlighted the fact that this was a very simulating process involving farmers' perceptions, action and commitment. Moreover, results have shown the great potential of the tool, with an increase of FO activities, self-initiatives and management skills (Gennet and Martin, 2012). According to the identified needs, and following the success of this project, AVSF, with the support of researchers from CIRAD, decided to develop its own tool using the same participatory methodology: the involvement of key stakeholders in defining evaluation criteria and scoring these criteria.

The main objective of our study was the participatory development of a tool to assess VAHW performance and level of activity. Our aim was to initiate a process of participatory evaluation and to harmonize perception of the needs, expectations and responsibilities of VAHW among the different actors and to ensure that the results are used for change. To build this evaluation tool, a series of meetings was arranged targeting VAHWs as well as the main stakeholders working in animal health systems in Cambodia. The work was carried out in several steps leading to a criteria grid to evaluate VAHW sustainability and capacities (Table A1).

## 2. Material and methods

### 2.1. Study area

Two provinces were selected according to the presence/absence of diverse NGOs working in the field of animal health and in collaboration with VAHWs. Indeed we assumed that their involvement in a community project in the province would impact not only their answers, due to the perception of their activity by NGOs, but also their commitment in the development process of the criteria grid. Moreover, the presence of an NGO in the area undoubtedly impacts VAHW sustainability. The objective of this methodology was to detect the different perceptions of VAHWs according to the context in which they operate. Prey Veng province was thus chosen because of the historic presence of AVSF in the area, while Svay Rieng province was chosen because no NGO was working with VAHWs to our knowledge. Because of time constraints only one district was selected per province. In Prey Veng province, Ba

**Table 1**
Synthesis of the results from phases 1 to 4.

| | Stakeholders involved | Participants | Functions | Categories | Evaluation criteria |
|---|---|---|---|---|---|
| Phase 1 (Ba Phnom) | CV[a] | 10 | 24 | 4 | X |
| | Active VAHW[b] | 10 | 21 | 4 | |
| | Inactive VAHW[b] | 8 | 21 | 4 | |
| Phase 1 (Kampong Rou) | CV[a] | 11 | 21 | 4 | X |
| | Active VAHW[b] | 9 | 20 | 4 | |
| | Inactive VAHW[b] | 8 | 21 | 4 | |
| Phase 2 | CV[a] | 4 | 24 | 4 | 26 |
| | Active VAHW[b] | 4 | | | |
| | Inactive VAHW[b] | 2 | | | |
| | DV[c] | 2 | | | |
| Phase 3 | DAHP[d] representative | 1 | 20 | 4 | 30 |
| | PAHP[e] representative | 2 | | | |
| | NaVRI[f] representative | 2 | | | |
| | FAO[g] representative | 1 | | | |
| | NGOs[h] representative | 3 | | | |
| Phase 4 | CV[a] | 4 | X | 5 | 39 |
| | Active VAHW[b] | 4 | | | |
| | Inactive VAHW[b] | 2 | | | |
| | DV[c] | 2 | | | |
| | DAHP[d] representative | 1 | | | |
| | PAHP[e] representative | 2 | | | |
| | NaVRI[f] representative | 2 | | | |
| | FAO[g] representative | 3 | | | |
| | NGOs[h] representative | 3 | | | |

[a] Commune Veterinarian.
[b] VAHW: Village Animal Health Workers.
[c] DV: District Veterinarian.
[d] DAHP: Department of Animal Health and Production.
[e] PAHP: Provincial office of Animal Health and Production.
[f] NaVRI: National Veterinary Research Institute.
[g] FAO: Food and Agriculture Organization.
[h] NGOs: Non-Governmental Organizations.

Phnom district was chosen due to the presence of an active, locally recognized association of VAHWs supported by AVSF. In Svay Rieng province, the district of Kampong Rou was selected because VAHWs were more isolated and received no support from NGOs.

### 2.2. Targeted population

To improve the relevance of our tool it was fundamental to triangulate the various levels and sources of information. Therefore we decided to integrate the points of view of a maximum number of stakeholders involved in the animal health services or with specific knowledge or expectations related to VAHW activities and to select local and national actors. In each district three groups of VAHWs were selected by the District Veterinarian: active VAHWs (officially trained and still exercising their activity at least in their own village), inactive VAHWs (officially trained but no longer exercising their activity or never did) and Commune Veterinarians (CVs). CVs are the unofficial representatives of VAHWs at commune level, appointed by the DV or by the VAHWs of the commune; their role is to facilitate communication with government representatives. The DV is a DAHP representative at district level; he is in charge of implementing and enforcing animal health regulations. Local authorities, policy makers, ministry representatives, local and international institutions (Food and Agriculture Organization of the United Nations and NGOs) were also involved. They were invited to several meetings in the framework of the study and were involved in developing the tool by demonstrating their expectations and perceptions of VAHW activities. Private sector representatives (from Medivet, Bunlay Kry Progress and CP) working in relation with animal breeding, animal production and animal health were contacted but were not available at the time of our study. Per diem was provided to all stakeholders who attended the meetings.

### 2.3. Design of the criteria grid

The design of the criteria grid was conducted in six phases as described in Fig. 1, from March to November 2011. Meetings held in the field were conducted in Khmer and directly translated into English, while the workshops in Phnom Penh were conducted in English and translated into Khmer. The meetings held in the field were coordinated by two researchers, one from the Royal University of Agriculture of Phnom Penh and one from CIRAD. These facilitators acted as catalysts and tried not to take part in the discussions.

#### 2.3.1. Phase 1: Identification of VAHW functions

During the first phase, VAHWs and CVs from the same district were brought together for a half-day meeting. The objective was to help them identify and formalize their functions in their own community. A function was defined as an activity carried out by a VAHW at village level but also any action related to requirements from local or national authorities. The identified functions would then serve as a basis to develop the evaluation criteria. This method initiates thinking about the VAHWs' own perception of their roles and duties. Three half-day meetings were conducted in each district targeting three distinct groups of participants (cf. Section 2.2). We invited 10 participants to each meeting.

To foster more effective group discussion and collect as much information as possible the Metaplan method was chosen and adapted to the context. This method saves time and ensures the involvement of all participants in the group (© Metaplan GmbH, 2003). Each participant was provided with sheets of paper and wrote down one of their functions per sheet. Once collected by the research team, the papers were read out to the attendees and functions related to the same topic were grouped into categories selected by the participants. Having identified the categories, the research team encouraged discussion about all VAHW functions.

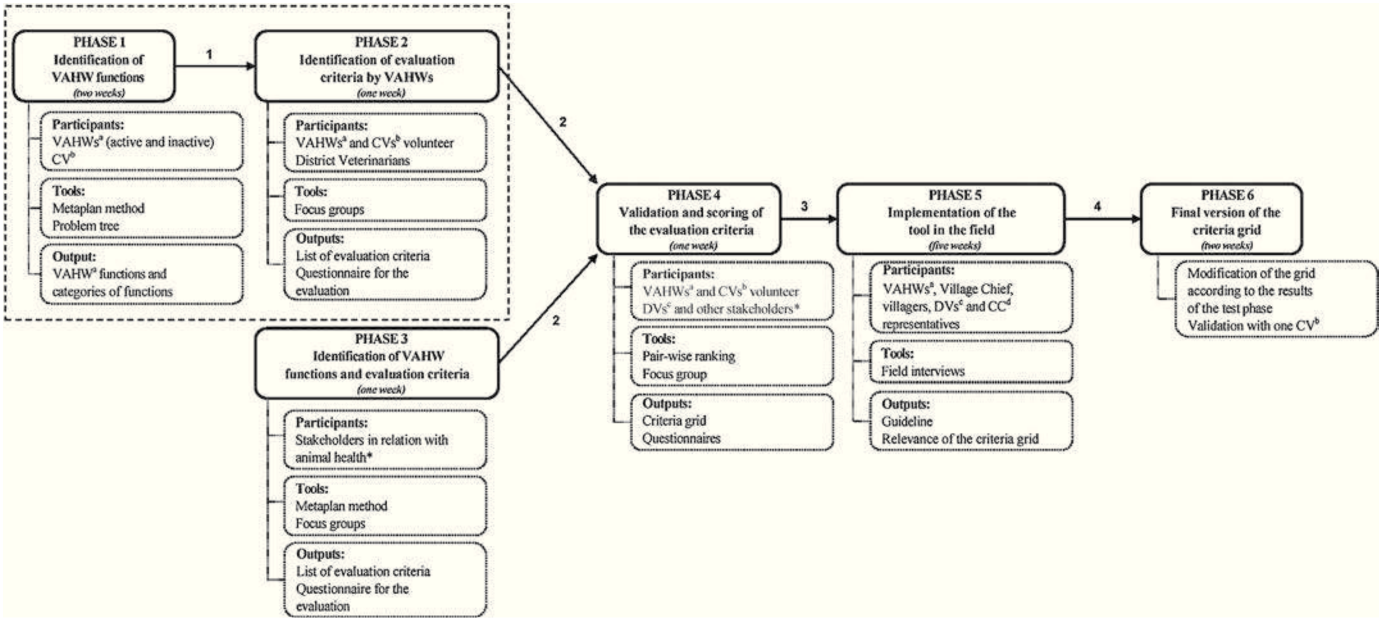


**Fig. 1.** Description of the phases implemented for the design of the criteria grid. (1) Use of the identified functions as a basis to develop evaluation criteria. (2) Use of the developed evaluation criteria to elaborate an evaluation grid. (3) Implementation of the elaborated criteria grid in the field. (4) Modification of the criteria grid according to field implementation. [a] VAHWs: Village Animal Health Workers. [b] CV: Commune Veterinarians. [c] DVs: District Veterinarians. [d] CC: Commune Council. [*] Representatives from the Food and Agriculture Organization, from the National Veterinary Research Institute, the Ministry of Agriculture, Forestry and Fisheries, and from Non-Governmental Organizations.

The facilitator was careful not to take part in the debate but merely to guide it in order to collect raw information. At the same time, a problem tree was used to define the VAHWs' work context and main constraints. The trunk represents the main problem faced by the participants, the roots, the causes or factors and the branches, the effects or consequences. This method is considered as heuristic as it helps to identify, prioritize and visualize problems (Veselý, 2008). The facilitator asked attendees about the main difficulties encountered by VAHWs in their activities. After a group discussion the participants agreed on one main difficulty, which was identified as the main problem. The facilitator had further discussions with the group to identify the main causes and consequences of this problem.

At the end of each meeting the research team asked for two volunteers to be involved in the next steps of the project. A total of 12 volunteers were invited: four active VAHWs, four inactive VAHWs and four CVs.

*2.3.2. Phase 2: Identification of evaluation criteria by VAHWs*

During the second phase, a half-day meeting was held, bringing together the volunteers from previous meetings and the DVs of the targeted areas. The objective was to define criteria to evaluate the functions identified during the first phase.

The research team chaired a discussion in which participants were invited to discuss and validate the set of categories and functions previously identified. Participants were then divided into four heterogeneous groups each including active, inactive, CV and DV. Each group worked on one specific category only. For each function, they had to (i) identify the ideal ways of performing it, (ii) identify the relevant stakeholders to interview to check whether this related function is well performed by the VAHW (e.g. villager, village chief), and (iii) work out the questions to be asked to assess VAHWs' performance level. Once the list had been drawn up within each group, one member of the group presented their work to the other participants. To validate, add or remove evaluation criteria open discussions were led by the facilitator.

*2.3.3. Phase 3: Complementary meeting to identify VAHW functions and evaluation criteria*

In the third phase, a half-day meeting was held in Phnom Penh gathering together the stakeholders directly involved in the training and coordination of VAHWs (Fig. 1): representatives from the FAO, from the National Veterinary Research Institute (NaVRI), from the MAFF, and from NGOs. As in the previous phases, the objectives were (i) to define VAHW functions, (ii) define evaluation criteria and (iii) draw up the associated questionnaire. To save time, the research team used the categories identified during the first phase as a basis for the meeting. The same approaches and participatory tools were then used (Fig. 1, phases 1 and 2).

*2.3.4. Phase 4: Validation and scoring of the evaluation criteria*

All the participants who joined the previous meetings were invited to a one-day workshop in Phnom Penh which was conducted in three stages. (1) During the first part of the meeting, the facilitator described the evaluation criteria in the provisional grid one by one with the associated questionnaires and asked the participants for their validation. Requested modifications were made following the agreement of all the attendees directly on the spot. (2) In the second phase, categories were ranked according to their relative importance in VAHW evaluation using a pair-wise ranking method. This is a slightly more complex ranking system whereby each item is compared individually with all the other items one-by-one in a consensus-oriented manner (Ameri et al., 2009). This approach is considered more reliable than simple ranking as it imposes the consideration of every possible relationship (AFENET, 2011). The exercise was carried out in two steps: first by asking VAHWs and CVs for their point of view and then by asking other attendees for validation. The number of times a category appears on the comparison table can be correlated to its rank and thus to its weight in the evaluation. Participants then allocated the 100 points of the grid to these categories according to their relative importance in VAHW evaluation. (3) In the final phase four heterogeneous focus groups were formed, each helped by a facilitator, to work on weighting the evaluation criteria. Indeed, each category is composed of several evaluation criteria that had to be weighted according to their relative importance in VAHW evaluation. Points previously allocated to the categories were attributed to the evaluation criteria by discussion within the group. Each group worked on each category. The results were then collected, means of the scores calculated and presented to the participants in order to lead to an agreement. At the end of the day the first complete list of scored evaluation criteria was accepted by common consensus, with a list of stakeholders to interview during the field evaluation and its associated questionnaire.

#### 2.3.5. Phase 5: Implementation of the criteria grid

The objectives of this test phase were to assess the convenience and ease of use of the tool in the field. To do so, four districts were selected according to the level of external support the VAHWs were receiving from local authorities, international organizations or NGOs.

Ba Phnom (support received from AVSF) and Kampong Rou district (no support) were selected in order to involve the VAHWs who designed the criteria grid. Bakan district in Pursat province was selected in view of the strong implication of the local authorities and the refresher training courses implemented by FAO (SLPP project, 2007). Angkor Chey district in Kampot province was finally selected to target the inactive VAHWs.

For Ba Phnom, Kampong Rou and Bakan districts, DVs provided us with two lists: the 10 most active VAHWs and the 10 most inactive. For Angkor Chey district, we only asked for a list of 10 inactive VAHWs. Among these lists the research team selected only available VAHWs. The objective was to interview active and inactive VAHWs in order to test the evaluation grid. The test phase was carried out in two parts, with three districts visited in July and the last one at the end of August 2011.

#### 2.3.6. Phase 6: Final version of the criteria grid

In accordance with the results of the test phase, the final version of the grid and associated questionnaires was designed. The research team made some changes relating to the implementation phase (phase 5) and the preliminary results obtained. This final version was then presented and validated by the head of the association of VAHWs from Ba Phnom, in the course of an interview.

## 3. Results

### 3.1. Phase 1: Identification of VAHW functions

During the first phase a total of six meetings were conducted. From eight to eleven participants attended these meetings (Table 1) and the groups identified 20 to 24 functions. These functions were similar for all the groups involved. During each meeting, attendees grouped the identified functions into the same four categories: treatment, production, vaccination and report. After compiling the results from the six meetings, a total of 28 functions were identified.

The problem trees of the six meetings were similar and participants identified the same constraint for VAHWs: the decrease of activity (Fig. 2). The inadequate skills of VAHWs, the issue of competition and the lack of recognition from their professional environment were identified as the main causes of this lack of sustainability.

### 3.2. Phase 2: Identification of the evaluation criteria and associated questionnaires

A total of 12 participants attended the meeting of the second phase (Table 1): four CVs, four active VAHWs, two inactive VAHWs and two DVs. During the meeting some functions were deleted or renamed, to reach a total of 24 functions. Working groups identified a set of 26 evaluation criteria. Indeed, for some functions attendees identified several evaluation criteria.

To assess these evaluation criteria, participants developed five questionnaires targeting: (i) villagers, (ii) village chief, (iii) Commune Council representative, (iv) DV and (v) VAHW.

### 3.3. Phase 3: Complementary meeting to identify VAHW functions and evaluation criteria

Nine participants joined the meeting in Phnom Penh (Table 1): one representative from the DAHP, two representatives from the NaVRI, two representatives of the Provincial office of Animal Health and Production (PAHP from Prey Veng and Svay Rieng provinces), one representative from FAO, three representatives from NGOs (one representative from Heifer, *Vétérinaires Ruraux du Cambodge* (VRC) and AVSF). During this meeting 20 functions were identified by attendees, grouped under the same four categories identified by other stakeholders during the first phase (cf. Section 3.1).

Thirty evaluation criteria were defined (Table 1), sometimes with several criteria associated to one function. To draw up the associated questionnaires the attendees identified five stakeholders: villagers, village chief, DV, representative from the government at the national level (officials from DAHP and from NaVRI) and VAHW. The questionnaires were completed by two quizzes which were proposed by the FAO representative and accepted by the attendees as a relevant additional tool in the evaluation process. The aim was to directly evaluate the VAHW's technical capacities to make a diagnosis by identifying the symptoms clearly exposed on pictures of local animals and to choose the appropriate medicine through a set of questions according to species, disease and other relevant factors (e.g. age).

### 3.4. Phase 4: Validation and scoring of the criteria

Participants from previous phases attended the workshop, joined by other representatives (Table 1): four CVs, four active and two inactive VAHWs, two DVs, one representative from DAHP, two from PAHP and from NaVRI, and three representatives from FAO and from NGOs.

The results of phases 2 (26 evaluation criteria) and 3 (30 evaluation criteria) were compared by the research team to remove similar criteria and a set of 36 evaluation criteria was finally obtained. The functions identified were similar among the different groups involved. After reviewing the results of the problem tree the research team suggested including an additional category, sustainability, with six evaluation criteria taken from the problem tree roots.

Finally a total of 42 criteria were presented to the 23 participants (Table 1). After discussions among the attendees certain criteria were deleted. The group finally agreed on a list of 39 criteria after having accepted the additional category. The two quizzes were presented to VAHWs and CVs and were accepted as relevant to the evaluation process.

The participants then ranked the final five categories and weighted them to reach 100 points: 39 points for evaluation criteria related to sustainability, 25 for treatment, 16 for production, 13 for vaccination and seven for reporting. Lastly, the working groups produced the scoring of the criteria and questionnaires.

### 3.5. Phase 5: Implementation of the criteria grid

Because of time constraints, only 36 VAHWs were evaluated: 17 active (6 in Ba Phnom, 4 in Kampong Rou and 7 in Bakan) and 19 inactive (3 in Ba Phnom, 2 in Kampong Rou, 3 in Bakan and 11 in Angkor Chey). To evaluate one VAHW it was necessary to interview 14 persons: the VAHW directly, 10 villagers, the village chief, one

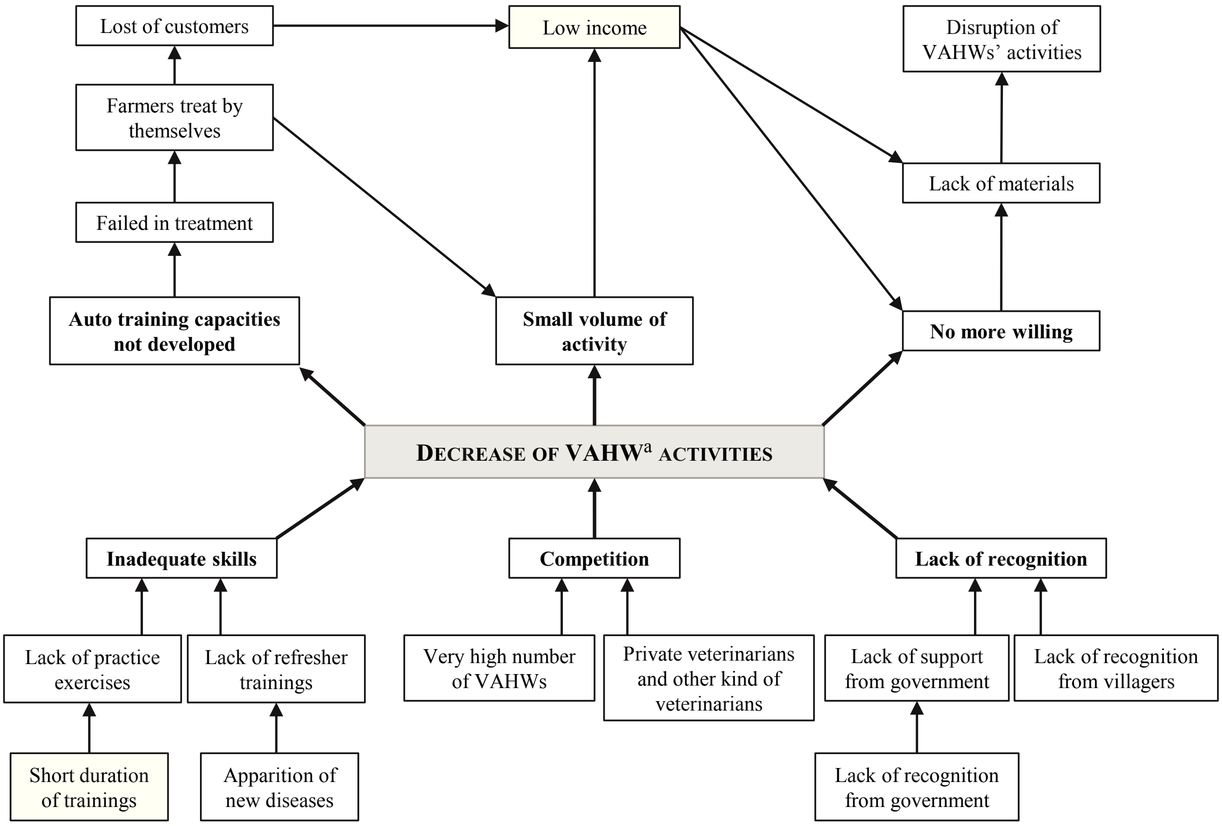


**Fig. 2.** Problem tree resulting from the first phase. [a] Village Animal Health Workers.

representative of the Commune Council and the DV. Indeed, participants agreed that interviewing 10 villagers would be enough to provide a fair representation of farmers' opinions without taking into account a preferred gender. During this test phase the VAHWs, village chiefs and villagers to be interviewed face to face defined the best way to implement evaluation in the field, while DVs and the Commune Council were to be interviewed by phone. The research team focused on villagers breeding at least one head of cattle or one pig. Indeed, services for poultry represent a very minor part of VAHW activities due to fact that farmers seldom call upon this type of service and rarely pay for it (CelAgrid, 2007). Moreover the villagers selected for the interview had to have called the VAHW during the current year.

After analyzing the VAHW scores it came out that the results of the evaluation did not clearly distinguish between active and inactive. Certain modifications had to be made to the scoring system.

During field evaluation, the objective was to interview ten villagers who had used the VAHW services during the current year. When evaluating an inactive VAHW the interviewers had to actively seek clients in the village, spending a huge amount of time and involuntarily increasing the score of the VAHW. To solve this problem it was decided to randomly interview villagers with at least one head of cattle or one pig. When the villager was a regular client of the VAHW, the previously developed questionnaire was used. But if the villager was not a client, a new questionnaire with negative points was introduced in the scoring system. For example, when one villager said he/she did not know who the village VAHW was, one negative point was taken into consideration for the final score calculation; while if he/she did not call on the VAHW during the previous year because his/her animals were not sick, no negative points were taken into consideration.

Using this final version of the tool the evaluation of one VAHW can be completed in 3 h, depending on stakeholders' availability.

### 3.6. Phase 6: Final version of the criteria grid

After modifications and validation from the CV of Ba Phnom the criteria grid was finally composed of five categories: sustainability, treatment, production, vaccination and reporting. VAHW sustainability was evaluated by assessing (i) the support given to the VAHW from his/her professional environment (local authorities and villagers), (ii) the VAHW's volume of activity, (iii) his/her work-experience and (iv) his/her geographic stability. The functions related to treatment were evaluated according to (i) the VAHW's availability to farmers, (ii) the information given to villagers related to the treatment of their animals and (iii) his/her diagnostic capacities and treatment approaches, which are evaluated by two quizzes. The first, to evaluate the VAHW's diagnostic approach, is composed of 12 diseases represented by clear pictures of the local animal symptoms the VAHW has to identify. The second is designed to evaluate the VAHW's treatment capabilities and is composed of 14 questions relative to the appropriate treatment to select according to disease and species. VAHW performance related to production is evaluated according to (i) his/her ability to demonstrate the best modes of production, and (ii) his/her ability to advise villagers on animal production. The evaluation regarding vaccination assesses (i) the VAHW's technical abilities, (ii) his/her involvement in official vaccination campaigns and (iii) the setting up of campaigns outside official ones. Finally, reporting functions are evaluated according to (i) the VAHW's involvement in reporting, (ii) knowledge about official diseases to report and (iii) advice to villagers about these diseases.

## 4. Discussion

VAHWs are on the front line of the national animal disease surveillance system in Cambodia, linking livestock owners to veterinary services. To improve animal health in this country this system needs to be effective and sustainable. Such objectives need to be evaluated to ensure that the quality of VAHW activities complies with a minimum set of standards and should be used as a prerequisite for continued participation in refresher training activities (Mariner et al., 2002).

Existing reports on the evaluation of community-based animal health workers tend to be written by external stakeholders in an ad hoc manner, solely focusing on the impact of their activities on the animal health situation of the village (EPIAT, 2002; Tadele, 2004), their knowledge level (CelAgrid, 2007), or their utility in an official disease surveillance system (Allport et al., 2005); rather than focusing on their own situation, skills and capabilities. Moreover, these evaluations are mostly based on closed-ended questionnaires (CelAgrid, 2007). One section of the OIE Tool for the Evaluation of Performance of Veterinary Services (OIE PVS Tool), for example, targets the competence of veterinary paraprofessionals. Indeed, veterinary paraprofessionals or community-based animal health workers have to be evaluated to assess the performance of the veterinary services of a country. But this top-down evaluation tends to be descriptive, assessing their ability to efficiently carry out their veterinary and technical functions (OIE, 2013). Even if evaluations using such a tool lead to recommendations for improvement, there is still a need to complete the process with internal evaluations taking into consideration stakeholders' expectations and perceptions as well as national animal health objectives.

According to the methodological guide for the training of community health workers developed by Thonnat (1993), Catley et al. (2004) and Peeling and Holden (2004), VAHWs are supposed to be able to treat and prevent animal diseases, organize vaccination campaigns and give advice to villagers related to animal health and production. Indeed, Catley et al. (2004) advocated assessing community-based animal health workers' (CAHWs) knowledge and skills, and cross checking the results obtained using standardized interviews with the CAHW's supervisor. They considered the CAHW's ability to make a correct diagnosis and implement correct drug administration as a key issue, highlighting the importance of supervision in the sustainability of such a system. (Catley et al., 2004; Leyland and Catley, 2002).

Stakeholders' resistance to being evaluated has long been documented (Smith, 2002), due to the fact that evaluation affects the individual in his/her social context (Taut and Brauns, 2003). To overcome this resistance we have developed an evaluation tool using participatory approaches and involving multi-level stakeholders. Our proposed evaluation tool was thus directly developed by the VAHWs, completed by relevant stakeholders and tested in the field. Very little input came from the research team. Following the results obtained from the problem tree method, the sustainability category was added to the tool. All participants agreed that this was a relevant category to take into consideration in the evaluation process, although its addition by the research team may have influenced their judgement. Moreover, having implemented the tool in the field, the research team highlighted the lack of distinction between active and inactive VAHWs. We have thus developed a specific questionnaire with negative points, which has been validated by a CV from the Ba Phnom district.

The method used to develop this evaluation tool clearly identified all the aspects of VAHW roles and functions; it led to their involvement in the process and better acceptability of evaluation. Thus, by opening the discussion, encouraging wide participation and using appropriate tools, some clarity of purpose was achieved (Bradley et al., 2002). The method helped stakeholders to form judgments by describing the system, identifying the criteria and giving value to these criteria. The process enabled key decision makers, funders and program beneficiaries to be in the same room, giving them the rare opportunity of exchanging points of view. Moreover, by involving government representatives in the full process, national objectives could be taken into consideration in the evaluation tool. Nonetheless, participation in one step of the evaluation is not sufficient in itself in the context of an inclusive approach. Stakeholders are involved at other levels in animal health services, as for example in the selection of VAHWs, which is done by villagers, the village chief or DV. Stakeholders' participation is not only sought for evaluation, it is present throughout the development, direction and guidance of the animal health services through partnerships between communities, government and the private sector (Leyland and Catley, 2002).

The development of an evaluation tool using such a method presents certain limitations. Indeed, to implement the method, time is required to schedule the meetings, as some phases need to be kept separate to avoid the potential influence of stakeholders' presence. For example: VAHWs' answers may be influenced by the presence of government and international organization representatives. This explains the need to separate phases 2 and 3. Another limit refers to the number of stakeholders to be interviewed to evaluate one VAHW. This process can be time-consuming, but does ensure relevant information regarding the VAHWs' activities and professional relations.

Our method of evaluation is not just an external observation and description of the current situation; it leads to quantitative results following a specific framework. It can therefore be used to identify the strengths and weaknesses of the system, not only leading to better refresher training courses but also to better evaluation of the survival rate of VAHWs, which is hardly ever carried out once the projects are over (Blanc et al., 2003).

Despite OIE recommendations on the need to define procedures to ensure the quality of the training and supervision of community-based animal health workers (Catley et al., 2004), the evaluation stage is rarely taken into consideration during project development, a limited budget is usually allocated for its implementation (Blanc et al., 2003) and evaluation findings are sparse and are not shared (KU Work Group for Community Health and Development, 2013). Even if the field implementation of our evaluation tool can be considered as low-cost, the evaluation process needs resources and can be time-consuming, as it requires the agreement of local authorities and the implication of several stakeholders in the field. The participatory methods in the development of the tool may enhance the probability of action being taken after the evaluation process (Zukoski and Luluquisen, 2002), but this does not solve the problem of poor dissemination of findings to a wider audience.

The developed tool has led to a better understanding of the situation and helped to define the criteria that influence VAHW effectiveness and sustainability. Nonetheless, it was limited to the technical effectiveness of VAHWs and did not target the allocative efficiency of such a system. Evaluating allocative efficiency would require developing a more complex tool to target the direct impact within the community, such as the decrease of animal morbidity and mortality or the growth of livestock productivity, and the indirect impact such as the reduction of public health risk or the improvement of human welfare (Riviere-Cinnamond, 2005).

Because participatory methods are more time-consuming than conventional processes (KU Work Group for Community Health and Development, 2013), we involved VAHWs from only two districts from two provinces. Moreover, as no complete list was available of VAHWs in the target areas with their accurate status (active or inactive) at the time of the study, the selection process may have induced a lack of representativeness and so may have had an influence on the accuracy of the tool. Another bias may have been introduced during the technical workshop conducted in the fourth phase. VAHWs may feel poorly understood by decision makers and have competing interests (Zukoski and Luluquisen, 2002). Some may have been somewhat reluctant to provide information when confronted with persons associated with government authorities. Other features of the field evaluation tool are the five closed questionnaires directly asking for local stakeholders' opinions of the VAHW. Personal relations between these stakeholders and the VAHW may influence the answers and may introduce bias in the results of the evaluation (Blanc et al., 2003). For this reason a minimum of 14 stakeholders should be interviewed to reduce subjectivity when assessing the satisfaction of beneficiaries. Biases may also have been introduced due to the translation process, affecting the understanding of stakeholders despite the efforts of the research team. Finally, the research team may have influenced participants' perception in weighting the "sustainability" category in the evaluation as they allocated the highest number of points to this category.

Another study, following the present one, implemented this evaluation tool on a larger scale between December 2011 and March 2012. The objective was to assess 300 VAHWs in Cambodia; the results will be reported in greater detail in a subsequent publication. They will be analyzed to compare the DVs' perception of VAHWs effectiveness with what is obtained from the criteria grid evaluation as well as to estimate the factors associated with a high level of effectiveness so that these can be fed into future training programs.

CAHWs in developing countries are expected to earn their salary, at least in part, and replenish their equipment (e.g. drugs kit) by charging for the services and drugs sold to farmers (Riviere-Cinnamond, 2005). Many VAHWs have had to abandon their services because they lacked the resources with which to sustain the slow rate of payment (CelAgrid, 2007). Hence there is a need to extend the economic criteria to include in the evaluation. These economic criteria should focus on economic viability and financial sustainability (Riviere-Cinnamond, 2005). A full impact assessment would be useful to evaluate the cost-benefit of such a system at community level but also at national level to assess the global impact on farmers' livelihoods in Cambodia.

Many NGOs are working in the field of animal health in Cambodia, and this tool could be used as a progress indicator for their projects with ex-ante and ex-post evaluations. The results could be pooled between these organizations and could help to improve the tool. Moreover, the tool could be of service to NGOs in valorizing the results they present to the backers.

The participatory process in evaluation could also be proposed to assess health volunteers in Cambodia, where their roles and responsibilities, compensation framework and institutionalizing of management structures and supervision remain complex (Mitchell, 2006). It could also be used to assess the various health stakeholders in other countries on a larger scale. In a One Health approach, a participatory tool using the same method could be developed to assess the effectiveness of community-health workers in the control of zoonotic diseases. This may lead to better communication between health services and would help to identify possible avenues for improvement.

## 5. Conclusions

This methodology, involving stakeholders at every step, has great potential for public health as there is a general lack of evaluation in the health promotion sector (Jolley, 2013; Carvalho et al., 2004; Springett, 1995). The evaluation of community-based (animal) health workers tends to focus on measuring changes in mortality and morbidity, while the evaluation outcomes may include increased individual or community levels of empowerment, increased collaboration and action for change by stakeholder groups, implementation of new public policy to support health (Jolley, 2013). Indeed, the evaluation criteria, comparable to performance indicators, were developed by the VAHWs and relevant stakeholders according to their own perceptions. This tool can be considered as a management tool leading VAHWs to improve their efficiency and effectiveness; and as an educational process in which VAHWs and other participants increase their understanding of the situation (Springett, 1995).

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## Appendix A.

**Table A1**
Criteria grid for the evaluation of VAHWs.

| | People to interview | Sustainability | 39 |
|---|---|---|---|
| S1 | DV–CC–Village Chief | Satisfaction from local authorities: Village chief, Commune Council District Vet | 4 |
| | | Support from 3 of them | 4 |
| | | Support from 2 of them | 3 |
| | | Support from 1 of them | 2 |
| | | No support from local authorities | 0 |
| S2 | Villager | Trust from villagers | 10 |
| | | 100% villagers trust the VAHW | 10 |
| | | Between (≥) 90% and (<) 100% villagers trust the VAHW | 7 |
| | | Between (≥) 75% and (<) 90% villagers trust the VAHW | 4 |
| | | Between (≥) 50% and (<) 75% villagers trust the VAHW | 1 |
| | | Less than (<) 50% villagers trust the VAHW | 0 |
| S3 | VAHW | Volume of activity as a VAHW | 9 |
| | | First source of income | 9 |
| | | Second source of income | 6 |
| | | Third source of income | 3 |
| | | More than third source of income | 0 |
| S4 | VAHW | In how many villages do you work? | 4 |
| | | More than one | 4 |
| | | One | 0 |
| S5 | VAHW | How long have you been working as a VAHW? | 5 |
| | | 5 years or more | 5 |
| | | 4 years | 4 |
| | | 3 years | 3 |
| | | 2 years | 2 |
| | | Less than 2 years | 0 |
| S6 | VAHW | Do you own a house in the village? | 7 |
| | | Yes | 7 |
| | | No | 0 |

| | People to interview | Treatment | 25 |
|---|---|---|---|
| T1 | Villager | Does the VAHW go to the farm when villagers ask for it? | 3 |
| | | VAHW always goes to cure animals when villager call him (100% of villagers who called him) | 3 |
| | | VAHW very often goes to cure animals when villager call him (between (≥) 80% and (<) 100% of villagers who called him) | 2 |
| | | VAHW often goes to cure animals when villager call him (between (≥) 50% and (<) 80% of villagers who called him) | 1 |
| | | VAHW sometimes goes to cure animals when villager call him (less than (<) 50% of villagers who called him) | 0 |
| T2 | Villager | Is the VAHW coming in less than 4 h after villager calls? | 2 |
| | | Yes for more than (≥) 80% of the villager interviewed | 2 |
| | | Yes for less than (<) 80% of the villager interviewed | 0 |
| T3 | Villager | When the VAHW visited your sick animal, did he take the temperature? | 3.5 |
| | | Yes for all villagers (100%) | 3.5 |
| | | Yes for villagers between (≥) 80% and (<) 100% | 2 |
| | | Yes for between (≥) 50% and (<) 80% of villagers | 1 |
| | | Yes for less than (<) 50% of villagers | 0 |
| T4 | Villager | Did the VAHW give you the name of the disease and advices about the disease? | 1.5 |
| | | More than (≥) 80% say the VAHW gave them the name of the disease and advices | 1.5 |
| | | Between (≥) 50% and (<) 80% say the VAHW gave them the name of the disease and advices | 1 |
| | | Less than (<) 50% say the VAHW gave them the name of the disease and advices | 0 |
| T5 | Villager | Were you satisfied by the cost of the treatment of VAHW? | 3 |
| | | 100% of villagers are satisfied | 3 |
| | | Between (≥) 70% and (<) 100% of villagers are satisfied | 2 |
| | | Between than (≥) 50% and (<) 70% of villagers are satisfied | 1 |
| | | Less than (<) 50% of villagers are satisfied | 0 |
| T6 | Villager | Were you satisfied by the efficiency of the treatment of VAHW? | 2.5 |
| | | 100% of villagers are satisfied | 2.5 |
| | | Between (≥) 70% and (<) 100% of villagers are satisfied | 2 |
| | | Between than (≥) 50% and (<) 70% of villagers are satisfied | 1 |
| | | Less than (<) 50% of villagers are satisfied | 0 |
| T7 | VAHW | What do you ask to the farmer before making a diagnosis? | 2 |
| | | What kind of faeces? | How many animals are sick/died? |
| | | What kind of feed? | Is it a new animal/introduce recently? |
| | | Do they eat? | Did you give treatment already? |
| | | How long the animal is sick? | Are your animals vaccinated/for what? |
| | | 4 good answers | 2 |
| | | Less than 4 good answers | 0 |

**Table A1** ( *Continued.* )

| | People to interview | Treatment | 25 |
|---|---|---|---|
| T8 | VAHW | Make a diagnosis (quiz) | 4 |
| | | 12 good answers (100%) | 4 |
| | | Between 9 and 11 good answers (≥75% and <100%)) | 3 |
| | | Between 6 and 8 good answers (≥50% and <75%) | 1 |
| | | 5 or less than 5 good answers (<50%) | 0 |
| T9 | VAHW | Treatment (quiz) | 3.5 |
| | | 14 good answers (100%) | 3.5 |
| | | Between 10 and 13 good answers (≥75% and <100%) | 2.5 |
| | | Between 7 and 9 good answers (≥50% and <75%) | 1 |
| | | 6 and less than 6 good answers (<50%) | 0 |
| | **People to interview** | **Production** | **16** |
| P1 | Villager | Do you know if some villagers are going to visit VAHW's farm? | 3 |
| | | Yes for 100% of villagers | 3 |
| | | Yes for villagers between (≥) 75% and (<) 100% | 2.5 |
| | | Yes for villagers between (≥) 50% and (<) 75% | 1.5 |
| | | Yes for villagers between (≥) 25% and (<) 50% | 0.5 |
| | | Yes for less than (<) 25% | 0 |
| P2 | Villager | Provide advices to villagers about production and economic analysis | 4 |
| | | VAHW gives advices to most of villagers about production (≥75% to 100%) | 4 |
| | | VAHW gives advices to villagers about production (≥50% to <75%) | 2 |
| | | VAHW doesn't give advices to villagers about production (<50%) | 0 |
| P3 | VAHW | Are you still raising animals? What animals do you have? | 5 |
| | | Yes, pigs and cattle | 5 |
| | | Yes, pigs or cattle | 3 |
| | | Yes, only poultry | 1 |
| | | No | 0 |
| P4 | VAHW | Do you implement improved technique in you farm, and in which fields? | 4 |
| | | Feeding Breeding Housing Hygiene Recording Deworming Vaccination | |
| | | 4 or more | 4 |
| | | 3 fields | 3 |
| | | 2 fields | 2 |
| | | 1 field | 1 |
| | | 0 field | 0 |
| | **People to interview** | **Vaccination** | **13** |
| Vaccination campaign organized by government and NGO | | | |
| V1 | DV | Did you have a report for each vaccination campaign? | 1 |
| | | Yes | 1 |
| | | No | 0 |
| V2 | Village Chief | Is there a place where VAHW use to organize vaccination campaign? | 1 |
| | | Yes | 1 |
| | | No | 0 |
| V3 | Village Chief | Does the VAHW carry out vaccination in the frame of government or NGO campaign? | 2 |
| | | VAHW carries out more than 50% of vaccination campaigns conducted in the village | 2 |
| | | VAHW carries out less than 50% of vaccination campaigns conducted in the village | 0 |
| Vaccination out of vaccination campaign organized by government | | | |
| V4 | Villager | Inform villagers about vaccination (benefits and advantages) | 1 |
| | | 100% were informed | 1 |
| | | Between (≥) 75% and (<) 100% of the villagers were informed | 0.75 |
| | | Between (≥) 50% and (<) 75% of the villagers were informed | 0.5 |
| | | Less than (<) 50% of the villagers were informed | 0 |
| V5 | Villager | Carry out vaccination out of the frame of vaccination campaign | 2 |
| | | Yes for all the villagers interviewed (100%) | 2 |
| | | Yes for villagers interviewed between (≥) 75% and (<) 100% | 1.5 |
| | | Yes for villagers interviewed between (≥) 50% and (<) 75% | 1 |
| | | Yes for less than (<) 50% of villagers interviewed | 0 |
| V6 | Villager | Give advices to villagers about how to take care animals after vaccination | 1 |
| | | All villagers received advices (100%) | 1 |
| | | Between (≥) 75% and (<) 100% of villagers received advices | 0.75 |
| | | Between (≥) 50% and (<) 75% of villagers received advices | 0.5 |
| | | Less than (<) 50% of villagers received advices | 0 |
| General | | | |
| V7 | VAHW | How do you store your vaccines? | 3 |
| | | VAHW uses a fridge to conserve his vaccines | 3 |
| | | VAHW uses an ice box with ice to conserve his vaccines | 1.5 |
| | | VAHW has no ice to conserve his vaccines | 0 |
| V8 | VAHW | For all the vaccine, which animal you cannot vaccinate? | 2 |
| | | Sick animals | 2 |
| | | Other answer | 0 |

**Table A1** ( *Continued.* )

| | People to interview | Reports | 7 |
|---|---|---|---|
| R1 | DV | Does the VAHW is regularly invited to meetings? | 1 |
| | | Yes | 1 |
| | | No | 0 |
| R2 | DV–CC | Does the VAHW follow DV's recommendations after outbreaks? DV CC | 0.5 |
| | | VAHW follows DV's recommendations more than 80% of the time | 0.5 |
| | | VAHW follows DV's recommendations less than 80% of the time | 0 |
| R3 | DV–CC–Village Chief | Does the VAHW reports high morbidity/mortality in less than 12 h? DV CC VC | 1 |
| | | To District Vet | 1 |
| | | Not to District Vet but to Village Chief and/or Commune Council | 0.5 |
| | | No report/report in more than 12 h | 0 |
| R4 | DV | Does the VAHW report to DV about animals' movement and census? | 1 |
| | | VAHW often does report to DV about animals movement and census | 1 |
| | | VAHW sometimes does report to DV about animals movement and census | 0.5 |
| | | VAHW rarely does report to DV about animals movement and census | 0 |
| R5 | Villager | Did the VAHW inform you about contagious disease in the district or about the analysis results after samples in your farm? | 1 |
| | | Yes for more than (≥) 50% of villagers | 1 |
| | | Yes for villagers between (≥) 30% and (<) 50% | 0.5 |
| | | Yes for less than (<) 30% of villagers | 0 |
| R6 | Villager | When you particularly fear for your animals health (unknown disease, high mortality), who do you call? | 1.5 |
| | | VAHW for more than (≥) 80% of villagers | 1.5 |
| | | Other | 0 |
| R7 | VAHW | What are the four diseases do you have to report? | 1 |
| | | Avian flu in poultry | Haemorrhagic septicaemia in cattle |
| | | PRRS in swine | Foot and mouth disease in cattle |
| | | 4 good answers | 1 |
| | | 3 good answers | 0.75 |
| | | 2 good answers | 0.5 |
| | | 1 good answer | 0.25 |
| | | No good answer | 0 |

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# ANNEX 4

Original Paper

# Use of a Text Message-Based Pharmacovigilance Tool in Cambodia: Pilot Study

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## Abstract

**Background:** There is no functional pharmacovigilance system in Cambodia to our knowledge. Mobile phone–based tools, such as short message service (SMS) text messages, are increasingly used for surveillance purposes.

**Objective:** To pilot-test the FrontlineSMS mobile phone–based tool for notification of adverse events, using Cambodia's only International Vaccination Center at the Institut Pasteur du Cambodge as a field site.

**Methods:** People receiving vaccinations, aged over 18 years, and who owned a cell phone were recruited in the study following informed consent. The names and mobile phone numbers of the participants interviewed were entered each day into the FrontlineSMS software. Two days after being vaccinated, participants received an automatically generated SMS text message asking whether any adverse events had occurred. Their SMS reply was number-coded and exported from the software daily to an Excel spreadsheet and examined before being saved. If the participant replied with a code for a severe adverse event (8 or 9), they were automatically advised to consult the nearest doctor.

**Results:** The active surveillance study was conducted over 72 days in the spring of 2012. Patients agreed to be asked by SMS text message whether unwanted events had occurred after vaccination. Of 1331 persons aged over 18 years referred to the vaccination unit, 184 (13.8%) were asked and agreed to participate. When texted for clinical status 48 hours after vaccination, 52 (28.3%) participants did not reply, 101 (54.9%) sent an immediate SMS reply, and 31 (16.8%) sent an SMS reply after additional prompting. Of the initial 184 participants, 132 (71.7%) replied. These 132 participants received 135 vaccine doses and 109 (82.6%) reported no adverse events, whereas 23 (17.4%) reported adverse events, all benign.

**Conclusions:** Notification using an SMS-based text message system is already used in Cambodia for syndromic surveillance in health centers and reporting by health care workers. Our results show that such tools can also be useful for notification by patients or health users in Cambodia, especially in an urban setting.

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**KEYWORDS**
cellular phone; text messages; texting; short message service; vaccines; adverse events; surveillance; adverse drug reaction reporting systems; pharmacovigilance

## Introduction

The burden of disease can be threefold in developing countries faced with communicable diseases, noncommunicable diseases, and sociobehavioral illnesses [1]. Most of these may require treatment or prevention through medication or vaccines. In addition to the expectable adverse events in the normal usage of registered drugs, developing countries also face a plague of counterfeit or substandard drugs [2-5]. Pharmacovigilance—a form of epidemiological surveillance that monitors the occurrence of adverse events of drugs [6,7] or vaccines [8-10] to guide timely corrective action and mitigate risk—is an essential tool for patient safety in developed countries and in an increasing number of developing countries [11]. Cambodia, a developing country in Southeast Asia, is not among the 109 countries participating in the World Health Organization (WHO) Programme for International Drug Monitoring maintained in collaboration with the Uppsala Monitoring Center in Uppsala, Sweden [12]. To our knowledge, there is no functional pharmacovigilance program in Cambodia.

Pharmacovigilance has been conducted using complex and rigorous notification procedures in developed countries, but it faces challenges in developing countries because of issues with clinician awareness, clinical expertise, or nonfunctional reporting systems [11,13,14]. Therefore, some programs or countries have circumvented these challenges by implementing mobile phone-based and Web-based tools using short message service (SMS) text messaging for immediate notification of adverse events [15,16].

FrontlineSMS is one such reporting tool [17]. It has been used in Cambodia for various health-related projects, but always for information exchange among health providers and stakeholders [18-20]. An Epidemiology Master student helped pilot its use for surveillance in direct link with health users in a vaccination center. More than 25,000 vaccine doses were administered to 16,630 health users in 2012 (Figure 1) referred to the International Vaccination Center at the Institut Pasteur du Cambodge (IPC), the only such vaccination center in Cambodia (Figure 2). The aim of this study was to field-test the FrontlineSMS software to see whether it could provide effective and timely notification of vaccine adverse events.

**Figure 1.** Vaccination at the International Vaccination Center, Institut Pasteur du Cambodge.

**Figure 2.** The waiting room of the international vaccination center at the Institut Pasteur du Cambodge.

## Method

The research project received ethical approval from the national ethics committee on health research on February 17, 2012. Data collection began March 12, 2012, and ended May 31, 2012.

During that period, a research assistant from the epidemiology and public health unit at IPC (a native Khmer speaker) spent several hours each day at the International Vaccination Center to recruit participants. Participants were eligible to be included in the study if they were aged over 18 years, came to the center to be vaccinated themselves (ie, not for their children), agreed to participate, owned a cell phone, and knew how to send SMS text messages. If so, the research assistant informed them about the study, read through the protocol, explained the objectives of the pharmacovigilance project in Khmer, and asked the participants to complete an informed consent form. Information about their name, age, place of residence, type of vaccine, and mobile phone service provider were collected. The names and mobile phone numbers of the participants interviewed were entered each day in the FrontlineSMS software.

Two days after being vaccinated, participants received an automatically generated SMS text message. This message thanked them for participating and asked whether any adverse events had occurred. Their SMS reply was number-coded as follows: 0=no adverse event, 1=mainly redness and/or pain at the injection site, 2=mainly fatigue and/or weakness, 3=mainly headaches, 4=mainly fever, 5=mainly runny or congested nose, 6=mainly muscle pains, 7=mainly abdominal pain, 8=seizures or neurological problems, and 9=severe allergic reaction. Only 1 code was allowed per reply. Messages received were exported from the software daily to an Excel spreadsheet and examined before being saved.

Upon receiving the text reply, a software-generated message was sent. If the codes corresponded to no or a moderate adverse event (codes 0-7), the reply was: “We have received your message. Thank you for having participated.” If the participant sent back a code for a severe adverse event (8 or 9), the reply read: “You have reported a severe adverse event. Please consult the nearest doctor as soon as possible. If in Phnom Penh, we recommend that you refer to Hôpital Calmette.” (The Hôpital Calmette is a national reference hospital where the emergency department team had been informed of the study.) In cases when a severe adverse event was reported, the research assistant called the participant’s cell phone number directly to follow-up on the participant. If the case was referred to Hôpital Calmette, transportation costs were covered by the study. There was no other financial compensation to participants, including for costs associated with sending SMS text messages.

## Results

The study took place between March 13 and May 25, 2012, for a total of 72 days: 53 days of which the International Vaccination Center was open and 19 days of which it was closed (weekend or national holidays, Figure 3). During some of those days, the research assistant did not recruit participants because she was involved in another study.

During the 53 days that the International Vaccination Center was open in that period, 1331 persons aged over 18 years (684 women and 647 men) came for vaccinations at the center (mean 25.1 persons aged ≥18 years per day, Figure 4).

Of the 1331 vaccinees, 184 were asked and agreed to participate to this pilot study (97 female, 87 male). Of these 184 participants, 165 (90.2%) resided in Phnom Penh; 6 (3.3%) in Kampong Speu; 3 (1.6%) each in Kandal and Kompong Cham, respectively; 2 (1.1%) in Siem Reap; and 1 (0.5%) each in Takeo, Battambang, Mondulkiri, and Rattanakiri, respectively. Mean age of all 1331 health users during that period was 34.8 years (SD 12.7, range 18-95), although the subgroup of study participants was younger (mean 26.9 years, SD 7.8, range 18-65). The 184 participants subscribed to 6 cell phone companies, the largest of which accounted for 83 (45.1%) of the participants.

The 184 health users who initially agreed to participate in the study received a total of 192 vaccine doses for 17 different diseases (Table 1).

**Table 1.** Vaccines administered to study participants and reported adverse events for the pharmacovigilance pilot study at the Institut Pasteur du Cambodge from March to May 2012 (N=184).

| Vaccine[a] | No adverse event | Mainly redness and/or pain at the injection site | Mainly fatigue and/or weakness | Mainly fever | Mainly runny or congested nose | No reply | Total |
|---|---|---|---|---|---|---|---|
| Hepatitis A | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Hepatitis B | 39 | 4 | 3 | 1 | 0 | 30 | 77 |
| Haemophilus influenza | 2 | 0 | 0 | 1 | 0 | 0 | 3 |
| Japanese encephalitis | 9 | 0 | 0 | 0 | 0 | 1 | 10 |
| MMR | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| Meningitis | 2 | 0 | 0 | 0 | 0 | 0 | 2 |
| Chickenpox | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Pneumococcus | 2 | 0 | 0 | 0 | 0 | 2 | 4 |
| Rubella | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| Tetanus | 13 | 3 | 1 | 0 | 0 | 3 | 20 |
| Tetanus & rabies | 2 | 0 | 0 | 0 | 0 | 2 | 4 |
| DTCP | 2 | 1 | 1 | 0 | 1 | 0 | 5 |
| Typhoid | 2 | 0 | 0 | 0 | 0 | 0 | 2 |
| HPV | 10 | 3 | 0 | 1 | 2 | 4 | 20 |
| Influenza | 17 | 0 | 0 | 0 | 0 | 5 | 22 |
| Influenza & Hib | 2 | 0 | 0 | 0 | 0 | 0 | 2 |
| Influenza & tetanus | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Rabies | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| Yellow fever | 4 | 0 | 0 | 0 | 0 | 2 | 6 |
| Yellow fever & meningitis | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| Total | 109 | 12 | 5 | 3 | 3 | 52 | 184 |

[a] MMR: measles, mumps, rubella; DTCP: diphtheria, tetanus, pertussis, polio; HPV: human papillomavirus; Hib: *Haemophilus influenzae* serotype B.

Most of the vaccinations given were against hepatitis B (41.8%), influenza (11.9%), tetanus (10.9%), and human papillomavirus (HPV) (10.9%). Fifty-two participants (28.2%) did not send a reply (including 30 of 77 who received vaccination against hepatitis B), and 132 (71.7%) did send a reply, of which 101 (76.5%) completed the study as per the study protocol and sent a correct SMS text reply, whereas 31 (23.5%) participants had to be contacted twice because they replied incorrectly or did not reply at all (Figure 2). These 132 respondents received a total of 137 doses of vaccine. In all, 109 (82.6%) respondents reported no occurrences of adverse events, whereas 23 (17.4%) did report adverse events, none of which were severe (Table 1). Twelve (52.2%) of these adverse events pertained to redness at the injection site, and 3 (13.0%) pertained to fever. The time between the initial sending of the SMS text and the reply from participants was documented in 120 messages (mean 0.4 days, SD 0.82, range 0-5). The reply was received within the same day in 91 (75.8%) of documented answers.

**Figure 3.** Number of health users at the international vaccination center and inclusions in the SMS pilot study, Institut Pasteur du Cambodge, March-May 2012.

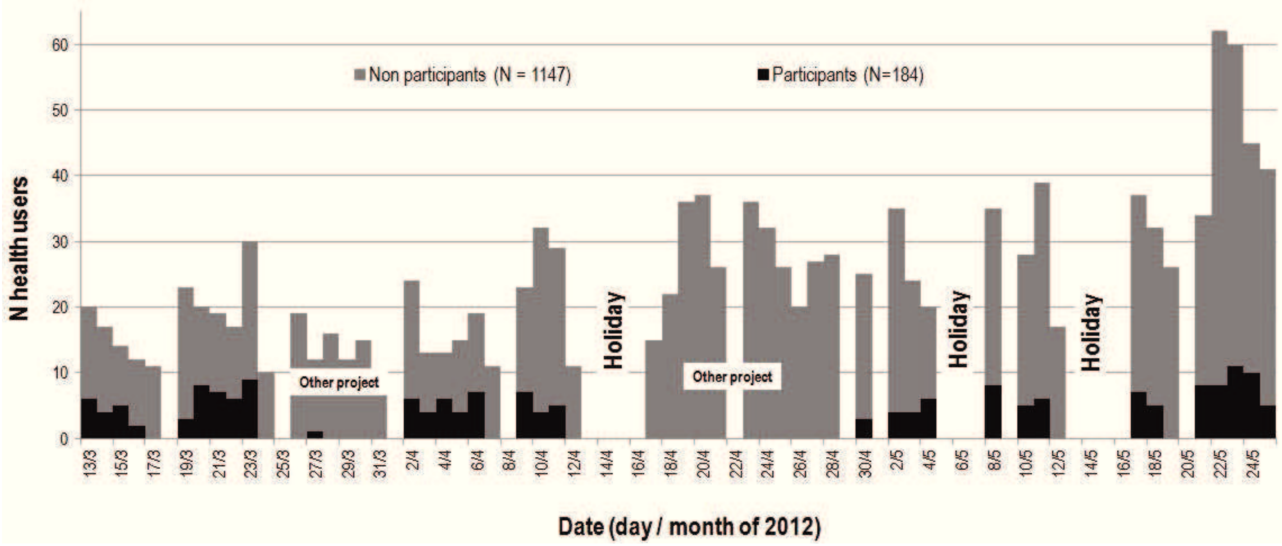
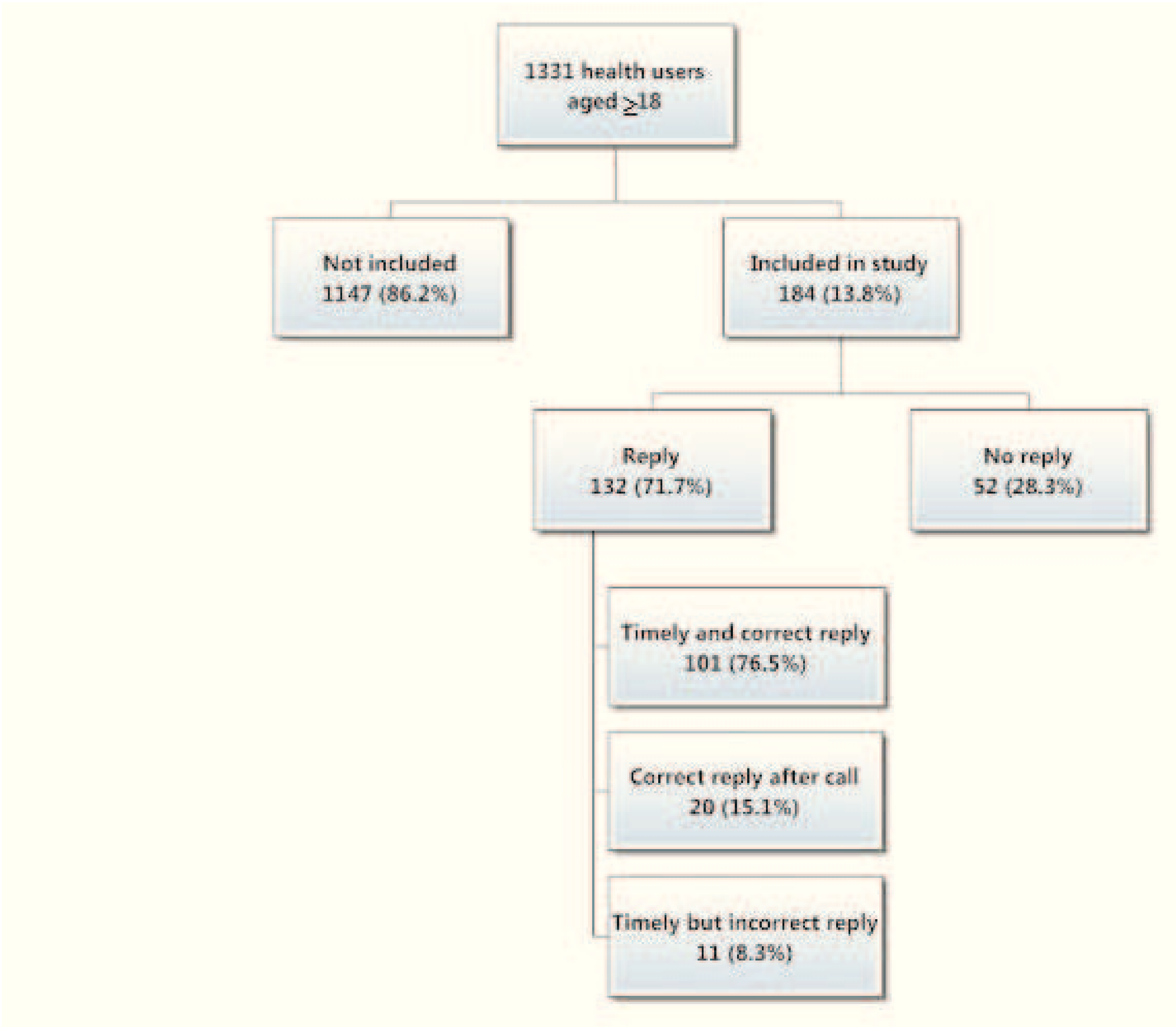



**Figure 4.** Flowchart of patient recruitment in the pilot SMS text-based pharmacovigilance study at International Vaccination Center, Institut Pasteur du Cambodge, March-May 2012 (percentage total may not equal 100% due to rounding).



## Discussion

The objective of this pilot study was to assess the feasibility of an SMS text-based reporting tool for pharmacovigilance in Cambodia. According to the International Communications Union database, there were 69.9 mobile-cellular telephone subscriptions per 100 (%) inhabitants in Cambodia in 2011 (slightly less than India), up from 7.95% in 2005 [21]. This translates to approximately 10 million cellular telephone subscriptions in Cambodia in 2011, a country with an estimated population of approximately 14 million [22].

To our knowledge, this pilot SMS text-based system for active detection of adverse events following vaccination is the first functional pharmacovigilance system in Cambodia, the first SMS text-based surveillance system relying on health users' participation in Cambodia, and the first to use SMS text-based surveillance for adverse event detection anywhere [20]. In this project, operating costs were modest, with only part-time activity dedicated to entering cell phone numbers, downloading SMS replies, and checking that no SMS texts received alerted to severe adverse events.

During the 2.5-month pilot phase, the participation rate was high with a 71.7% response rate. Of 77 persons who were vaccinated against hepatitis B, 30 (39%) sent no reply. Although this percentage may seem high, the hepatitis B vaccines were the most frequently administered, and the small study group makes nonreply percentages vary greatly.

With 132 participants replying and 24 reporting adverse events (none severe), the prevalence of adverse events was slightly higher than expected. The expected rate of adverse events following immunization is estimated to be in the order of 10%, except for diphtheria, tetanus, pertussis (DTP) or tetanus boosters in which fever occurs in nearly half of recipients [23]. In 2008, in Australia, 1542 adverse events (7.2 per 100,000 population) following immunization were notified by manufacturers, health professionals, or the public [24]. This passive surveillance system also includes children, who are the main recipients of vaccines. Of these adverse events, 41% were site reactions and 16% were fevers. Our data, albeit on a far more modest scale and not including children, showed comparable percentages (52.2% and 13.0%, respectively). A study conducted in the United Kingdom showed that patients tend to report more benign adverse drug reactions than health care providers, and concluded that patient-based pharmacovigilance may usefully complement health care provider reporting of adverse events [25].

The participants' response rate was unexpectedly high, probably enhanced by the use of short and simple SMS text-based reply codes. This research project also had a research assistant to explain the protocol at length in the national language, which would not be the case in a daily operational setting where a simple leaflet or poster would provide information to the health users.

Our study suffers from biases and limitations. Firstly, the number of participants was very limited. The epidemiological findings of such a small and short study on adverse events are difficult to extrapolate. Secondly, the patients recruited all attended the IPC's International Vaccination Center in Phnom Penh. Costs there may be higher because of state-of-the-art quality control carried out on vaccines imported primarily from Europe. Therefore, recruitment may have been biased toward younger, more affluent, well-informed, urban residents more accustomed to sending SMS text messages. This limits the possibility of extending similar systems outside of large urban centers within Cambodia, at least in the short term. Experience with SMS text-based surveillance in the rural setting found that many farmers did not know how to send text messages [18]. Thirdly, only the last-generation cellular telephones support Khmer fonts or pictures of Khmer-language text, whereas the vast majority of cellular phones do not. Lastly, some operators mainly offer voice-based communications and no data or SMS text transfers because telephone communications are relatively cheap and there is no advantage to sending a text message.

Bearing these limitations in mind, this small pilot study serves as a proof of concept that health user–sent, SMS text-based surveillance strategies can be used in an urban Cambodian setting. This is an important step in Cambodia where health surveillance systems facing numerous challenges may often be dysfunctional and where pharmacovigilance is absent. Our secondary objective was also met, which was to become proficient in the use of FrontlineSMS for other potential applications. Technology for mobile telephone–based active surveillance appears to be cheap, easy to implement, simple, and quick to be mastered by field staff. This approach will be used by the Epidemiology and Public Health Unit at the Institut Pasteur du Cambodge to implement follow-up programs, such as monitoring outcomes in rabies postexposure prophylaxis at IPC's Rabies Prevention Clinic (over 20,300 referrals in 2011) or in prospective studies on dengue in urban settings.

**Acknowledgments**

We wish to gratefully acknowledge the health users at IPC's international vaccination center for agreeing to participate in this pilot study. This study was conducted thanks to a grant from the Pierre Ledoux Foundation and additional support from the Centre de coopération internationale en recherche agronomique pour le développement (Cirad). We also want to acknowledge the Social Impact Lab Foundation for developing and allowing free access to the open-source FrontlineSMS software package.

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## Abbreviations

**DTP:** diphtheria, tetanus, polio
**DTCP:** diphtheria, tetanus, pertussis, polio
**HPV:** human papillomavirus
**IPC:** Institut Pasteur du Cambodge
**SMS:** short message service
**WHO:** World Health Organization

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# ANNEX 5

# Abstract submission form

| | |
|---|---|
| **Poster or Oral** | Oral |
| **Session** | Field epidemiology in poultry |
| **Invited by session organiser** | No |
| **Title of Abstract** | Spatio-temporal analysis of avian influenza H5N1 outbreaks in human and poultry population in Cambodia. |
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In Cambodia, highly pathogenic avian influenza H5N1 (A/H5N1 HP) virus infection has widely affected the poultry population. Most of the outbreaks have been detected through passive surveillance, either in animal or in human. Declared villages are often the top of the iceberg; delays between the first case and the detection enable the virus to spread from house to house and then village to village through direct or indirect transmission. Recent spatial analysis showed that during the several epizooties occurring in Thailand there were few points of disease emergence and that most of the outbreaks were the consequence of short distance dissemination. Between February 2010 and February 2011, 4 outbreaks of A/H5N1 HP have been spatialy investigated in order to understand how local spread happened and to identify the most important determinants of disease propagation.

For each outbreak, field investigation of all the villages within a maximum of 20 km radius of the first case reported were conducted in order to collect information about census of poultry, mortality level in the previous months, species affected, symptoms, date of onset, date of end, movement in and out of the village. Possible cases of A/H5N1 HP were defined with the use of inclusion criteria based on mortality level and clinical signs, criteria established from a previous study about the definition of a specific case definition of A/H5N1 HP in Cambodia.

In total 588 villages were visited, out of them 132 have been included as cases with important difference in their repartition between each outbreak. Spatial analysis showed that the origin of new outbreaks in Cambodia are various from long distance dissemination through movement of poultry product or infected people, to short distance dissemination with a postive association with the presence of road network. Some of this findings could be used by the veterinary services to limit the number and the size of future outbreak in the poultry population.

# ANNEX 6

***How to Reach the Poor? Surveillance in low-income countries, lessons from experiences in Cambodia and Madagascar***

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**Abstract**

Surveillance of animal diseases in developing countries faces many constraints. Innovative tools and methods to enhance surveillance in remote and neglected areas should be defined, assessed and applied in close connection with local farmers, national stakeholders and international agencies. The authors performed a narrative synthesis of their own publications about surveillance in Madagascar and Cambodia. They analysed the data in the light of their fieldwork experiences in the two countries' very challenging environments. The burden of animal and zoonotic diseases (e.g. avian influenza, African swine fever, Newcastle disease, Rift Valley fever) is huge in both countries that are among the poorest in the world. This implies a lack of human and financial means to ensure effective surveillance of emerging and endemic diseases. Several recent projects have shown that new approaches can be proposed and tested in the field. Several advanced participatory approaches are promising and could be part of an innovative method for improving the dialogue among different actors of a surveillance system. Thus, 'participatory modelling', developed for natural resources management involving local stakeholders, could be applied to health management, including surveillance. Data transmission can benefit from the large mobile-phone coverage in these countries. Ecological studies and advances in the field of livestock surveillance should guide methods for enhancing wildlife monitoring and surveillance. Under the umbrella of the One Health paradigm, and in the framework of a risk-based surveillance concept, a combination of participatory methods and modern technologies could help to overcome the constraints inherent to the low-income countries. These unconventional approaches should be merged in order to optimize the surveillance of emerging and endemic diseases in challenging environments.

**Keywords:** challenging environment, Cambodia, Madagascar, participatory surveillance, companion modelling.

## 1. Introduction

In 2010 the World Bank estimated that 21% of the population in developing countries were extremely poor (making a living with less than $1.25 per day), representing approximately 1.21 billion people (World Bank, 2014). Seventy five percent of these people live in rural areas and depend on agriculture and livestock raising for their livelihoods (Otte et al., 2012). Even with the acceleration of urbanization in developing countries, this situation will remain unchanged in the coming decades, with the majority of poor continuing to live in rural areas (United Nations, 2011). In Asia and Sub-Saharan Africa, the two poorest regions in the world, farm animals play a major role in food security by providing access to high quality food, better crop production (with manure and traction) and an important store of wealth and insurance in case of crop failure or sickness (Smith et al., 2013). In these regions, farming systems aim to ensure subsistence that is they produce low and unpredictable profits but require minimal external inputs. Poor rural farmers typically live in areas with a lack of infrastructure and limited access to markets, therefore a household's livelihood strategy cannot rely on a single source of income and farmers often prefer to keep multispecies herds in order to manage potential risks (Perry and Grace, 2009). Lack of disease control strategies and poor husbandry practices are common and result in a high prevalence of endemic production diseases, making herds and flocks more susceptible to epidemic diseases of high morbidity or mortality (Herrero et al., 2013). A significant number of these infectious diseases are zoonoses that can be transmitted to humans through direct or indirect contact. In low income countries, zoonotic diseases are responsible for 12% of human sickness and mortality (Grace et al., 2012) with the poorest populations being the most commonly affected.

Death of any livestock in a poor household will have an impact on the livelihood of the entire family, as they own fewer animals and rely almost exclusively on them for food, transport and farm work (Bordier and Roger, 2013). The impact will be even greater during disease epidemics, leading to sudden and rapid mortality of animals and often an important decrease in demand due to the fear of diseases, depriving the poorest families of critical assets and increasing their vulnerability (Perry et al., 2002). In this context surveillance and response systems are essential keys for the control of animal diseases. An effective surveillance system will have the capacity to rapidly detect the presence of the disease, to process the information and to provide appropriate responses to the decision makers and the stakeholders (Grosbois et al., 2015). The main objective of surveillance is to minimize the economic impact and the public health hazards resulting from epidemics, especially by the most vulnerable sectors of the population. However, the main difficulty of disease surveillance in many poor regions is the dearth of basic means to collect and transmit veterinary and public health data and samples from small farms and backyard livestock. Despite the capacity-efforts undertaken by OIE, with the use of the Performance of Veterinary Services (PVS) tool (OIE, 2014a), and the numerous projects implemented by agencies (e.g. FAO to control the H5N1 epizootic), the human resources needed for sustainable surveillance and rapid response - official services, public and private veterinarians, technicians - are often insufficient. Furthermore, when implemented, surveillance systems often suffer from a lack of coverage and fail to reach the poorest populations (Randolph et al., 2007). Data reports are often delayed, incomplete or biased. Several factors have been identified that contribute to disease underreporting: low density of health facilities with poor communication systems, poor awareness of disease by livestock owners, risk of penalty or stigmatization, distrust of governmental authorities and lack of qualified staff (Halliday et al., 2012). As a result, poorest farmers often rely on traditional "know-how" for animal disease management and don't perceive *a priori* how their participation in surveillance systems could contribute to improving their livelihoods.

CIRAD (French Research Centre for International Development) is a research institution specialized in working in tropical areas. Its mission is to support the rural development of developing countries through research and training actions and by exchanging technical and scientific knowledge (http://www.cirad.fr/en). Over the years, CIRAD has been actively involved in the development of research projects in the tropical countries. One recent research topic was the development of new and original tools for the design and evaluation of surveillance and control systems for animal diseases in order to support the most vulnerable populations in rural settings. Cambodia and Madagascar are among the poorest countries in the world, belonging to the 36 low-income economies ($1,035 or less of Gross

National Income per capita). Significant percentages of the populations of Madagascar (82.4%) and Cambodia (53%) live below the poverty line (earning less than $1.25 /day), representing the 4th and 38th poorest countries in the world respectively (World Bank, 2013).

The ministries of agriculture and the veterinary services of Madagascar and Cambodia are long-standing partners of CIRAD, with well-established research collaborations that will continue within the development of research platforms and regional networks. The research and development activities were set up to support the management of transboundary and emerging diseases through collaborative research. In these two geographic areas, researchers have primarily focused on developing a better understanding of the epidemiology and the risk factors of priority diseases (e.g. African swine fever and Rift Valley fever in Madagascar; foot-and-mouth disease and Japanese encephalitis in Cambodia) in order to develop more effective surveillance and control strategies (Vigier, 2011). More recently, researchers have worked on the design of more adapted evaluation frameworks for surveillance in developing countries and on the conception of innovative tools to assess the epidemiological and socioeconomic performance of surveillance in challenging countries (Cappelle et al., 2013). After more than a decade of collaboration within each country, we felt it was important before proposing new research projects to compare and analyse the research conducted by CIRAD into methods and tools to evaluate and improve the surveillance and control systems in Madagascar and in Cambodia. We believe that comparison of experiences and cross analysis of the research implemented in these two challenging environments could assist in development of new approaches and sustainable solutions for these low socioeconomic environments. Moreover, this approach will help us to prepare the phase of "impact evaluation" process that will be launched by the management of CIRAD in 2015/2016 for several case-studies including surveillance methods and systems. Our objective was to produce an overview of surveillance methods and tools currently developed or implemented by CIRAD researchers in Madagascar and Cambodia, and to critically analyse and review their field feasibilities in order to determine their benefits, and to strategically provide effective, targeted correctional interventions and recommendations.

## 2. Materials and methods

The methodology consisted of a systematic review of papers related to surveillance in Madagascar and Cambodia, followed by the use of narrative synthesis to compare and analyze the results of the systematic review. In order to meet our objectives, we limited our study to papers that have been published under projects implemented in whole or in part by CIRAD and by the authors of this paper who have an in-depth knowledge of the challenging environments of these countries.

### 2.1. Sources of information:

We searched the period 2004 to April 2014 on Scopus for papers in English or French using the following key words AFFIL (CIRAD) AND ALL ("Madagascar OR Cambodia") AND ALL ("Surveillance OR monitoring OR information system") and Google Scholar™ with the following key words, "CIRAD" AND "Madagascar OR Cambodia" AND "Surveillance OR monitoring OR information system" AND "animal diseases". Additional searches were performed using CIRAD's database, AGRITROP, and project websites (FSP project [GRIPAVI 2006-26] funded by the French Ministry of Foreign and European Affairs (MAEE) http://gripavi.cirad.fr/en/ , and DGAL funded project [FRIA-08-009 REVASIA]. http://revasia.cirad.fr/en/ ). All documents retrieved were screened to exclude papers that were not written by authors from CIRAD (homonyms or presence of the word CIRAD in the article or in the reference list of the paper), that were not about infectious animal diseases and from which no recommendation about surveillance systems could arise. Two reviewers conducted the appraisal and authors of selected studies were consulted in order to assess the contents and validity of the findings.

### 2.2. Narrative synthesis:

The choice of a narrative synthesis method was driven by the large variability of research protocols described in the papers retrieved by the review and by the qualitative nature of our results. This method allows the aggregation of qualitative data in order to produce a comprehensive analysis and synthesis of the results of a systematic review, using a textual approach (Popay et al., 2006).

The narrative synthesis method has been mainly developed for systematic review of intervention studies (Arai et al., 2007). The process usually follows four elements (development of a theoretical model, preliminary synthesis, assessing relationships in the findings, and validation of the synthesis).

The studies included in our review are different from intervention studies and are composed of various types (observational and descriptive studies, analytical studies, qualitative studies), therefore we have developed a modified process for our narrative synthesis involving 1) a description of the background of the studies implementation that we want to compare (country profile) 2) synthesis with textual description of each study, grouping of the studies, tabulation of results across studies 3) comparisons between studies and visualisation of the connection among findings with the use of radar charts and spider diagrams 4) testing the validity of interpretations by consulting primary authors of the studies.

The main objectives of this synthesis were to list and critically review surveillance tools and methods developed in Madagascar and Cambodia, in order to draw recommendations for future research in similar contexts. To be able to do that, we needed to first describe the socio-economic contexts of the two countries, the main diseases under surveillance with their epidemiological contexts and the tools and methods used by CIRAD researchers. Therefore the following data were extracted from each study in the form of textual description: details about the country in which the study was implemented, epidemiological and ecological conditions of the diseases (or health events) targeted in the study, type of surveillance described or mentioned (passive, active, risk-based, participatory etc.), population included in the surveillance, method or tool tested during the study, limitations and advantages of these methods or tools and recommendations for surveillance and control systems. Data that describe the current situations in Madagascar and Cambodia were completed with additional literature research and compiled under a "country profile".

## 3. Results

### 3.1. Flow diagram and data description:

A total of 148 papers were identified from Scopus and 63 from Google Scholar™. After exclusion and verification of duplicates, 17 and 5 papers remained respectively: 20 research articles (Baron et al., 2013; Bellet et al., 2012; Calba et al., 2014; Chevalier et al., 2011; Collineau et al., 2013; Conan et al., 2013; Costard et al., 2009; Desvaux et al., 2006; Domenech et al., 2006; Guerrini et al., 2014; Netrabukkana et al., 2014; Peyre et al., 2011; Rasamoelina-Andriamanivo et al., 2014; Ravaomanana et al., 2011; Reynes et al., 2005; Rith et al., 2013; Roger et al., 2004; Tarantola et al., 2014; Trevennec et al., 2011; Vergne et al., 2012), one policy brief (Roger, 2012) and one conference proceeding paper (Cappelle et al., 2013). The additional search in AGRITROP and CIRAD's projects' websites identified 11 new documents: 1 policy brief (M. Figuié et al., 2013), 4 technical reports (Antoine-Moussiaux et al., 2011; CIRAD, 2009; Desvaux, 2008; Thonnat, 2005), 4 conference proceeding papers (Figuié, 2013; Figuié and Desvaux, 2011; Figuié and Peyre, 2013; Roger et al., 2008), one thesis manuscript (Rasamoelina Andriamanivo, 2011) and one research paper (Renard, 2010). A total of 33 documents were used for this synthesis. The literature selection process is illustrated in Figure 1.

### 3.2. Data description:

Selected data were retrieved from the papers and grouped according to geographic area and disease or health event targeted by the study before being tabulated. These data are represented in three different tables according to the country or geographic areas targeted (Table 1 for Cambodia; Table 2 for Madagascar; Table 3 for regional research activities). The tools or methods implemented or described within the papers have been included in the tables and a qualitative assessment of their limitations and advantages was completed, using the attributes listed in the OIE guidelines for surveillance (OIE, 2014b) and the expertise of the authors of the reviewed papers. A summary of the main qualities of the tools and methods was displayed in radar chart form (Figure 2). The main limitations were the lack of representativeness, specificity, sustainability and simplicity. The main advantages were the sensitivity, the ownership, the usefulness and the flexibility. Qualitative case descriptions were used to compare data between countries in order to 1) identify similarities and differences in the epidemiological situations of the main transboundary, emerging and zoonotic diseases 2) identify methods and tools in data collection and data transmission that would be interesting to share between countries 3) understand the variability between the efficacies of the surveillance methods or tools within different population compartments, to inform the implementation of improved surveillance.

## 3.3. Country profiles:

As the purpose of our article is to provide generic recommendations for improving surveillance methods in a context of resource poor settings, we started by analyzing the epidemiological situations in Cambodia and Madagascar and providing elements of comparison between the 2 countries, on the basis of the 33 papers selected for the study.

### 3.3.1. Madagascar

Madagascar is one of the poorest countries in the world, with 82.4% of its population (22.29 million inhabitants in 2012) living in extreme poverty (i.e. earning less than $1.25 per day). The life expectancy is 64 years and 67% of the people live in rural areas (World Bank, 2013). The agriculture sector accounts for 27.3% of national GDP, with the majority of people raising livestock. The total bovine population is estimated at 10 million. Common cattle endemic disases are bovine tuberculosis (Rasolofo Razanamparany et al., 2006), anthrax (Blancou, 1968), blackleg (Rajaonarison et al., 2001), tick-borne diseases (Stachurski et al., 2013) and internal parasitism. In 2008-2009, Madagascar was severely affected by Rift Valley fever (RVF) (Andriamandimby et al., 2010). Besides the direct economic losses affecting farmers, with high mortality of young stock and high abortion rates in females, outbreaks of disease also damaged commercial trade of both live animals and farmed products. Similarly, the poultry industry plays an essential role in the Madagascar economy and livelihood. Food and Agriculture Organization of the United Nations estimates the domestic poultry population at 34.4 million birds (FAOSTAT database 2011: http://faostat.fao.org/). Small-scale commercial farms and backyard farms account for two thirds of the rural population and most of the Malagasy poultry are farmed in these systems (Ocean-Consultant, 2004). Therefore, avian disease outbreaks can lead to major consequences on household economies. Newcastle disease (ND) is the most prevalent poultry disease, accounting for 44% of poultry mortalities in the suburban area of the capital Antananarivo (Maminiaina et al., 2007).

With 1.38 million animals (FAOSTAT database 2011: http://faostat.fao.org/), the pig production sector is also significant, despite the devastating consequences that recurring outbreaks of African swine fever (ASF) since its introduction in the country (Roger et al., 2000) and classical swine fever (CSF) (Paton and Greiser-Wilke, 2003) have had on the livelihood of smallholders.

#### 3.3.2. Cambodia

In 2012, the population of Cambodia was 14.86 million people, with 80% living in rural areas. Despite increasing economic growth, 2.8 million of people are still considered very poor (earning less than $1.25 per day). Life expectancy is 71 years, and 40% of children under the age of 5 are in a malnourished condition (World Bank, 2013). The agriculture sector accounts for 30% of national GDP, and the livestock sector is the third most important subsector contributing about 5% of the GDP. The total bovine population is estimated at 3.68 million animals (MAFF, 2012). The annual mortality due to bovine diseases is estimated at 1%. Smallholders are facing numerous threats, including annual outbreaks of foot-and-mouth disease (FMD), endemic in Cambodia, and the presence of haemorrhagic septicaemia and internal parasites (Nampanya et al., 2012). Eighty five percent of rural households own pigs and raise the animals in traditional farming systems, with small herd sizes. It is not unusual to find only one animal in the poorest families. The annual pig mortality is very high, 46%, due to the endemic circulation of various infectious diseases (FMD, CSF, porcine reproductive and respiratory syndrome) (Shankar et al., 2012). Backyard poultry are present in almost every household, and the Ministry of Agriculture, Forestry and Fisheries of Cambodia (MAFF) estimated the total population of birds at 15 million. Production is characterised by low biosecurity level, with high risk of contagious diseases (ND, fowl cholera) and a high level of mortality (between 30% to 60% per year) (Zilberman et al., 2012). Highly pathogenic avian influenza (HPAI) H5N1 virus has been present in Cambodia since 2004, with regular outbreaks in the poultry sector. The disease, with a flock mortality rate above 50% within 1 to 3 days, had a dramatic effect on farmers' livelihoods, exacerbated by the national policy of culling without compensation, causing extreme financial losses for poor small-scale breeders (Zilberman et al., 2012).

To date, 42 avian outbreaks and 56 human cases have been identified, with a very high case fatality rate of 66% (WHO, 2014).

### 3.4. Comparative analysis of the epidemiological and ecological situations of the main transboundary (TADs), emerging (EIDs) and neglected tropical diseases (NTDs):

The two countries had similar TADs, EIDs and NTDs affecting or threatening their livestock sector. Regarding TADs, African swine fever (ASF) is endemic in Madagascar (Ravaomanana et al., 2011), which is also at risk for foot-and-mouth disease (FMD) due to its proximity to endemic areas (e.g. Mozambique). In Cambodia the situation is reversed, FMD is endemic (Bellet et al., 2012) and ASF absent. Nevertheless, ASF is prevalent in Africa and more recently in Russia, thus the increase of international trade and the high density of wild boars in Eurasia amplify the risk of ASF virus introduction in Southeast Asia and China, where the pork industry is growing strongly (Verbeke and Liu, 2014). HPAI H5N1, initially viewed as an EID in Southeast Asia, is now considered to be endemic in Cambodia. To date HPAI H5N1 virus has not affected Madagascar, but the virus could potentially be introduced by migratory wild birds through the East Africa-West Asia flyway (Olsen et al., 2006). Newcastle disease is highly prevalent in Asia (Miller et al., 2015) and Africa, including Madagascar (Miguel et al., 2013). Its clinical and epidemiological similarity to HPAI H5N1 drove the development of joint “avian pests” surveillance systems, mainly in Africa, including Madagascar (Rasamoelina-Andriamanivo, 2011).

Rift Valley fever (RVF) is a recurrent issue in Madagascar (Nicolas et al., 2013). The virus was first isolated in 1979, from mosquitoes trapped in the Perinet forest (Moramanga District), without any reported human or animal clinical cases (Fontenille et al., 1987; Morvan et al., 1991). The first recorded outbreak occurred during the rainy season of 1990-1991 (Morvan et al., 1992) in both human and animal populations. The last outbreak was recorded in 2008-2009, during two consecutive rainy seasons, affecting the whole country (Andriamandimby et al., 2010). Numerous cases in humans (418 reported cases of which 59 were laboratory-confirmed) and in ruminants were reported. Cambodia, like the rest of tropical and subtropical areas of South East Asia and China, may be considered at risk of RVF, although in this region it is still an exotic disease. Japanese encephalitis (JE) is responsible for 10000 to 15000 deaths per year in the world (Tarantola et al., 2014) and occurs in Southeast Asia but is not currently in the Indian Ocean countries. In Cambodia the JE annual incidence rate was estimated to be 10.6 per 100,000 children aged under 15 (Touch et al., 2009). Because of international trade and the presence of potential mosquito vectors for both RVF and JE in both continents, RVF and JE may be exported and cause new outbreaks in areas currently disease-free.

Most NTDs mentioned in the papers that we analysed are zoonoses. Rabies is highly prevalent in both countries but its incidence is widely underestimated and only the tip of the iceberg is revealed by human post-exposure treatments in the capital cities, i.e. Antananarivo (Andriamandimby et al., 2013) and Phnom Penh (Ponsich et al., 2012). Bovine tuberculosis (bTB) is quite well described in Madagascar (Marcotty et al., 2009) but insufficiently documented in Southeast Asia, including Cambodia (Bordier and Roger, 2013).

### 3.4 Comparison of data collection and transmission methods applied in both countries:

Participatory methods are used and validated for data collection on FMD in Cambodia (Bellet et al., 2012) and on ND in Madagascar (Rasamoelina-Andriamanivo, 2011). These approaches could be implemented for the surveillance of other TADs including ASF in light of similarities in the farming systems' characteristics and stakeholders' behaviours (Costard et al., 2009). HPAI surveillance in Cambodia (Desvaux et al., 2006) is still deficient despite H5N1 emerging in 2004. When HPAI H5N1 outbreaks are confirmed, the current policy in Cambodia is based on culling of poultry in the affected village, without economic compensation. These control measures lead to under-declaration and under-detection of H5N1 (Burgos et al., 2008), which often means that the discovery of HPAI H5N1 presence in a region is first detected by a human case (Leboeuf, 2009). In Madagascar, HPAI viruses have not been reported but the ecosystem favours the potential emergence and spread of influenza, as drivers like rice paddies and the mixing of poultry and pig species prevail (Paul et al., 2014). Pilot surveillance systems have been set up by non-governmental organizations (NGO), FOFIFA (Madagascan National

Centre of Applied Research for Rural Development) and CIRAD in the Lake Alaotra region. The results showed that a combination of participative and event-based surveillances allowed benefits to accrue from the advantages of each: the high sensitivity of the participatory approach and the specificity of event-based surveillance (Rasamoelina Andriamanivo, 2011). Syndromic surveillance for RVF is recommended in Madagascar using a specific definition, e.g.. a set of symptoms including haemorrhagic fever in humans (Balenghien et al., 2013) and abortions in animals. The occurrence of RVF generally coincides with a sudden onset of abortions at all stages of pregnancy, with deaths of young animals following an acute febrile disease, associated with liver damage in most cases. However, severity of clinical symptoms depends on species, ranging from acute mortality to a mild febrile syndrome. As described in many African countries, the virus may circulate silently at a very low level, either without or with few clinical signs. This cryptic transmission during inter-epidemic phases is extremely difficult to detect (FAO, 2003). Only sero- and/or viro-surveillance could be theoretically carried out for early detection but these procedures require considerable resources.

Although the number of mobile phones per capita is lower in Madagascar than in Cambodia (World Bank 2013, http://data.worldbank.org/indicator/IT.CEL.SETS.P2), the low cost and ease of notification of a mobile surveillance pilot system tested in Cambodia (Baron et al., 2013) make it an interesting option for the Malagasy context. Indeed, in both countries networks of community-based workers (Village Animal Health Workers in Cambodia; Community Animal Health Workers in Madagascar) have been created and have increased the sensitivity of disease detection (CelAgrid, 2007; Rasamoelina-Andriamanivo et al., 2014). However, late and underreporting still prevails, with problems of lack of compensation for outbreak responses in outreach areas, the burden of extra duties, and the economic penalties for farmers when reporting is followed by mass culling of infected animals (Burgos et al., 2008).

### 3.5 Comparison of cross-sector surveillance in both countries:

Outputs from field surveys applied to bats in Cambodia (Reynes et al., 2005) and to rodents (Olive et al., 2013) and bushpigs (Rouillé et al., 2014) in Madagascar could be translated into surveillance and monitoring protocols in both countries. Few risk-based surveillance programmes have been designed for wildlife, however, methods combining environmental monitoring (through remote sensing for example) and ecological monitoring of wild species (such as regular censuses of different species and populations) can allow the implementation of real time risk mapping and the adaptation of an active surveillance programme to seasonal changes (Cappelle et al., 2010). In Cambodia, the monitoring of the population dynamics of *Pteropus lylei* allowed researchers to implement a targeted monitoring of Nipah virus circulation and could be used to create a permanent and cost-effective surveillance system (Cappelle et al., 2014). It would be also valuable to involve rural populations living at the edge of protected areas and close to wildlife (e.g. wild pigs, bats, rodents) in surveillance programs. In fact, because of the livelihood dependence of local people on natural resources, i.e. wildlife hunting and natural resource gathering, villagers in these fringe areas could play an essential role for Government veterinary and human health services, giving them access to the eco-epidemiological status of priority mammalian species. The reinforcement of health monitoring policies could benefit from participatory eco-epidemiological monitoring in countries such as Cambodia and Madagascar. Such alternative approaches are well suited for less-developed countries with poorly resourced veterinary services and in remote areas where formal data collection methods are difficult to implement. In such places the active participation of the local populations and their knowledge have been acknowledged as a powerful means to design health surveillance. Their involvement can increase contact and trust with government agents and also encourages transparency of any epizootic adaptive management.

International agencies have developed specific veterinary public health surveillance activities in Cambodia in response to the HPAI H5N1 crisis. Serological surveillance of duck sentinel flocks and virological surveillance in market places for the detection of HPAI H5N1 (Horm et al., 2013) have been implemented. Monitoring has also been developed as a research tool in pig abattoirs to detect the circulation of the pandemic strain of influenza virus H1N1 (Rith et al., 2013). These methods have successfully demonstrated virus presence but are too expensive to be maintained by the national authorities, especially with the current decline in regular funding. However, the recent circulation in

China of a new influenza virus, H7N9 which is low pathogenic for poultry but highly pathogenic for human, has placed the need for joint surveillance of influenza in animals and humans in the spotlight (Wu et al., 2015).

## 4. Discussion

A systematic review of previously published information and recent CIRAD researchers' experiences in Cambodia and Madagascar were used to analyse similarities, gaps and potential cross-cutting lessons for animal disease surveillance systems. To overcome extensive deficiencies in surveillance systems, diverse methods or tools have been tested with varying degrees of success, summarized in Figure 3. Some of these methods (e.g. participatory surveillance) have proved their effectiveness in practice in both countries and could be replicated in other settings. Other methods have shown potential for success (e.g. sms data transmission) but they will need a certain amount of modification or adaptation to be really effective in such settings. This could be achieved through dialogue and sharing of experiences among researchers working in Cambodia, in Madagascar and in other developing regions. Finally, some methods such as syndromic surveillance appear too complex to be implemented on their own, highlighting the need to develop new approaches tailored to resource poor situations. On the basis of these results, highlighting trends in the epidemiological situations and surveillance systems of TADs, EIDs and NTDs in Madagascar and Cambodia and trends regarding surveillance methods (data collection and transmission, One Health collaboration), we propose recommendations for an improvement of data collection and transmission, stakeholders' involvement and a rationale for risk management.

### 4.1. Alternative data collection approaches:

We have highlighted that in the resource poor settings context of the studies implemented in Cambodia and Madagascar, participatory disease surveillance is a very relevant alternative for data collection. It explores community-based information networks and uses a range of methods and tools (semi-structured interviews with key informants, scoring and visualising techniques) to enable communities to share their traditional knowledge about the clinical and epidemiological features of local diseases and to understand disease patterns leading to control decisions (Jost et al., 2007). The main approach of participatory surveillance is to identify community-specific case-definition of threats (which can be evaluated using laboratory diagnostics) and to conduct risk-based surveillance. This approach allows for rapid and effective collection of data with limited use of resources, but is more adapted to diseases with clearly recognizable clinical signs.

Innovative syndromic approaches seem also to be well adapted to our resource poor settings and challenging field conditions, for instance monitoring volumes of veterinary medicine sales or trade prices for short-cycle animal species. This could address the lack of flexibility of traditional systems and help poor countries to set up early warning systems for unknown emerging diseases (OIE, 2014b).

We have also shown that “One Health”, based on joint work with medical services, which generally have a greater field presence, could be very efficient to improve the design of surveillance systems, especially for zoonoses. In addition, incorporating wildlife and bushmeat monitoring into surveillance systems could also help to monitor pathogens hazardous for livestock and/or human populations.

Elaborate methods for monitoring and surveillance of domestic animals have been developed in the past decades, but ecological characteristics of wildlife species make it difficult to apply these methods to wild species (Ryser-Degiorgis, 2013). When direct observation is too challenging, indirect methods can be used to investigate the disease ecology in wild animal populations. Non-invasive sampling methods can for example help to reach the required sample size. Nipah virus was first isolated in bats through urine collection on plastic sheets deployed under the trees of a flying-fox roost, no capture or handling of any bat was necessary (Chua et al., 2002). The same technique was successfully implemented in Cambodia to isolate Nipah virus for the first time (Reynes et al., 2005). The implementation of non-invasive methods for wildlife sampling and monitoring should be defined and sharpened in the field.

Nevertheless this raises the issue of implementing an effective One Health collaboration among environment and animal health sectors in national contexts mostly characterised by sectoral and “in silo” political management (Waage et al., 2010).

### 4.2. Adaptive data transmission:

As emphasized in our synthesis, the widespread diffusion of mobile phone networks, even in the most remote areas, can enable the use of mobile communication devices (mobile health or mHealth), such as phones, tablet computers and personal digital assistants (PDA), to collect and share animal and human health data. A light but efficient surveillance system of targeted diseases or syndromes could then be established. As it has been noted by the NGO Colalife (http://www.colalife.org), "*Coca-Cola seems to get everywhere in developing countries, yet essential medicines don't. Why?*" Answers to this question could point to new ways to develop non-conventional channels for the transmission of surveillance samples and information in the resource poor settings, situations and remote areas that have been targeted in our article. Remoteness or resource poor settings are not inescapable obstacles as long as we are able to identify motivations and incentives that make sense for the stakeholders. The key question could be to identify the right incentives.

### 4.3. Non-conventional stakeholders involvement

Our narrative synthesis clearly states that collaboration and communication between government officers and local people in the framework of surveillance is difficult and raises a lot of issues. Among them, we have highlighted divergences in points of view regarding risk perception and disease management. Here below, we propose some action tools aiming at co-building and co-designing shared representation of the epidemiological situation, involving the relevant stakeholders obtaining key health information and allowing the identification of incentives (not only financial) to their participation at community level. This rationale could contribute to elaborate, well-accepted data collection methods through effective collaboration between policy makers, veterinarians and civil society. Indeed, the various stakeholders concerned with animal health surveillance have their own rationales and practices in terms of risks perception and monitoring. These practices differ between the sectors involved (public health, veterinary services, environment, land planning, livestock trading, etc.) and action level (government officers, international agencies representatives, traders, communities' representatives etc.). Furthermore, animal health crises can generate conflicts and stress at the level of a local community.

Information diffusion and sharing during such crises is sensitive. This type of sensitive data and information (such as sudden death cases in poultry for example) are obviously better shared within small social groups with pre-existing trust relationships (Figuié and Desvaux, 2011). These social groups (involving different stakeholders such as experienced farmers, traders, drug sellers, village heads etc. in the same community) implement non-conventional surveillance practices based on intensive social networking and information sharing. These knowledge and "know-how" of these stakeholders, in terms of animal health management and their social networking, could be valuable for the improvement of surveillance systems at the local community level. However, effective cooperation between these non-conventional networks and the official surveillance networks appears to be often insufficient (Muriel Figuié et al., 2013).

Participatory approaches to mapping and modelling are potentially mediating tools to support dialogue and data collection with different interest groups. They can be used to collect users' knowledge about socioeconomic and environmental factors at the scale of a local community or to improve institutional coordination. In addition, participatory approaches could help to better understand local behaviour rules and the principles of "collective action" (Sandler, 1992) for decision making when people involved in the same community are facing similar risks.

The impact of such knowledge sharing on the improvement of cross-sector dialogue has already been demonstrated in the framework of natural resource management with the "Companion Modelling" approach (ComMod association, © ComMod 2010). This participatory modelling has been developed in the field of renewable resources management to tackle issues regarding decision processes, common property, and institutional coordination (Etienne, 2011). The final objective of such an approach is that stakeholders are likely to identify, through a consultation process, the issues for which they could share joint interest, in order to obtain win-win solutions. Participatory modelling uses conceptual models, role-playing games, and agent-based modelling in an iterative way to search for acceptable collective solutions through scenario assessment.

The implementation of participatory modelling in the fields of surveillance and health risk management is currently developed in the framework of several research projects. Stakeholders (including researchers) learn together by creating, modifying, observing and assessing simulations. When different stakeholders have very divergent points of view on the same system, a “Companion Modelling” approach allows, though iterative focus group discussions, to co-design a common representation of the situation. This co-built representation (at the first steps, a conceptual model) can then evolve toward agent-based models allowing scenario testing, role-playing games etc. Agent-based models are stochastic computer simulations applied to investigate the interactions between “agents”- i.e. people, things, places, and time - which are encoded to behave and interact with other agents and the environment. This modelling approach is relevant in the field of epidemiology (Galea et al., 2010). The procedures enable discussion, communication, negotiation, knowledge sharing and provide a strong basis for the common identification of socially acceptable solutions. Knowledge, perceptions, behaviour, and practices evolve along the process and can lead to collective action plans and better stakeholders’ mobilization to implement them.

Within such an approach, a surveillance system (involving official, private and non-conventional stakeholders) could be modelled. Simulations could be used as a collective decision making process involving various stakeholders (non-conventional stakeholders and officers from public health, veterinary services and environmental sectors for example). The purpose of the decision making is an improved management of “health risks”. Public health and veterinary public health would then be perceived as “common good” (Ostrom, 2000) to be managed collectively.

### 4.4. Global recommendations:

A potential improvement of surveillance systems could arise from the establishment of routine communication schemes. Such collaboration will be successful if information flow and data sharing improve from both sides (government officers and community members). Beyond individual relationships with farmers involved in outbreaks, routine communication procedures should be established. As researchers working in developing territories, we must move beyond the “surveillance of surveillance" so often emphasised: while networks of networks, including regional networks, are necessary, they do not usually tackle problems at the source i.e. at herd and farms levels. Health management in challenging environments needs innovative methods and tools that are built in close connection with rural populations and stakeholders. The integration of different disciplines (biology, ecology, social and modelling sciences) and sectors (veterinary, medical, environmental and rural development) is needed to address the challenges posed by surveillance in resource-constrained settings. In contexts such as Cambodia or Madagascar, where resources for surveillance are restricted and often dependent on uncertain and variable external funding, a priority should be placed on the use of cost-effective methods and tools. Participatory modelling and simulation can assist decision makers and local stakeholders to design such methods (Collineau et al., 2013; Duboz, 2013). In the same way, design of risk-based surveillance systems, using exposure and risk assessment methods, should be supported (Stärk et al., 2006). This will help to identify surveillance needs, set priorities, select appropriate surveillance activities and allow for optimal allocation of resources.

It will be necessary to combine the diverse systems in order to optimize the surveillance of emerging and endemic diseases in these countries. This must be conducted in partnership with the various local and national stakeholders, and be consistent with the recommendations of international agencies (OIE, FAO, WHO). A combination of participatory approaches, companion modelling and modern information technology could enable weaknesses in the surveillance systems to be better identified and help to overcome some of the constraints inherent in developing countries. Comparing experiences from a range of low-income countries allows the generation of new knowledge, supports development and fuels the debate among scientists and policy-makers on how to improve animal health surveillance through better collaboration.

## 5. Conclusion

The review allowed us to highlight the main limitations and advantages of the tools and methods developed and assessed in the field of diseases' surveillance in Cambodia and Madagascar (Figure 2). A lot of the methods are linked to the design of risk-based approaches enabling the surveillance to be more cost-effective at the expense of representativeness. But this drawback has a little impact when the surveillance objective is the early detection of disease. Lack of simplicity and sustainability of the processes are directly connected to the environment of work. Innovative tools, typically developed during specific and time-framed projects, can be at first seen complex but may become simpler as they become more used and endorsed by policy-makers. Indeed, sustainability remains a great challenge and for that purpose, we should improve the interactions with governmental organisations, international agencies, and donors about the research outputs on innovative surveillance approaches. Flexibility and usefulness of the methods are critical in poor resources countries. Ownership and sensitivity are linked and are often the main weaknesses of the surveillance systems in these countries.

Finally, the in-depth analysis of studies implemented in Madagascar and Cambodia shows that there is generally poor communication between farmers, various stakeholders and authorities. While information is often communicated to farmers when there is a confirmed case of a major disease, feedback on surveillance results for other diseases to the rural populations most affected is on the other hand commonly insufficient.

In accordance with the international standards and recommendations of OIE, FAO, and WHO, the research on innovative and creative methods and tools should be developed for adapting surveillance systems in poor countries largely at-risk and highly vulnerable to emerging and endemic animal and zoonotic diseases.

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Table 1: Description of the papers retrieved for Cambodia via the review: by disease, species, type of tools described, limitation / advantage of the tools, recommendation and current surveillance implemented. *We used the list of attributes published in the OIE guidelines for surveillance (OIE, 2014b).

| Cambodia and Regional Studies including Cambodia | | | | | | |
|---|---|---|---|---|---|---|
| Reference | Disease(s) /surveyed events | Species | Tools and/or methods mentioned or described | *Limitations**<br>**Advantages*** | Recommendations for surveillance implementation | *Current surveillance in the country (2013-2014)* |
| Conan et al., 2013 | Poultry diseases | Poultry | Field surveys | *Representativeness*<br>**Sensitivity** | Design of risk-based surveillance | *Passive. (Active for HPAI)* |
| Calba et al., 2014 | Avian influenza (H5N1 HPAI) | Poultry | Participatory evaluation of community-health workers effectiveness | *Sustainability*<br>**Ownership** | Systematic assessment and evaluation | *Passive and Active. Risk-based surveillance (wet markets)* |
| Collineau et al., 2013 | | | Passive surveillance, modelling | *Simplicity*<br>**Flexibility** | Use modelling to improve surveillance design | |
| Desvaux et al., 2006 | | | Participatory surveillance/risk based surveillance (wet markets) | *Specificity*<br>**Ownership** | Development of participatory approaches | |
| Figuié and Desvaux, 2010 | | | Non-conventional (informal) surveillance | *Specificity*<br>**Ownership** | Need for various systems (informal, private) to be integrated | |
| Figuié and Fournier, 2010 | | | National and international management of Risks | *Simplicity*<br>**Usefulness** | Insertion in the local context | |
| Figuié et al., 2013 | | | Non-conventional (informal) surveillance | *Specificity*<br>**Ownership** | Need for various systems (informal, private) to be integrated | |
| Fournié et al., 2012 | | | Field (wet markets) surveys | *Representativeness*<br>**Sensitivity** | Design of risk-based surveillance | |
| Peyre et al., 2011 | | | Evaluation of cost-efficacy of surveillance system | *Simplicity*<br>**Usefulness** | Implement economic evaluation | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Netrabukkana et al., 2014 | Swine influenza | Pig | Farms and abattoirs repeated surveys | *Representativeness*<br>**Simplicity** | Targeted surveillance at farm and sero-monitoring at abattoir. | *Passive* |
| Rith et al., 2013 | | | Sero-surveillance | *Sustainability*<br>**Sensitivity** | Design of systematic surveillance of influenza viruses on farms | |
| Trevennec et al., 2011 | | | Field surveys | *Representativeness*<br>**Sensitivity** | Design of One Health Surveillance | |
| Bellet et al., 2012 | Foot-and-Mouth disease | Cattle | Participatory surveillance | *Specificity*<br>**Ownership** | Development of participatory approaches | *Passive* |
| Vergne et al., 2012 | | | Quantitative evaluation using capture-recapture | *Simplicity*<br>**Flexibility** | Systematic assessment and evaluation | |
| Baron et al., 2013 | Side-effect of vaccination | Human | Mobile phone-based active surveillance | *Sustainability*<br>**Timeliness** | Develop tailored systems of SMS-reporting for developing countries | *No surveillance* |
| Reynes et al., 2005 | Nipah | Human & Bats | Sero and viro-surveys | *Representativeness*<br>**Sensitivity** | Design of One Health Surveillance | *Syndromic (human). Surveys (bats)* |
| Tarantola et al., 2014 | Zoonotic encephalitis | Human, Reservoirs | Syndromic and sentinel surveillance (Human) | *Sensitivity*<br>**Flexibility** | Design of human syndromic surveillance for zoonoses | *Syndromic (human). Passive (animals)* |
| Antoine-Moussiaux et al., 2011 | Animal infectious diseases | Multispecies | Economic evaluation | *Representativeness*<br>**Usefulness** | Implement economic evaluation | *Passive and active* |
| Cappelle et al., 2013 | Zoonoses | Multispecies | Passive and active surveillance | *Sustainability*<br>**Flexibility** | Design of One Health Surveillance | *Passive and active* |
| Roger et al., 2008 | Zoonoses and animal diseases | Multispecies | Passive and active surveillance | *Sustainability*<br>**Flexibility** | Design of One Health Surveillance | *Passive and active* |

Table 2: Description of the papers retrieved for Madagascar via the review: by disease, species, type of tools described, limitation / advantage of the tools, recommendation and current surveillance implemented. *We used the list of attributes published in the OIE guidelines for surveillance (OIE, 2014b).

| Madagascar and Regional Studies including Madagascar | | | | | | |
|---|---|---|---|---|---|---|
| Reference | Disease(s) or surveyed events | Species | Tools and/or methods mentioned or described | *Limitations/Constraints*<br>**Opportunities** | Recommendations for surveillance implementation | *Current surveillance in the country (2013-2014)* |
| Guerrini et al., 2014 | Avian Influenza & Newcastle Disease | Poultry | Serological and ecological surveys of LPAI | *Representativeness*<br>**Sensitivity** | Design of risk-based surveillance (risk mapping) | *Passive and active/repeated surveys* |
| Rasamoelina-Andriamanivo, 2011 | | | Passive & participatory surveillance | *Specificity*<br>**Ownership** | Development of participatory approaches | |
| Rasamoelina-Andriamanivo et al., 2014 | | | Modelling of contact networks | *Simplicity*<br>**Specificity** | Design of risk-based surveillance (risk mapping) | |
| Chevalier et al., 2011 | Rift valley fever | Cattle | Epidemiological study | *Representativeness*<br>**Specificity** | Design of risk-based surveillance (risk mapping) | *Passive/sentinel sites (Human) and passive (Cattle).* |
| Ravaomanana et al., 2011 | Swine fevers | Wild pigs | Field surveys | *Representativeness*<br>**Flexibility** | Design tailored-surveillance for wildlife | *Passive* |
| Costard et al., 2009 | | Domestic pig | Epidemiological study | *Representativeness*<br>**Flexibility** | Identification of Risk factors / Design of risk-based surveillance | |
| Roger et al., 2004 | Animal and zoonotic diseases | Multispecies | Private/Public interactions | *Flexibility*<br>**Sustainability** | Need for various systems (informal, private) to be integrated | *Passive and/or Active* |
| Thonnat, 2005 | Animal and zoonotic diseases | Multispecies | Passive surveillance | *Sensitivity*<br>**Ownership** | Training of village animal health workers for surveillance | *Passive and/or Active* |

Table 3: Description of the papers about regional researches retrieved via the review: by disease, species, type of tools described, limitation / advantage of the tools, recommendation and current surveillance implemented.

| **Global: Africa and SE Asia** | | | | |
|---|---|---|---|---|
| Reference | Disease(s) or surveyed events | Species | Tools and/or methods mentioned or described | Recommendations for surveillance implementation |
| CIRAD, 2009 | Avian Influenza & Newcastle Disease | Poultry and wildbirds | Passive and active | Design of Risk-based surveillance. Development of participatory approaches |
| Domenech et al., 2006 | Animal and zoonotic diseases | Multispecies | Passive and active | Linking regional and international surveillance |
| Figuié and Peyre, 2010 | Avian influenza (SRAS) | Poultry, Human | Governance | Design of One Health Surveillance |
| Renard, 2010 | Avian influenza | Poultry | Marketing and value chain analysis | Design of risk based-surveillance (markets) |
| Roger, 2012 | Zoonoses | Multispecies | Conventional and participatory approaches | Design of One Health Surveillance |

**Figure 1:** Flow diagram of the selection process for the systematic review of CIRAD research papers on surveillance in Madagascar and Cambodia. *One document was a thesis manuscript.

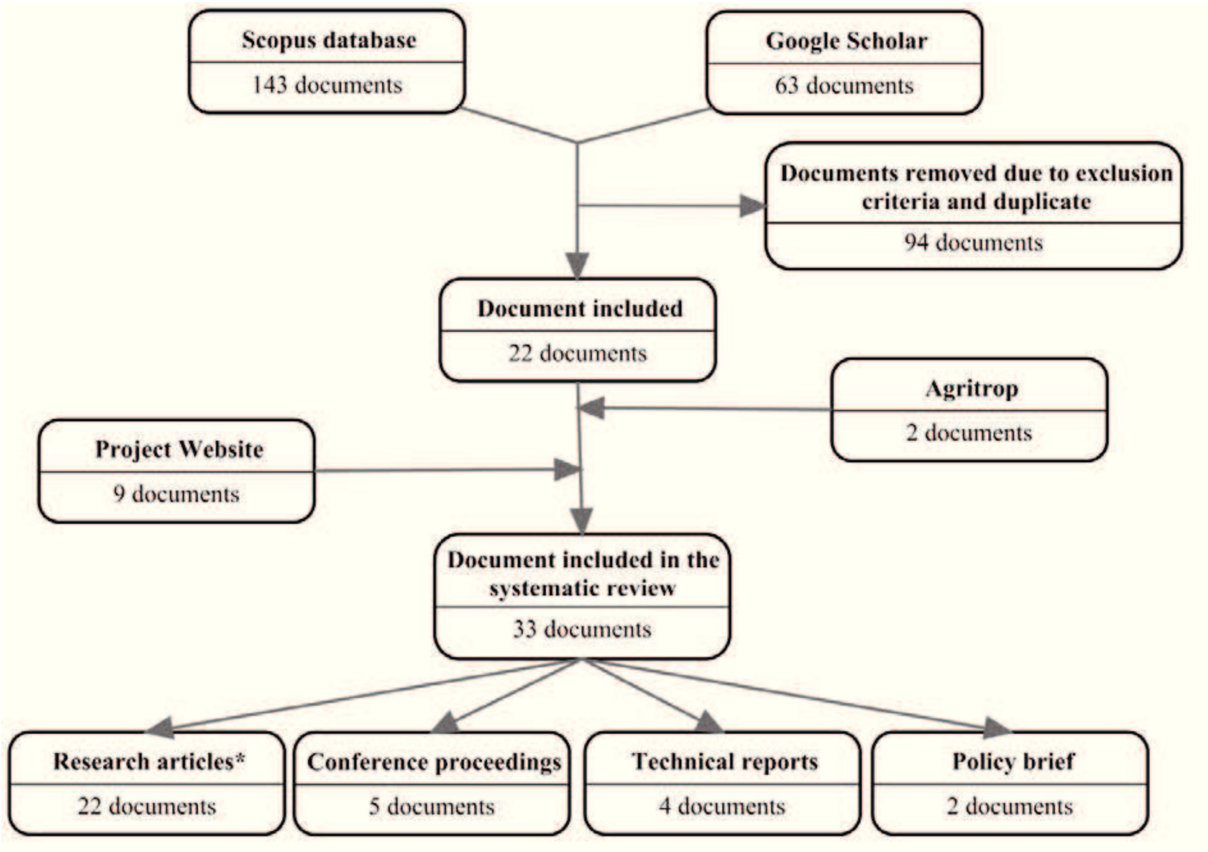


**Figure 2:** Radar chart of the main qualities of tools and methods applied in Madagascar and in Cambodia within the publications included in the systematic review of CIRAD research papers (n=28)

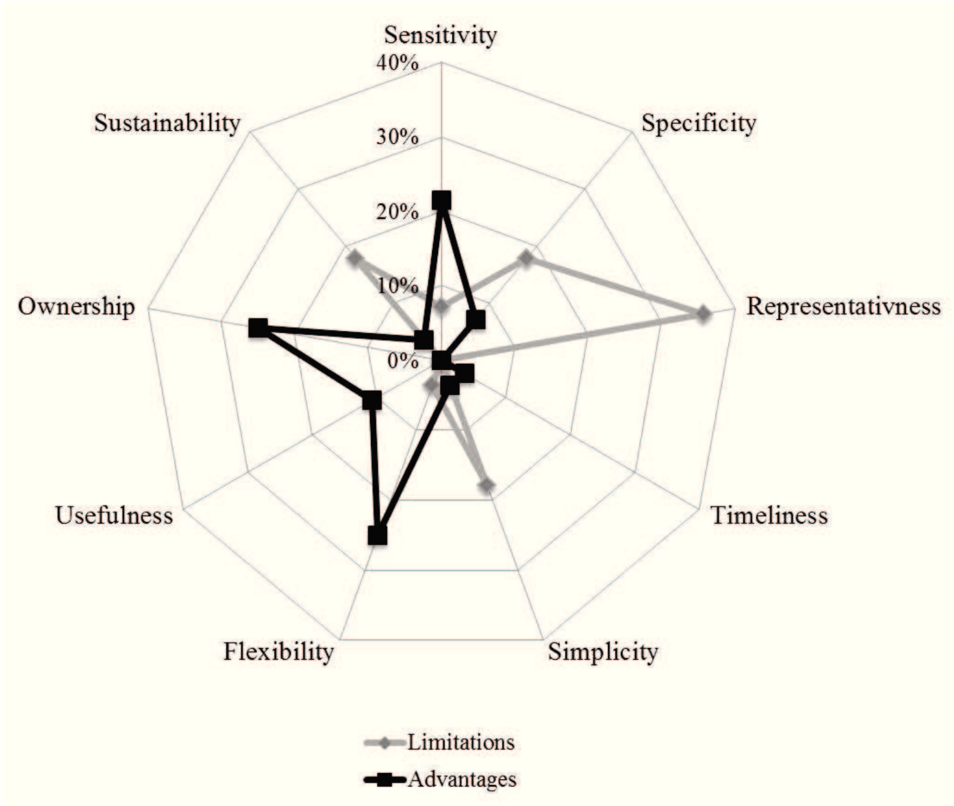
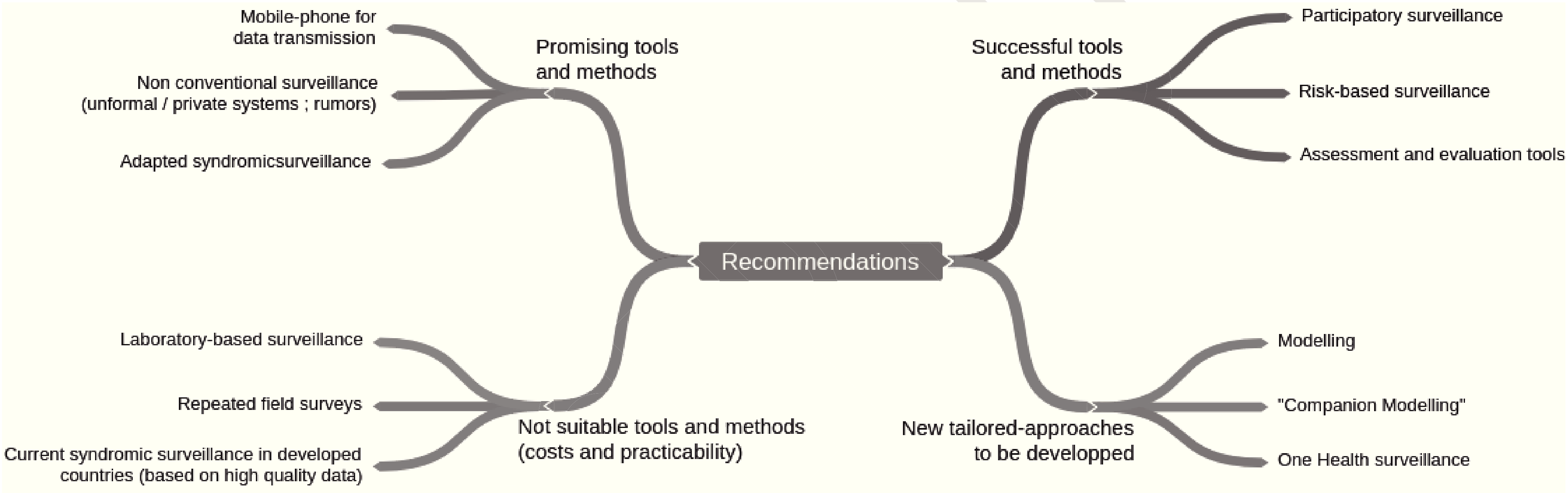


**Figure 3:** Spider diagram summarising the variability of success of tools and methods and the main recommendations to improve surveillance in developing countries, drawn from the systematic review of CIRAD research papers (n=33)



# ANNEX 7

# QUESTIONNAIRE ABOUT VHW TRAININGS IN CAMBODIA

Name of your organization:

______________________________________________________________________________

Can you describe the main activities of your organization?

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

Are you still active in terms of Village Health Workers (VHW) training? ☐ Yes ☐ No

How many years has your organization been training VHW in Cambodia?

______________________________________________________________________________

In total how many VHW did your organization train in Cambodia?

______________________________________________________________________________

Can you assess the number of VHW you trained per province, district and if possible commune?

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

Which main topics did you target during your training courses?

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

Does your training include a follow up of VHW when starting their activity? If yes how long is it?

______________________________________________________________________________

Does your module include refresher trainings: when? How do you assess the needs of refresher training?

________________________________________________________________________________
________________________________________________________________________________
________________________________________________________________________________
________________________________________________________________________________

What kind of support do you provide to the VHW you trained?

☐ Technical support ☐ Material/ Equipment ☐ Financial support

☐ Other support, precise wich: ____________________________________________

Are the VHW you trained supported by the Government?

☐ Technical support ☐ Material/ Equipment ☐ Financial support

☐ Other support from the Government, precise wich: ____________________________

Do the VHW you trained receive a salary? ☐ Yes ☐ No

If yes, who pay them? ☐Government ☐ NGO ☐ Villagers ☐ Others:___________

Are the VHW you trained connected with Health authorities (at the Commune, District and Province levels)? ☐Yes ☐ No

Do you know if the VHW you trained use to work in connection with the Village Animal Health Workers ? ☐ Yes ☐ No

Do you know other organizations that trained / are training VHW in Cambodia? If yes, can you transmit us their name and representatives contact?

________________________________________________________________________________
________________________________________________________________________________
________________________________________________________________________________
________________________________________________________________________________
________________________________________________________________________________
________________________________________________________________________________
________________________________________________________________________________
________________________________________________________________________________
________________________________________________________________________________
________________________________________________________________________________
________________________________________________________________________________
________________________________________________________________________________
________________________________________________________________________________
________________________________________________________________________________
________________________________________________________________________________

# ANNEX 8

## ADDITIONAL QUESTIONNAIRE FOR VAHWs

Province: ______________________________

District: ______________________________

Commune: ______________________________

GPS coordinate: ______________________________

Name of the VAHW: ______________________________

Village: ______________________________

Date of interview: ______________________________

### ABOUT THE TRAINING

1. Who organized the first training for you to become a VAHW? ______________________________

2. Year of training: ______________________________

3. How have you been selected?

   ☐ Volunteer ☐ Selected by village chief

   ☐ Elected by villagers ☐ Other: ______________________________

4. Methodology of training:

   ☐ Consecutively (only one session) ☐ Separately (module by module)

5. How many days was this first training? ______________________________

6. How many villagers have participated? ______________________________

7. Are there any field follow-ups from the trainers after training completed?

   ☐ Yes ☐ No

8. If yes, how many times? ______________________________

9. How did the trainers conduct the field follow-ups?

   ☐ Individually ☐ Individually and per group ☐ Per group

10. Did you have any refresher trainings?

    ☐ Yes ☐ No

| Year of refresher training | Organization | Topic | Duration |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

11. Have you ever do practice exercises during training or refresh trainings?

 Yes  No

12. If yes, what kind of exercises?________________________________________

____________________________________________________________

13. Did the trainer provide you some tools (books, basic equipment, etc.)?

 Yes  No

14. If yes, what kind of tools? __________________________________________

____________________________________________________________

**PERSONAL INFORMATION**

1. How old are you?________________________________________________

2. Are you able to write and read?

   Write:  Yes  No Read:  Yes  No

3. How do you go to visit farmers?

    By foot  Bicycle  Moto

    Car  Other:______________________________________

4. Are you a member of an association?

    Yes  No

5. What are the activities of your association?

    Selling medicine  Animal raising  Selling chemical fertilizer

    Producing animal feed  Cash saving  Credit

    Doesn’t know  Other:______________________________________

6. What activities are you doing out of your VAWS's job?

☐ Farming ☐ Raising animals ☐ Owner of a pharmacy

☐ Business ☐ Civil servant ☐ Other:____________________

7. What is your first source of income?

☐ Farming ☐ Raising animals ☐ Pharmacy ☐ VAHW

☐ Business ☐ Civil servant ☐ Other:____________________

**ENVIRONMENT**

1. How many heads of cattle are there in your village?

☐ < 50 ☐ 50 to 100 ☐ 100 to 200 ☐ > 200 ☐ Doesn't know

2. How many heads of pigs are there in your village?

☐ < 50 ☐ 50 to 100 ☐ 100 to 300 ☐ > 300 ☐ Doesn't know

3. How many heads of chickens are there in your village?

☐ < 3000 ☐ 3000 to 5000 ☐ 5000 to 7000 ☐ > 7000 ☐ Doesn't know

4. How many heads of Muscovy ducks are there in your village?

☐ < 100 ☐ 100 to 300 ☐ 300 to 500 ☐ > 500 ☐ Doesn't know

5. How many heads of free-grazing ducks are there in the village?

   - About small scale:

☐ < 100 ☐ 100 to 300 ☐ 300 to 500 ☐ > 500 ☐ Doesn't know

   - About flocks:

☐ < 3000 ☐ 3000 to 5000 ☐ 5000 to 7000 ☐ > 7000 ☐ Doesn't know

6. Is there a market in this village?

☐ Yes ☐ No

7. Where is the meat in the village coming from?

☐ This village ☐ This commune ☐ This district

☐ This province ☐ Other ☐ Doesn't know

8. Is there a slaughterhouse in the village?

   ☐ Yes ☐ No ☐ Doesn't know

9. How many VAHWs are there in your commune?____________________

10. Is there competition with VAHWs from other village or with other stakeholders (DV, private vet or traditional Khmer medicine)?

    ☐ Yes ☐ No ☐ Doesn't know

11. Do you receive any support from DV?

    ☐ Yes ☐ No

12. If yes, what kind of support? ____________________

    ____________________

13. Do you think villagers trust in your capacities?

    ☐ Yes ☐ No ☐ Doesn't know

14. Why?____________________

15. Is there any NGO working in your village?

    ☐ Yes ☐ No ☐ Doesn't know

16. If yes, in which field? ____________________

17. Since how long?____________________

## ECONOMIC ASPECTS

1. Do you have a book keeping?

   ☐ Yes ☐ No

2. If yes, what do you record in this?____________________

   ____________________

3. How many households do you provide animal health and production services per month? __________

4. What is your annual/monthly benefit from VAHW activity?____________________

5. Around how many visits do you do per month? ____________________

**REPORT**

1. Are doing meetings with the DV?

   ☐ Yes ☐ No

2. If yes, does he provide you some perdiem?

   ☐ Yes ☐ No

3. In case of disease outbreak who do you report to?

   ☐ Village Chief ☐ District Vet ☐ PDA

   ☐ OAHP ☐ Central level ☐ Other:____________________

4. Do you know the hotline of the central level?

   ☐ Yes ☐ No

5. How many reports per year are you doing? ____________________

6. How do you report?

   ☐ Oral report directly ☐ By phone ☐ Putting on paper ☐ Other:____________

7. Would be interesting by a reporting system by text?

   ☐ Yes ☐ No

8. Would you be interesting in collaboration with human health services?

   ☐ Yes ☐ No

9. Do you think there is any problem in the reporting system?

   ☐ Yes ☐ No

10. What kind of problem?____________________

11. How to improve it?____________________

# ANNEX 9

# Outbreak investigation

Village……………………………….                VC ☐      VAHW ☐
Date………………………………….                Name …….…………………………..
Number of Household:……………

1- Have you hear about the H5N1 outbreak in Pralay Meas?     Yes     No

2- How many poultry have you in the village?     Ducks: …………….     Chickens: ……………..

3- How many flocks of ducks (more than 50 heads) are there in the village?..................

4- Did you experience any mortality for the last 3 months in your village?
Yes     No (>>17)

| | October | November | December | January | February |
|---|---|---|---|---|---|
| 5- How many ducks died | | | | | |
| 6- How many chickens died | | | | | |
| 7- When the mortality did start | | | | | |
| 8- When the mortality did finish? | | | | | |
| 9- Which Symptoms have you noticed in ducks | ☐ diarrhea ☐ violet/swollen combs, wattles and head ☐ Necktwist ☐ Motionless ☐ Sudden death ☐ Other:…………… ……………………….. | ☐ diarrhea ☐ violet/swollen combs, wattles and head ☐ Necktwist ☐ Motionless ☐ Sudden death☐ Other:……………… | ☐ diarrhea ☐ violet/swollen combs, wattles and head ☐ Necktwist ☐ Motionless ☐ Sudden death ☐ Other……….. | ☐ diarrhea ☐ violet/swollen combs, wattles and head ☐ Necktwist ☐ Motionless ☐ Sudden death ☐ Other:…………… | ☐ diarrhea ☐ violet/swollen combs, wattles and head ☐ Necktwist ☐ Motionless ☐ Sudden death ☐ Other:…………… |
| 10- Which symptoms have you noticed in chickens? | ☐ diarrhea ☐ violet/swollen combs, wattles and head ☐ Necktwist ☐ Motionless ☐ Sudden death ☐ Other:……….. | ☐ diarrhea ☐ violet/swollen combs, wattles and head ☐ Necktwist ☐ Motionless ☐ Sudden death ☐ Other:…………… | ☐ diarrhea ☐ violet/swollen combs, wattles and head ☐ Necktwist ☐ Motionless ☐ Sudden death☐ Other:……….. | ☐ diarrhea ☐ violet/swollen combs, wattles and head ☐ Necktwist ☐ Motionless ☐ Sudden death☐ Other:……………… | ☐ diarrhea ☐ violet/swollen combs, wattles and head ☐ Necktwist ☐ Motionless ☐ Sudden death ☐ Other:…………… |

11- Do you have currently any household with sick poultry in your village? Yes No

12- How were you informed about the mortality? ……………………………………………………

13- What did you do at the time of the outbreak? (several option possible)
Burning/Burying dead animals □ Eating sick and remaining healthy animals □
Selling sick and remaining healthy animal □
If yes,
□ in market : Name………………… Village………………… Commune: …………………
□ with middlemen: place of selling………………………
Other:………………………………………………………………………………………………………………….

14- Did you inform anybody of the outbreak? (several option possible)
Nobody □ Other Village Chief □ Commune council □ District chief □
District Veterinarian □ Other…………………..

15- When did you report? …………/………../……….

16- What happened?...............................................

17- Do you know if people from your village bought poultry before the outbreak? Yes No

If yes,
□ in market : Name………………… Village………………… Commune: …………………
□ with middlemen: place of selling………………………

18- Do you know if other villages experienced as well high mortality in their flock at the same time? Yes No
If, yes could you give the name of the village and the date when the outbreak started:
Village:………………………………………. Date:……………………………
Village:………………………………………. Date:……………………………
Village:………………………………………. Date:……………………………
Village:………………………………………. Date:……………………………

19- Do you know if the ducks of your village are in contacts with flocks from other villages?
Yes No If yes, which villages:……………………………………………………………………………
Commune:……………………………. District……………………

20- Do some duck flocks do a transhumance?
If yes: Where: …………………………………..
From ……………/…………./…………. to ……………./………./……………

21- Did people buy new poultry since the last outbreak?   Yes   No

If yes,

□ in market : Name…………………   Village…………………   Commune: …………………

□ with middlemen: place of selling………………………

22- Did people sell any poultry since November?   Yes   No

If yes

When?............/…………../………….

□ in market : Name…………………   Village…………………   Commune: …………………

□ with middlemen: place of selling………………………

23- Do you know if people from your village buy poultry from Vietnam?   Yes   No

If yes, from which market in Vietnam……………

Why?...............................................................

When?.............................................................

# ANNEX 10

**Annex A-4**
**Communicable Disease Control Department**

**Kingdom of Cambodia**
Ministry of Health
Nation – Religion – King

## WEEKLY ZERO REPORTING FORM - Health Center

Date form is submitted: ________________

by ○ SMS ○ template SMS ○ fax ○ phone call to number:_____________

Name of reporting officer:______________________

Province/Municipality: _________________Operational District:___________________________

Health Centre:________________________________

Reporting period: Week_____________

From Wednesday Date: _____ Month_____ Year______, to Tuesday: Date____ Month ____Year__

| SYNDROME | DISEASE | NEW CASES | |
|---|---|---|---|
| | | Case | Dead |
| Acute Neurological Syndrome | Total number of cases: | | |
| If possible, please specify: | ACUTE FLACCID PARALYSIS ☎ (suspected poliomyelitis) | | |
| | MENINGOENCEPHALITIS | | |
| | RABIES – suspected ☎ | | |
| Acute Respiratory Syndrome | Total number of cases: | | |
| If possible, please specify: | ACUTE RESPIRATORY INFECTION | | |
| | DIPHTHERIA – suspected ☎ | | |
| Acute Skin Syndrome | Total number of cases: | | |
| If possible, please specify: | MEASLES – suspected ☎ | | |
| | DENGUE INFECTION – suspected | | |
| Acute Jaundice Syndrome | JAUNDICE | | |
| Acute Diarrhea Syndrome | Total number of cases: | | |
| | WATERY DIARRHEA (Suspect CHOLERA) ☎ | | |
| | BLOODY DIARRHEA | | |
| Tetanus | NEONATAL TETANUS – suspected☎ | | |
| Other | UNKNOWN DISEASE OCCURRING IN A CLUSTER ☎ | | |
| Consultations (not including routine visits, follow-ups or vaccinations) | **TOTAL NUMBER** | | |

A single suspected case of the diseases marked with (☎) should be reported immediately to your Operational district Rapid Response Team (RRT) using the outbreak alert form. For other diseases the immediate alert threshold is $\geq$ 5 cases in one week or $\geq$ 7 cases in two weeks of one disease or 1.5 times the expected number in average of previous 3 weeks.

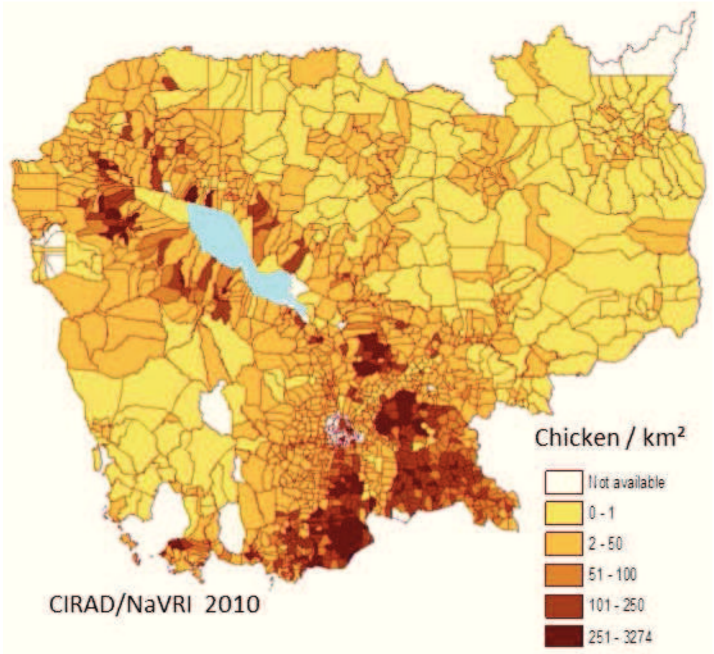
______________________________________

Date, name and signature of health center chief

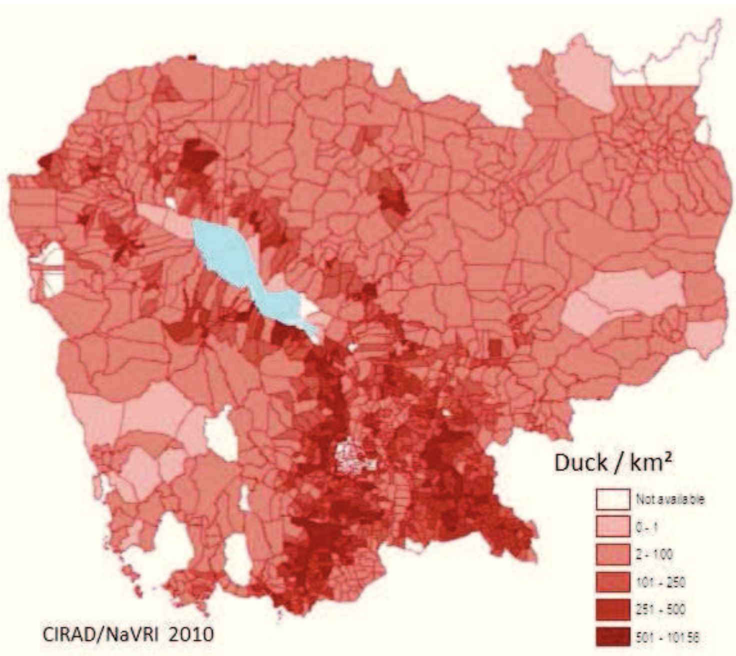
______________________________________

Name and signature of person reporting, if not the chief

# ANNEX 11




**Map of chicken population density per commune in Cambodia**




**Map of duck population density per commune in Cambodia**

# ANNEX 12

| Province | Age | Gend er | Onset of case | First visit | Detection | Time of med care | Time of confirmation | Delay (onset-Ttt) | Delay (onset-Ttt) | Number of place visited* | Output of the case |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Kampot | 2 | F | 08/03/14 | PM | | 13/03/14 | 14/03/14 | 5 | 6 | 3 (PM, PC, KB) | Death |
| Kampong Chnnang | 11 | M | 03/03/14 | PM in village | | 06/03/14 | 06/03/14 | 3 | 3 | 3 (PM, PH, KB) | Death |
| Kandal | 8 | M | 24/02/14 | PM in village | | 05/03/14 | 06/03/14 | 9 | 10 | 2 (PM, KB) | Recovering |
| Phnom Penh | 3 | M | 22/02/14 | PC | | 02/03/14 | 03/03/14 | 8 | 9 | 3 (PC, NPH, CH) | Death |
| Kampong Cham | 11 | F | 09/02/14 | | NAMRU | 20/02/14 | 20/02/14 | 11 | 11 | 1 (PH) | Recovering |
| Kampong Cham | 10 | F | 26/01/14 | Medicines at home | NAMRU | 20/02/14 | 29/01/14 | 25 | 3 | 1 (PH) | Recovering |
| Kratie | 4 | M | 08/02/14 | | Mobile surveillance | 13/02/14 | 14/02/14 | 5 | 6 | 1 (PH) | Recovering |
| Kratie | 8 | M | 31/01/14 | PC | | 07/02/14 | 08/02/14 | 7 | 8 | 3 (PC, RH, PH) | Death |
| Kratie | 2 | F | 01/02/14 | | | 07/02/14 | | 6 | | | Death |
| Kampong Thom | 5 | M | 24/01/14 | PC | | 31/01/14 | 01/02/14 | 7 | 8 | 2 (PC, PH) | |
| Pailin | 29 | M | 26/10/13 | Local health Center | | 01/11/13 | 09/11/13 | 6 | 14 | 3 (X, PC, PH) | Death |
| Kampong Speu | 3 | M | 05/11/13 | PM in village | | 08/11/13 | 09/11/13 | 3 | 4 | 2 (PM, PH) | |
| Kampot | 10 | M | 28/10/13 | PM | | 07/11/13 | 07/11/13 | 10 | 10 | 2 (PM, PH) | |
| Pursat | 2 | F | 17/10/13 | PM in village | | 25/10/13 | 30/10/13 | 8 | 13 | 2 (PM, PH) | Death |
| Battambang | 6 | F | 14/10/13 | Treatment in village | | 24/10/13 | 24/10/13 | 10 | 10 | 2 (PM, PH) | Stable condition |
| Kampong Thom | 8 | F | 08/10/13 | Village Clinic | | 14/10/13 | 17/10/13 | 6 | 9 | 3 (X, PC, PH) | Stable condition |
| Kampot | 2 | F | 11/09/13 | Village Clinic | | 16/09/13 | 16/09/13 | 5 | 5 | 3 (PM, PC, KB) | Death |
| Takeo | 5 | F | 07/09/13 | PC | | 13/09/13 | 14/09/13 | 6 | 7 | 2 (PC, PH) | Recovering |
| Phnom Penh | 15 m | M | 16/08/13 | PC | | 27/08/13 | 30/08/13 | 11 | 14 | 2 (PC, PH) | |
| Kandal | 6 | M | 21/07/13 | Medicines at home | FSS study - pool samples | 23/07/13 | 17/08/13 | | 27 | 2 (PC, PH) | Recovering |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Kandal | 5 | F | 01/08/13 | Health Center | | 10/08/13 | 10/08/13 | 9 | 9 | 3 (X, PC, PH) | Critical condition |
| Battambang | 9 | M | 26/07/13 | Medicines at home | | 09/08/13 | 09/08/13 | 14 | 14 | 2 (PC, PH) | Stable condition |
| Prey Veng | 3 | M | 03/07/13 | Medicines at home | | 09/07/13 | 10/07/13 | 6 | 7 | 2 (PC, PH) | Stable condition |
| Kampot | 6 | F | 24/06/13 | | | 28/06/13 | 28/06/13 | 4 | 4 | 2(PC, PH) | Death |
| Phnom Penh | 58 | M | | | Retested for H5N1 | | 21/06/13 | | | | Recovering |
| Kampong Speu | 5 | F | | | Retested for H5N1 | | 02/05/13 | | | | Recovering |
| Kampot | 5 | M | 27/03/13 | Medicines at home | | 31/03/13 | 02/04/13 | 4 | 6 | 2 (PC, PH) | Critical condition |
| Kampong Cham | 35 | M | 08/02/13 | PM in village | | 13/02/13 | 23/02/13 | 5 | 15 | 3 (PM, PH, PH) | Death |
| Kampot | 20 m | M | 06/02/13 | PM in village | | 18/02/13 | 19/02/13 | 12 | 13 | 2 (PM, PH) | Death |
| Kampot | 3 | F | 03/02/13 | PM in village | | 06/02/13 | 11/02/13 | 3 | 8 | 3 (PM, PH, KB) | Critical condition |
| Takeo | 5 | F | 25/01/13 | PM in village | | 31/01/13 | 07/02/13 | 6 | 13 | | Death |
| Kampot | 9 | F | 19/01/13 | PM in village | | 27/01/13 | 28/01/13 | 8 | 9 | 2 (PM, PH) | Death |
| Kampong Speu | 17 m | F | 13/01/13 | PM in village | | 17/01/13 | 26/01/13 | 4 | 13 | 2 (PM, PH) | Death |
| Kampong Speu | 35 | M | 13/01/13 | PM in village | | 21/01/13 | 23/01/13 | 8 | 10 | 2 (PM, PH) | Death |
| Takeo | 15 | F | 11/01/13 | PM in village | | 17/01/13 | 21/01/13 | 6 | 10 | 2 (PM, PH) | Death |
| Phnom Penh | 8 m | M | 08/01/13 | NPH | | 09/01/13 | 22/01/13 | 1 | 14 | 1 (PH) | Recovering |
| Kampong Speu | 10 | F | 20/05/12 | PM in village | | 25/05/12 | 26/05/12 | 5 | 6 | 2 (PM, PH) | Death |
| Kampong Chhnang | 6 | F | 22/03/12 | Village | | 28/03/12 | 30/03/12 | 6 | 8 | 2 (PM, PH) | Death |
| Banteay Mean Chey | 2,5 | M | 03/01/12 | PM in village | | 09/01/12 | 12/01/12 | 6 | 9 | 2 (PM, PH) | Critical condition |
| Kampong Cham | 6 | F | 07/08/11 | PM in village | | 13/08/11 | 13/08/11 | 6 | 6 | 2 (PM, PH) | Death |
| Banteay Mean Chey | 4 | F | 10/07/11 | PM in village | | 18/07/11 | 20/07/11 | 8 | 10 | 2 (PM, PH) | Death |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Prey Veng | 7 | F | 24/05/11 | PM in village | | 31/05/11 | 08/06/11 | 7 | 15 | 2 (PM, PH) | Death |
| Prey Veng | 5 | F | 11/04/11 | PM in village | | 13/04/11 | | 2 | | 2 (PM, PH) | Death |
| Kampong Cham | 11 | F | 22/03/13 | PM in village | | 29/03/13 | | 7 | | 3 (PM, RH, PH) | Death |
| Banteay Mean Chey | 11 m | M | 05/02/11 | | | 15/02/11 | | 10 | | PH | Death |
| Banteay Mean Chey | 19 | F | 05/02/11 | | | | | | | PC | Death |
| Phnom Penh | 5 | F | 30/01/11 | | | 30/01/11 | | 1 | | PH | Death |
| Prey Veng | 27 | M | 13/04/10 | HC | | 16/04/10 | | 3 | | 2 (PC, PH, CH) | Death |
| Kampong Cham | 57 | M | 11/12/09 | | | 16/12/09 | 16/12/09 | 5 | 5 | 1 (PH) | Stable condition |
| Kandal | 19 | M | 28/11/08 | HC | | 30/11/08 | 11/12/08 | 2 | 13 | 2 (PC, PH) | Treated |
| Prey Veng | 12 | M | 29/03/06 | PH | | 04/04/06 | | 6 | | 1 (PH) | Death |
| Kampong Speu | 3 | F | 14/03/06 | | | 20/03/06 | | 6 | | | Death |
| Kampot | 20 | F | | | | | | | 0 | HCMC PI | Death |
| Kampot | 8 | f | 29/03/05 | Distric RHl | | | | | | 2 (RH, PH) | Death |
| Kampot | 28 | M | 17/03/05 | | | 21/03/05 | | 4 | | 1 (PH) | Death |
| Kampot | 25 | F | | | | | 01/02/05 | | | HCMC PI | Death |
| *Kampot* | *14* | *M* | | | | | | | 0 | | *Death* |

PM= Private Med ; PC= Private Clinic ; PH= Provincial Hospital ; KB= Kantha Bopha ; NPH= National pediatric Hospital ; CH= Calmette hospital; RH=Referal Hospital

# ANNEX 13

**A 'One Health' approach to quantitatively compare human and animal surveillance systems for avian influenza H5N1 in Cambodia**

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Since 2003, nineteen human cases of highly pathogenic avian influenza (HPAI) have been reported in Cambodia, eight of them, all fatal, occurred in 2011 in people <19 years old. The source was mainly sporadic infection with direct exposition to sick poultry but this sudden increase of incidence was alarming for the national health authority of Cambodia. In order to assess the sensitivity of the national surveillance system of HPAI H5N1 in Cambodia, scenario tree modelling was used to describe and compare the components of the surveillance system in human and animal populations in order to make recommendations to enhance early detection of outbreaks. The human surveillance consists of two main components: one based on syndromic surveillance with weekly case reporting but with low capacity for laboratory confirmation and one, more research based, with a high sensitivity but low coverage. For the animal surveillance, several components were implemented but few were sustainable. The most established one is the passive surveillance based on the network of 12,000 Village Animal Health Workers. The sensitivity of this component was estimated to be 0.54 (95% CI 0.18-0.80) but with large variation between provinces. This study showed that some components in the animal surveillance system, like the market surveillance, need to be redefined in order to meet the objective of early warning and that there is a great effort needed to integrate human and animal surveillance together.

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**Why implementing co-ordinated systematic H5N1 post-vaccination systems is so hard and what needs to be done**

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Vaccination against HPAI H5N1 has been practised in Indonesia since 2004, particularly in the commercial layer sector. Whilst this vaccination – combined with improved biosecurity – has successfully prevented massive mortalities and production loss, ongoing evolution of the virus requires the development of surveillance systems to ensure that vaccination continues to be effective. Nevertheless, to date this has been difficult to implement due to the need to co-ordinate, for a given vaccine H5N1 seed antigen, the appropriate sampling regime together with the most effective test antigen in the haemagglutination inhibition (HI) test. In addition, post-vaccination test results can be difficult to interpret without knowledge of the infection status of the sampled birds. To progress a solution to this complex problem, we have worked with a small number of commercial layer producers in West Java, which is one of the areas of Indonesia worst affected by H5N1. Initially we undertook a cross-sectional survey to better understand vaccination and biosecurity practices, and this enabled us to develop an effective strategy of sero-sampling at the point-of-lay stage of pullets where vaccination is routinely practised. This has also assisted us to define quantifiable baseline serological responses, and to define clearly questions that require parallel studies regarding vaccine responses to test antigens. As importantly, we have defined a role for a DIVA (Differentiating Infected from Vaccinated Animals) ELISA based upon the M2e antigen to detect birds actively excreting virus. These concepts are now being implemented in follow studies in West and Central Java in an intensive longitudinal study of about 40 Sector Three poultry farms.

**Summary**

The Highly Pathogenic Avian Influenza virus H5N1 is still present in some of the poorest areas of the world as South-east Asia where the disease occurred on a regular basis in human and poultry. Early detection of the disease in poultry population is the most efficient method to avoid the spread of the virus to human. In poor rural communities of developing countries, such as Cambodia, this disease detection is often based on volunteer case reporting by farmers. However this surveillance method carries challenges when applied in difficult socioeconomic environments: low density of health facilities, poor communication systems, weak awareness of population, distrust on governmental authorities and lack of qualified staff. We have in this thesis conceived and applied new methods for the evaluation, the design or the improvement of passive surveillance in order to propose innovative methods to increase the involvement of rural communities in the reporting of zoonotic diseases.

Key words: Surveillance, Zoonotic diseases, Participatory methods, Evaluation

**Résumé**

Le virus de la grippe aviaire reste présent dans certaines des régions les plus pauvres du monde comme en Asie du sud-est où la maladie apparait de façon régulière chez l'homme et les volailles. La détection précoce de la maladie animale est la méthode la plus efficace pour éviter la propagation du virus aux humains. Dans les communautés rurales des pays en développement comme le Cambodge, cette détection repose souvent sur des déclarations volontaires des éleveurs. Cependant, de nombreuses contraintes apparaissent lorsqu'elle est mise en œuvre : faible densité des centres de santé, faible sensibilisation de la population, méfiance envers le gouvernement et manque de personnel qualifié. Nous avons dans cette thèse proposé et appliqué de nouvelles méthodes pour l'évaluation, la conception ou l'amélioration de la surveillance passive en Asie du sud-est, afin d’accroitre l’implication des communautés rurales dans la déclaration des maladies transmissibles à l’Homme.

Mots clés: Surveillance, Zoonoses, Méthodes participatives, Evaluation