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Consequences of underestimating ancient deforestation in South India for global assessments of climatic change

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Land-cover changes occurring before 1800 are often ignored in the estimation of CO_2 emissions, probably because they are poorly documented in most tropical countries. India appears to be an exception to this rule. It was possible to reconstitute the main stages of the land-cover history for a large region of South India, and therefore to retrace the dynamics of CO_2 emissions during nearly 1000 years. It was then possible to demonstrate that 25% of the total emissions occurred before 1800, and are mistakenly considered as more recent emissions.

Keywords: Ancient deforestation, carbon dioxide emissions, climate change, global assessments, land cover.

IN 2004, deforestation and biomass decomposition accounted for 17.3% of the total 49 Pg of CO_2-equivalent anthropogenic emissions of greenhouse gases (GHGs)[1], while fossil fuel consumption represented 56.6%. Global estimates of recent emissions are computed from country-level inventories following IPCC guidelines[2,3]. For past emissions, ancient land-cover changes are either neglected[4] or introduced through a historical frame[5,6]. In this communication, we assess the consequences of not considering ancient land-cover changes when estimating GHG anthropogenic emissions for a large study area located in South India (Figure 1), focusing on soil organic carbon (SOC) which represents the largest terrestrial C pool[7].

In 2001, the Intergovernmental Panel on Climate Change (IPCC)[4] calculations for land-use (LU) change related emissions amounted to 121 PgC for the period 1850–1990, with LU changes obtained by the difference between potential[8] and current[9] vegetation maps. Potential vegetation was represented by the 1850 land cover, with the implicit hypothesis that no significant deforestation occurred before that date, and that GHGs emissions due to land-use/land-cover changes had started at about the same time as those due to fossil-fuel consumption.

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When Houghton and Hackler[5], and Van Minnen *et al.*[6] calculated emissions for tropical Asia and for India respectively, historical frames of land-cover changes were introduced. Houghton and Hackler[5] considered the period before 1750 as the 'pre-disturbance period' (i.e. hypothesizing that no major anthropogenic land-cover changes had occurred before 1750), whereas Van Minnen *et al.*[6] proposed four world maps of the 'reconstructed agricultural area (cropland and pasture)' for AD 1700, 1800, 1900 and 2000. In both studies, ancient land-cover changes were not considered, while in the latter one, the 1700s map[6] surprisingly showed South India free of cultivated areas.

For estimating past SOC changes in our study area, reference stock (i.e. SOC stock under potential vegetation) was based on a potential vegetation map derived from the forest maps of Pascal *et al.*[10,11] and Ramesh *et al.*[12]. In these maps, the potential area of each vegetation type is mainly given by the bioclimate[13]. The potential vegetation types are either directly indicated on the forest maps or, in places where forests have been cleared, deduced from bioclimate maps[13]. According to the 'climax theory', this potential vegetation corresponds to the 'plesioclimax: i.e. the stage that would be reached within nearly a century if man and his cattle were to disappear'[14].

The multifactor method used in previous studies[15,16] for estimating the 1977 and 1999 SOC stocks was again used to compute the potential SOC stock, with potential vegetation replacing the 1977 or 1999 land cover. A figure of 0.554 PgC was obtained for the potential SOC stock of the study area. In the same area, recent findings[16] have established that the SOC stock was stable, around 0.433 PgC during the period 1977–1999 (0.4288 and 0.4369 PgC in 1977 (ref. 16) and 1999 (refs 15 and 16) respectively), and this despite an unabated deforestation. It was also established that the soil carbon losses in deforested areas were compensated by C sequestration elsewhere, mainly in recent plantations and in the newly irrigated croplands[16]. These explanations, which concern the SOC stock, can be probably extended to the biomass carbon stock because both are linked in the functioning of terrestrial ecosystems.

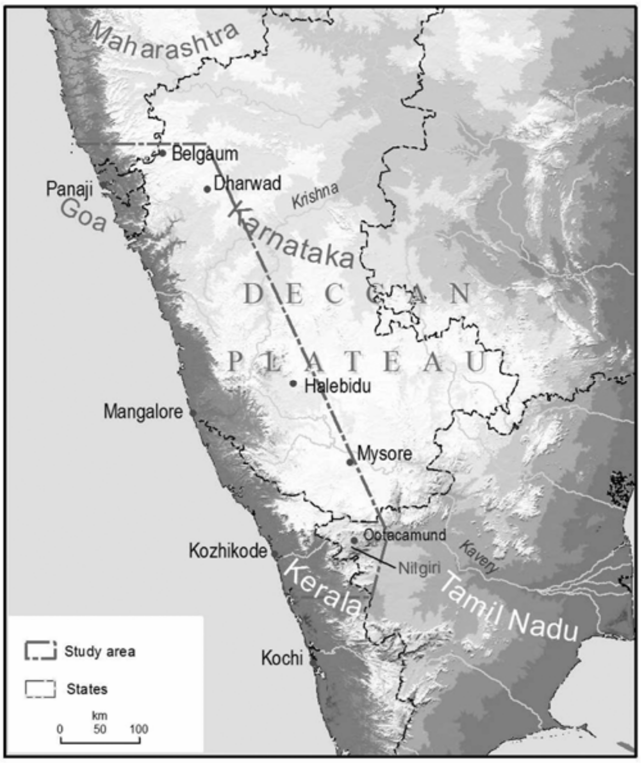

Figure 1. Location map showing the study area and the different places cited in the text.

When comparing the potential SOC stock (0.554 PgC) to the 1999 stock (0.437 PgC), the difference, 0.117 PgC, represents an estimate of the overall loss of C from the soil, i.e. only 21.1% of the potential SOC stock.

We agree with authors[5,6] who consider that the history of land-cover changes is key for understanding carbon stock variations. To integrate historical data in our ecological approach, we referred to the four historical modes of resources use (viz. gathering, nomadic pastoralism, settled cultivation and industry) defined by Gadgil and Guha[17] to describe the ecological history of India. Then, in order to go beyond a simple qualitative description, we used the broad correspondences established by Ellis and Ramankutty[18] between the main forms of human–ecosystem interaction and population density. The gathering mode corresponds to a population density < 1 person km^{-2}, while settled cultivation, and particularly irrigated cultivation, seems to need >100 persons km^{-2}. Intermediate densities (between 1 and 100 persons km^{-2}) correspond to the other modes of resources use (shifting cultivation and nomadic pastoralism). We may notice that, in the type of irrigated agriculture in semi-arid India known as 'tank irrigation', these figures are in agreement with those of Van Oppen[19], who showed that tanks appear when population density reaches 50–60 persons km^{-2} and disappear when it exceeds 220 persons km^{-2}.

In India, archaeological records suggest that the southern part of the peninsula was occupied later, compared to the Indus Valley, and was also less intensively studied by archaeologists and historians[20]. The period around 2500 BP was described as the starting time of settled agriculture and pastoralism in the drier parts of India[17], after a long period when gathering was the only mode of resources use. Pastoralism is attested by numerous dung mounds in semi-arid Karnataka, but Fuller[21] considered that most of these dung mounds were linked to seasonal encampments of a pastoral segment of the society rather than to permanent settlements. At the same period, because of the limited efficiency of stone-tools, the Western Ghats, as many other regions covered by moist forests, might have remained under the food-gathering mode associated with limited shifting cultivation[17].

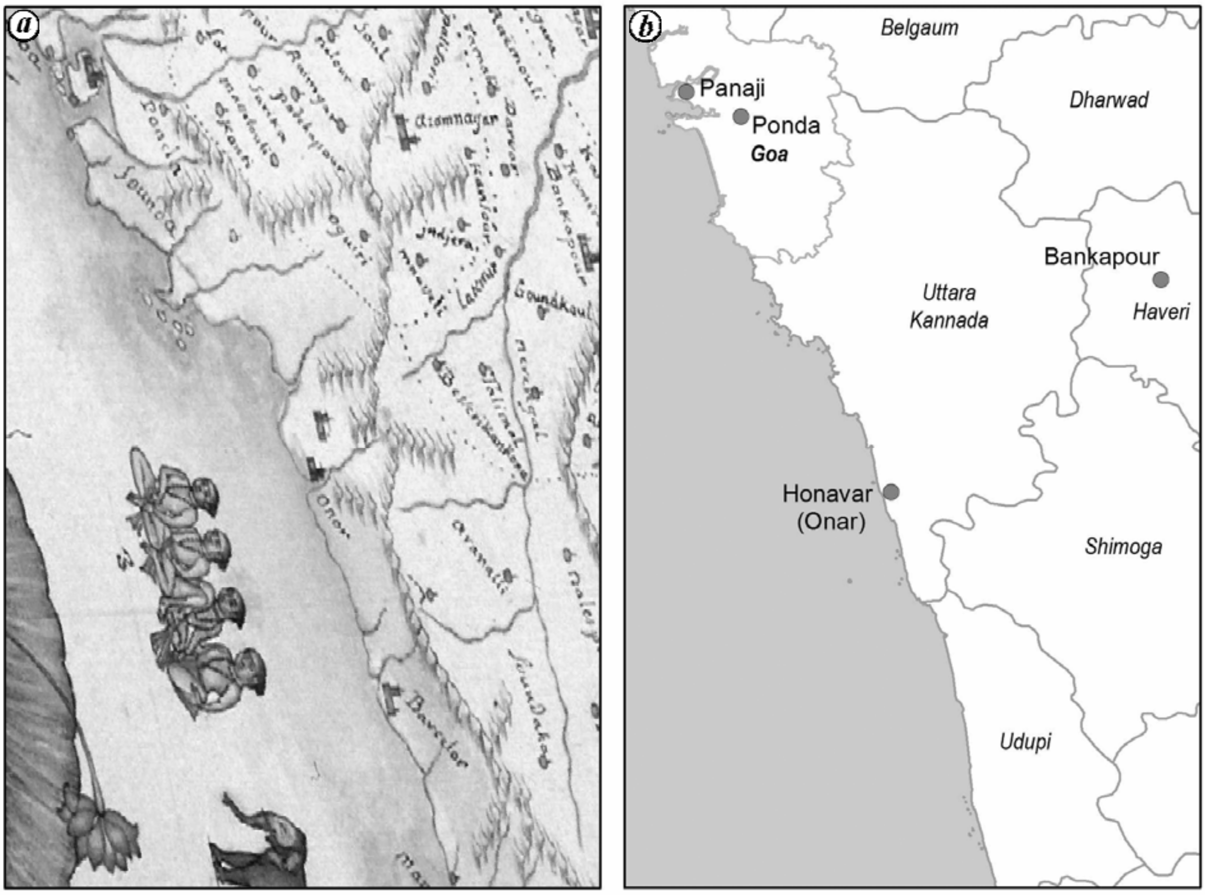

Figure 2. Map of the Belgaum–Goa region, north of the study area. ***a***, Corrected map of Gentil (1770) with Sarkars (e.g. Bankapour) and Parganas (e.g. Onar), the two lower levels of the Mughal administrative divisions; dotted lines represent boundaries of Sarkars. ***b***, Modern map showing present-day districts.

The oldest iron tools discovered in Karnataka were dated from 1050 to 950 BC; this age corresponds to the 'later Vedic period' (1000–600 BC) of Randhawa[22]. The use of iron tools, axes, sickles and ploughs of different types allowed efficient deforestation and, at the same time, extension of ploughed areas and the true transition to settled agriculture.

Further agricultural development of South India was made by rulers of local kingdoms. The first one, the Chera kingdom, corresponding to the present-day Kerala, flourished during the second century AD (ref. 22). Other kingdoms appeared later, mostly to the west of the study area on the deltaic formations of the west coast, and have developed irrigated rice cultivation. Their rulers have continued on the same basis, encouraging land clearance and promoting tank and canal irrigation: Cholas in the present-day Tamil Nadu and Hoysalas in northeast Karnataka (Mysore–Hassan districts) for nearly three centuries (AD 1000–1300). The Hoysalas established their first capital in Halebidu (25 km north of Hassan, Figure 1) during the 11th century; they encouraged agriculture, forest clearance to extend cultivated lands, and promoted tank and canal irrigation[23].

The Portuguese were the first Europeans to settle in India during the 16th century (Cochin, Goa) introducing groundnuts, tobacco, potatoes and red chillies.

Later, the 18th century situation attracts particular attention because it corresponds approximately to the period chosen by many authors[4–6] as the starting point of anthropogenic disturbance.

The maps of Gentil (1770) were helpful for documenting the 1750–1770s situation. Reprints of these historical maps were recently made available by Gole[24]. On these maps, place names have been given and are ordered according to three administrative sub-divisions in use in the Mughal Empire at that time, viz. Subas, Sarkars and Parganas. The Parganas were places of administrative importance where taxes were collected. For comparison with more recent maps, the maps of Gentil had to be geometrically corrected because they were established from route marches without accurate topographic survey[24], where only approximate distances between parganas were respected. We used some of the Parganas and Sarkars names and their modern correspondences to correct the maps of the Subas (Provinces) of 'Vizapour' (Bijapur) and 'Aiderabad' (Hyderabad), corresponding to the

Table 1. Details of soil organic carbon (SOC) stocks and surface areas per land-cover type at three different dates corresponding to (i) potential; (ii) 18th century situations with two land-cover hypotheses (a) and (b); and (iii) recent situations

	(i) Potential		(iia) 1770		(iib) 1770		(iii) 1977		(iii) 1999	
	Area (sq. km)	SOC stock (PgC)	Area (sq. km)	SOC stock (PgC)	Area (sq. km)	SOC stock (PgC)	Area (sq. km)	SOC stock (PgC)	Area (sq. km)	SOC stock (PgC)
Nilgiris ‘sholas’	1,294	0.013	1,294	0.014	1,294	0.014	461	0.005	461	0.005
Nilgiris grasslands	552	0.006	552	0.005	552	0.005	295	0.002	295	0.002
Evergreen forests continuum	46,789	0.287	44,000	0.282	44,000	0.282	3,656	0.023	3,509	0.023
Plateau moist deciduous forests	5,995	0.044	4,800	0.035	4,800	0.035	3,284	0.024	2,955	0.022
Plateau dry deciduous forests	33,748	0.204	5,500	0.036	5,500	0.036	3,068	0.020	2,916	0.019
Secondary/disturbed evergreen forest			5,000	0.032	5,000	0.032	13,250	0.076	11,594	0.073
Plateau cropland (rainfed)			2,520	0.009	5,040	0.018	18,940	0.069	9,700	0.035
Plateau cropland (irrigated)			250	0.001	560	0.003	9,343	0.047	18,524	0.089
Non-forest coastal lowlands, cultivated or not			1,500	0.006	1,500	0.006	5,835	0.025	6,545	0.025
Degraded forests, wastelands			22,943	0.085	20,108	0.091	23,907	0.105	22,121	0.100
Plantations			0	0	0	0	4,639	0.032	6,617	0.045
Miscellaneous/unclassified			–	–	–	–	647	–	643	–
Water	106		125	0.000	130	0.000	1,159	0	3,604	0
Total	88,484	0.554	88,484	0.522	88,484	0.520	88,484	0.429	88,484	0.437

present-day states of Karnatata, Kerala, Tamil Nadu and Goa plus the southern part of Maharashtra. Part of the corrected map corresponding to the Goa–Belgaum region in the north of the study area is given, Figure 2 *a*, along with a modern map, Figure 2 *b*, showing the present-day administrative divisions.

In 1807, after visiting a large part of the study area during 1800–1801, Buchanan[25] described a flourishing country, well cultivated, and gave numerous statistics, including those reporting that coffee was being imported in India[25,26].

In the late 1820s, the first commercial coffee plantation was established in Shimoga district, Karnataka[26], hence initiating the industrial mode of natural resource use in the study area[17]. From 1820 onwards, this mode of resource use had an important effect on deforestation in the evergreen ecosystems. Black pepper, coffee and cardamom were grown under the shade of medium-elevation evergreen forests after the undergrowth was cleared, while stands of low and medium-elevation evergreen forests were completely removed for rubber. Tea and cinchona (*Cinchona succirubra*) were grown above 1500 m altitude. Several timber or fuel wood species (*Eucalyptus* spp., *Acacia* spp.) were also planted in clear-felled areas or at the expense of high-altitude grasslands. The development of plantations probably led to compensation between SOC losses in deforested areas and gains in reforested ones as it is observed nowadays[16].

A special mention can be made of deforestation of deciduous forests due to the construction of the Indian railway network during the second part of the 19th century. Quoting different sources, Gadgil and Guha[17] reported that in India ‘in the 1870s, it was calculated that well over a million sleepers were required annually’. According to Legris[27] and Meher-Homji[28], these requirements led to selective felling of sal (*Shorea robusta*) in the dry deciduous forests of central India and of teak (*Tectona grandis*) in those of South India, and to such an extent that teak completely disappeared from forest stands in some places. In many other places, settled cultivation was still prevailing, with clear felling of forests for the extension of cultivated lands, forest degradation for fire wood and animal grazing, with a net loss of biomass and SOC stock.

From this concise historical scenario of the Indian peninsula, the following assumptions can be made: (i) shifting cultivation and nomadic pastoralism prevailed long before 1770, impacting most of the deciduous formations of the plateau and leading to a great extension of degraded forests and wastelands; (ii) in 1770, the Nilgiris was still the territory of the Badagas, Todas and Kotas communities[29], which had limited impact on their environment[29]; (iii) at that time there were no plantations in the study area; (iv) deforestation for food crops had marginally concerned evergreen forests and (v) irrigation was limited to the eastern side of the study area and covered less than 10% of the plateau cropland (in 1977, the area of irrigated cropland represented 33% of the total area of plateau cropland[16]).

The SOC dynamics of the study area can then be outlined at three reference dates. Till 1000 BC, all the area was covered by forests except for high-altitude grasslands; at that time, SOC stock can be considered close to the potential SOC stock, i.e. 0.554 PgC. Estimates of recent stocks gave 0.430 PgC for the 1999 situation[16], a figure stable during 1977–1999 as already mentioned[16].

The third date corresponds to the 1770s situation, i.e. at the time Gentil prepared his maps, and is also within the period that other studies[5,6] considered as corresponding to potential vegetation. To estimate SOC stocks at this point we simulated a land-cover scenario (Table 1) with plateau-cultivated areas limited to 10% (a) and 20% (b) of their 1999 extension. Both hypotheses gave estimates close to 0.520 PgC in 1770. Therefore about 0.030 PgC emitted before 1770 was neglected in most of the published scenarios[4–6] and *de facto* added to the more recent emissions. In other words, previous calculations transfer 25% of the total emissions from the pre-1770 period to the recent one. Without minimizing the seriousness of the depletion of carbon stocks in the contemporary period, we argue that the role of the pre-19th century times should be taken into account for an accurate evaluation of the variation in SOC in South India, as also in other countries of Asia with a long history.

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