Environ Earth Sci (2013) 68:2111–2121
DOI 10.1007/s12665-012-1896-4

ORIGINAL ARTICLE

Brick and tile clay mining from the paddy lands of Central Kerala (southwest coast of India) and emerging environmental issues

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Received: 4 September 2011 / Accepted: 3 August 2012 / Published online: 21 August 2012

Abstract The increasing demand for building materials has led to indiscriminate exploitation of clay-rich topsoil from wetlands including the paddy lands of Central Kerala in the southwestern coast of India. The problem is critical in areas adjoining the major developmental centers having low per capita land and natural resource availability. Loss of fertile topsoil, shrinkage of agricultural lands and consequent food security issues, erosion of naturally evolved nutrients, lowering of water table in wells adjacent to the mining sites, etc., are some of the major environmental issues arising from indiscriminate brick and tile clay mining. Although, brick and tile clay mining brings short-term economic benefits and employment opportunities to a section of people, the process in the long run creates severe damages to the environmental settings of the area. The present paper deals with a few aspects of brick and tile clay mining in the paddy lands of Central Kerala, especially around Kochi City, a fast developing urban-cum-industrial center in South India, which demands large quantities of building materials including bricks and tiles for construction of infrastructural facilities. It is estimated that 729,695 tons/year (ty^{-1}) of brick and tile clays are extracted from the coastal lowlands of Central Kerala, spreading to the Chalakudy (135,975 ty^{-1}), Periyar (483,820 ty^{-1}) and Muvattupuzha (109,900 ty^{-1}) river basins. The N, P and K loss through extraction of brick and tile clays amounts to 210 ty^{-1}, 96 ty^{-1} and 9,352 ty^{-1}, respectively. As nutrient loss is an irreversible process in human time scale, its implications on agricultural productivity is a matter of serious concern. The study warrants the need for a comprehensive policy with an aim to regulate the mining activities on an environment- friendly basis in the densely populated coasts of the world, in general, and the study area in particular.

Keywords Brick and tile clays · Paddy lands · Coastal wetlands · Southwest coast of India · Environmental issues

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Introduction

The demand for construction materials has been rising exponentially in many developing countries where rapid economic development has caused significant growth of the construction industry (De Leeuw et al. 2009). Indiscriminate extraction of raw clays for the manufacture of bricks and tiles from highly productive ecosystems such as wetlands, including paddy lands, in most cases results in serious environmental problems, which are irreparable in human time scale. The degradation of paddy lands assumes special importance as many of the South Indian states depend on rice the staple food of the region. The major environmental issues related to uncontrolled clay mining include fall in agricultural production, loss of fertile topsoil, lowering of water table in domestic wells adjacent to mining sites during the summer season and creation of fallow lands/waterlogged areas. However, it is also important that clay mining and manufacture of clay articles produce employment opportunities to a significant section of the people in the area. Additionally, thousands of laborers in the construction sector and a section of people in the traditional pottery industry also depend on clays and clay products for their livelihood.

Bricks and tiles have been used for building construction for many thousands of years. Essentially, the story of brick building is the story of good-quality brick making with earth/clay, in places where there is lack of other building materials such as wood and stone (Hayward 1978). Brick and tile making is found in most of the countries and the clay suitable for their manufacture is associated mainly with geologically recent deposits. Good deposits of brick and tile clays are found in gently rolling hills (ILO 1984). Many studies exist on various aspects of brick and tile earths. However, studies on the environmental impacts of clay mining are scarce. Here, we report the case of certain environmental problems caused by indiscriminate extraction of brick and tile clays from the paddy lands of Central Kerala in the southwestern coast of India and suggest a few corrective measures to resolve the adverse effects of clay mining.

Historical records

Clay is one of the most widespread and earliest mineral resources used by mankind. It carries records of ancient races inscribed upon tablets, in brick building, monuments and pottery. Clay industry, perhaps, represents the first large-scale mineral industry that has persisted through the ages. Bricks, tiles and clay tablets were extensively used by the Babylonians and Egyptians for building construction, irrigation and in writing materials. Asian and African dwellings were built with bricks made of clay. In India, manufacture of clay articles was predominant even in the time of the Harappan civilization. Excavations reveal that the Harappan settlements were built with a combination of mud bricks, burned bricks and other clay articles (Bateman 1960). A micro-level scanning of literature shows that there are several incidents that were responsible for the growth of clay mining and clay-based industrial establishments in the world. One of the best examples of such incidents is the Great Fire of London (GFL) in the year 1666AD. The GFL was instrumental in bringing the Rebuilding Act of 1667. The act gave a boost to the clay-based industrial establishments over the traditional wood-based establishments not only in England, but also in the entire world.

It is uncertain how far the production of clay articles in Kerala in the southwestern coast of India can exactly be traced back in history (Pronk 1997). The recent excavations in Pattanam, an archeological site located in the northern part of the study area, close to the mouth of Periyar River, unearthed evidences of extensive use of bricks and other clay articles dating back to ~3,000 years. As per the records of European travelers of the fifteenth and sixteenth centuries, clay article manufacture in Kerala was undertaken by a special group of people known as 'potters'. Later, in the beginning of the twentieth century, more and more people undertook clay mining and manufacture of clay articles as well as bricks and tiles. This has caused indiscriminate mining of clay-rich topsoil from paddy lands and other wetlands, imposing irreparable damages on the system.

Study area

The area selected for the present study is located in Central Kerala in the southwest coast of India between northern latitudes 9°0′–10°35′ and eastern longitudes 76°05′–77°25′ (Fig. 1). Of the total area of Kerala State, about 1/5th in the central part is drained by three important rivers: Chalakudy, Periyar and Muvattupuzha rivers. Geologically, a greater part of the drainage basin of these rivers is occupied by Precambrian crystallines. In the midlands, a portion of the Precambrian crystallines is lateritized (Padmalal et al. 2008). A small part near the mouth of these rivers is occupied by coastal sands and alluvium (Fig. 2). Land use types are distinctly governed by physiography and climate of the area with forests and forest plantations dominating the eastern part of the study area, followed by mixed crops in the midlands and agricultural land and water bodies in the lowlands (Fig. 3). Clay suitable for brick and tile making occurs in the paddy lands and adjoining wetlands in the midlands and lowlands of the study area having high population and development pressures.

The urban centers of the study area are also concentrated in the midland–lowland stretches. Kochi, one of the actively emerging cities in South India, situated in the lowlands of the study area, perhaps, has the highest density of population (6,277 inh km^{-2}) in the country. The suburbs of Kochi have become the nerve center for real estate activities in recent years. Also, the already initiated mega development projects like Vallarpadam Transshipment Container Terminal (VTCT), Liquified Natural Gas (LNG) terminal, etc., require huge quantities of bricks, roofing and flooring tiles and other building materials for infrastructural development (Sreebha and Padmalal 2011).

Materials and methods

A systematic fieldwork was carried out in the entire study area for the collection of relevant field data from various sources and of sediment samples for laboratory analyses. The areas where clay mining activities have become widespread were mapped using Survey of India (SoI) topo base maps in 1:50,000 scale. The total quantity of the clay extracted from the paddy fields/wetlands (Table 1) was determined from the areal extension and depth of the clay

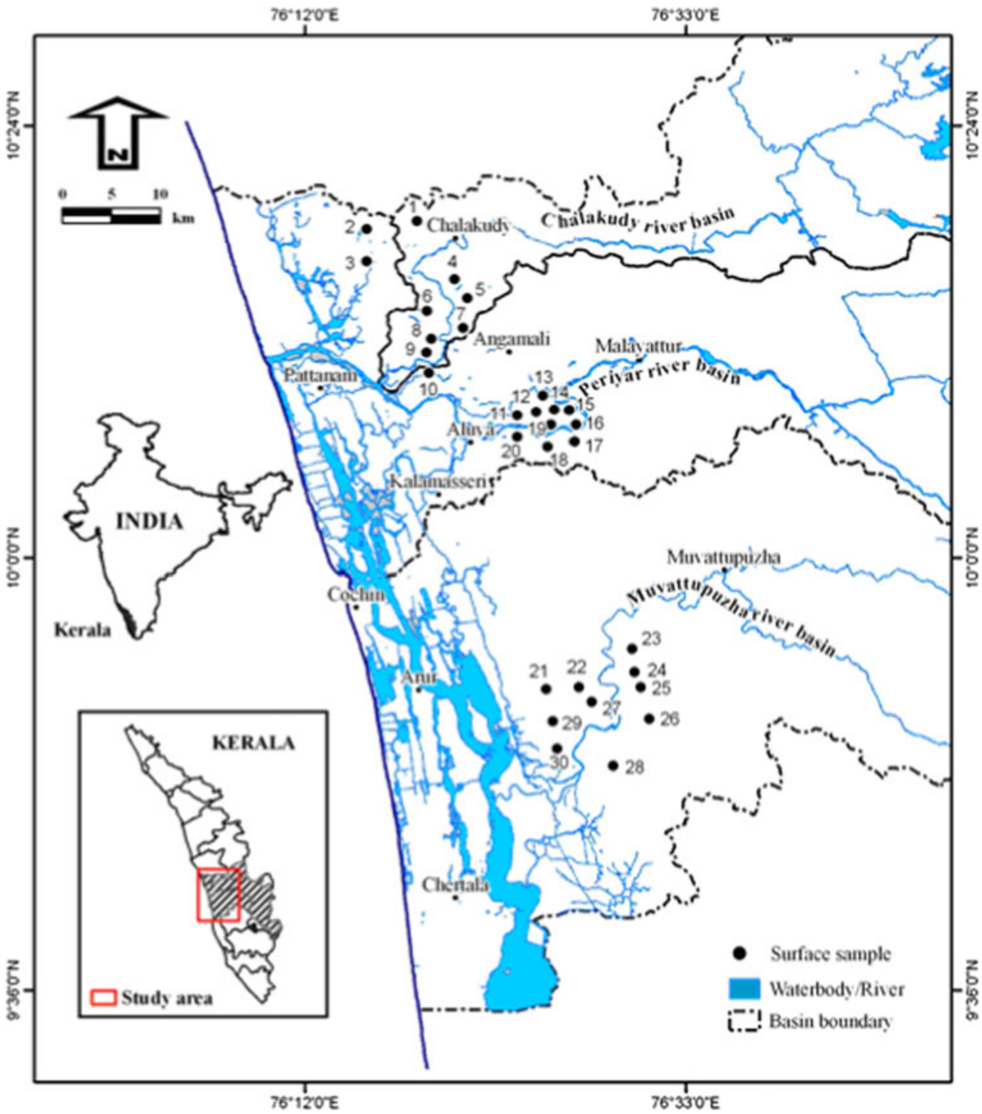


Fig. 1 Study area showing sampling locations

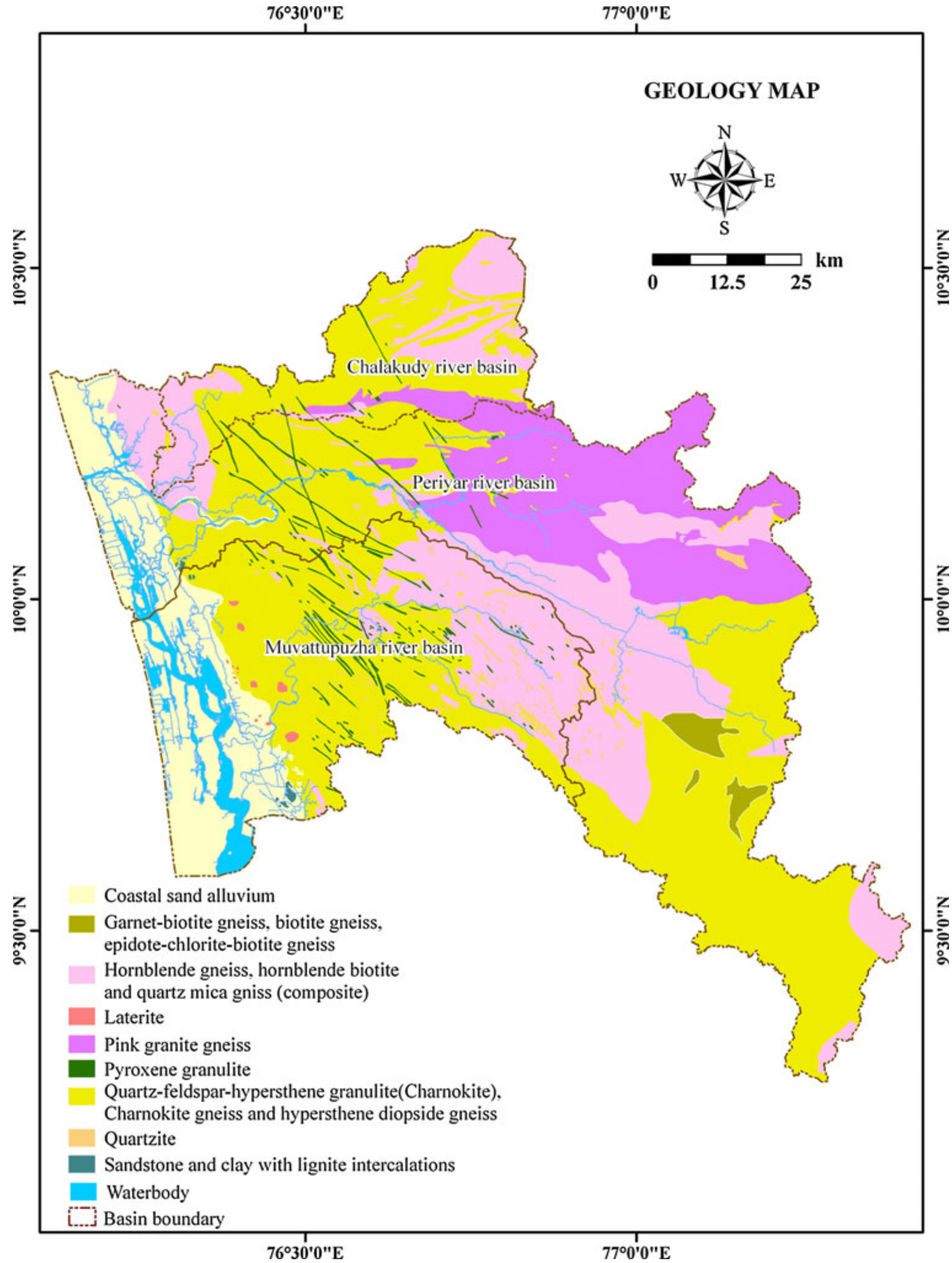
mine following geometrical methods. Quantitative details on clay mining were obtained from the State Mining and Geology Department (2009), which was another source of information. A total of 30 brick and tile clay samples from the major mining locations were collected for geochemical analysis (Fig. 1). The sand, silt and clay contents in the samples were determined by pipette analysis following Folk (1970). The sediments were dried at 55 ± 5 °C in a hot air oven. A portion of the dried sample was powdered and homogenized thoroughly for the estimation of geochemical parameters. The organic carbon and nitrogen contents in the samples were estimated and analyzed following the method of El Wakeel and Riley (1957) using wet chromic acid oxidation. The nitrogen and phosphorus contents were determined following the standard methods of Murphy and Riley (1962) and Saxena (1994), respectively. The powdered samples were then subjected to total digestion using HF–$HClO_4$–HNO_3 acid mixture and used for the estimation of P, and K following standard methods (APHA 1985). Flame photometric determination of potassium was performed according to the methods suggested by Saxena (1994).

Results

Physicochemical characteristics of brick and tile clays

The raw clayey materials excavated from paddy lands and other wetland systems of Central Kerala (Fig. 4a–c) contain varying proportions of sand (average diameter: 2–0.0625 mm), silt (0.0625–0.0039 mm) and clay (<0.0039 mm) particles. Table 2 shows the content of granulometric characteristics in the clay samples of the study area. Generally, silt- and clay- (i.e., mud) rich sediments are used for tile making, whereas clay deposits with

Fig. 2 Geological settings of the study area (*source:* GSI 1995)



fairly high proportions of sand are used for brick making. The granulometric analysis indicates predominance of silt- and clay-rich sediments in the Periyar river basin compared to the Chalakudy and the Muvattupuzha river basins.

Organic carbon (C-org) is an essential component of brick and tile clays as the burning of carbon provides the required internal heating of the clay articles. The C-org originates in the clays mainly from partially decayed plant residues and other organic sources. The relative proportion of C-org derived from allochthonous and autochthonous sources is a function of the characteristics of the catchment area in relation to the productivity of the environment of deposition of the clay-bearing formation (Hankanson and Jannson 1983). The content of C-org in the brick and tile clays of the Chalakudy river basin varies from 0.19 to 4.08 % (av. 1.56 %). The C-org content in the brick and tile clays of the Periyar and the Muvattupuzha river basins varies from 1.2 to 2.76 % (av. 1.81 %) and 0.59–2.3 % (av. 1.34 %), respectively. The enhanced levels of C-org noticed in the Periyar river basin may be attributed to high input of organic matter from the paleoforests that had blanketed the hinterlands of the depositional sites during the Early–Middle Holocene period. It is now established that the Early–Middle Holocene period in the southwest

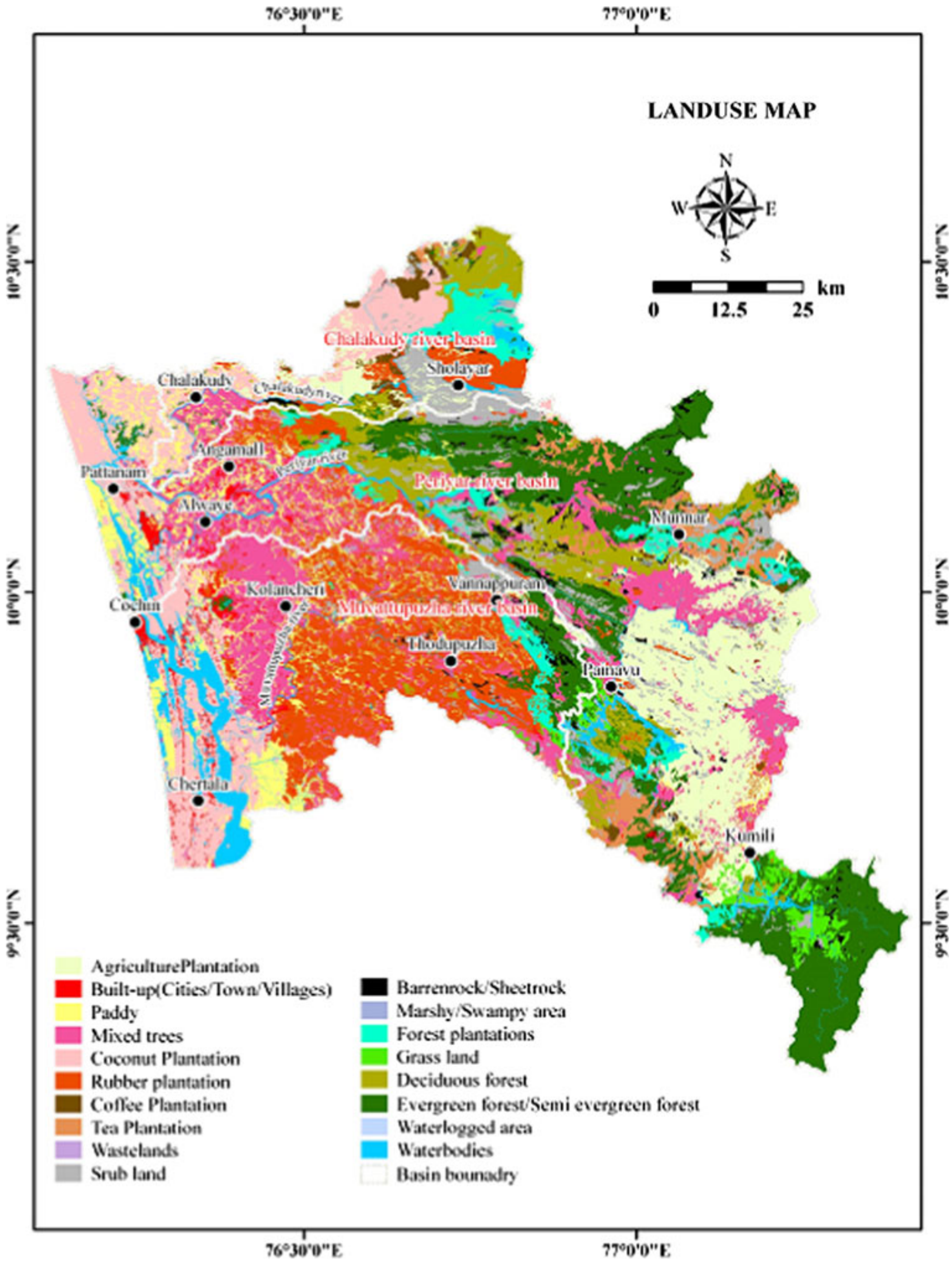


Fig. 3 Landuse map of the study area (*source:* KSLUB 2006)

Table 1 Details of rivers, clay-based industrial units and quantity of clay mining from the Chalakudy, Periyar and Muvattupuzha river basins of Central Kerala

River basin	River length (km)	Basin area (km^2)	Clay mining		Industries	
			Local bodies engaged	Quantity (ty^{-1})	Brick units	Tile units
Chalakudy	130	1,704	9	135,975	65	37
Periyar	244	5,398	11	483,820	229	45
Muvattupuzha	121	1,554	9	109,900	64	_
Total			29	729,695	358	82

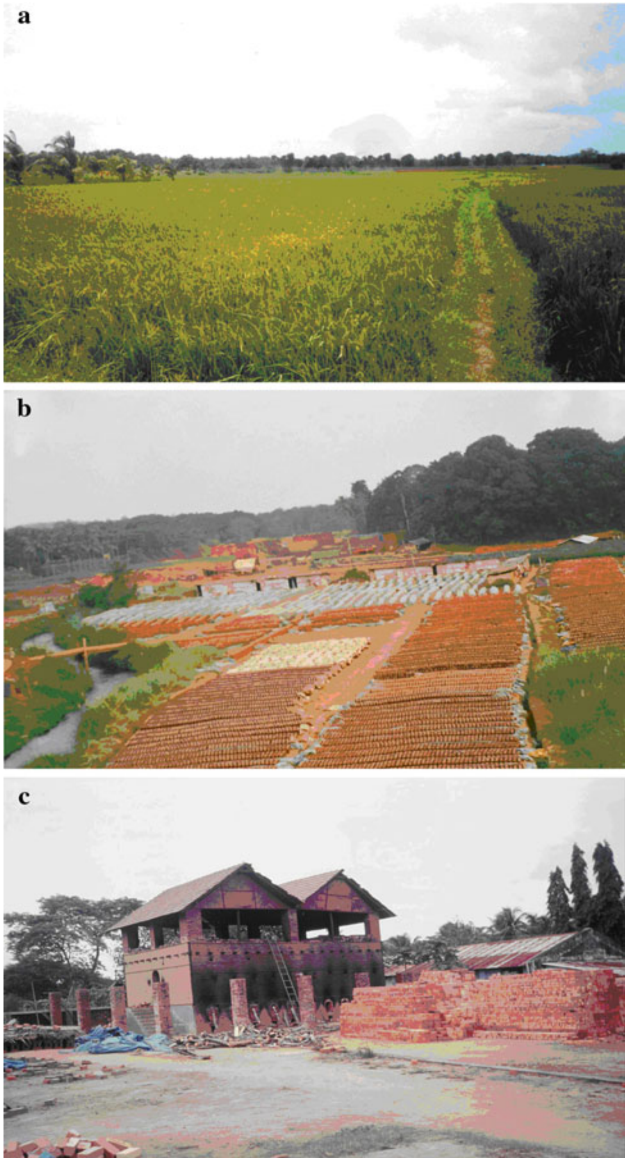


Fig. 4 Selected scenes from the study area. **a** An unaffected paddy land in the Chalakudy river basin; **b** a paddy land in Muvattupuzha river basin used for brick making; **c** a brick kiln in Periyar river basin

coast of India was affected by heavy rainfall and subsequent input of allochthonous organic and inorganic sediments. The rising spells of sea level at that period not only hindered the water flow, but favored the deposition of organically rich finer sediments in the wetlands adjoining the river confluence zones (Padmalal et al. 2010a, b, 2011). The reported C^{14} date of the organic carbon-rich sediments in the Periyar river basin at a depth of 4.7 m below ground level (bgl) yielded an age of 7,050 ± 140 years before the present (ybp) reiterates this view (Santhosh 2006).

The N content in brick and tile clay samples collected from the mining locations of Chalakudy river basin varies from 0.06 to 0.16 % (av. 0.112 %). The content of N in the Periyar and Muvattupuzha river basins varies from 0.01 to 0.02 % (av. 0.014 %) and 0.01 to 0.13 % (av. 0.04 %), respectively. Unlike C-org, the concentration of N in the Periyar river basin is comparatively lower than that of the Chalakudy and Muvattupuzha river basins. One of the reasons for the observed variation is, perhaps, the increased use of nitrogen fertilizers in the Chalakudy and Muvattupuzha river basins than the Periyar river basin where agricultural activity is low because of the proximity to the urban center, Kochi City. In Chalakudy river basin, the P in the brick and tile clays varies from 0.02 to 0.12 % with an average of 0.054 % and that in the Periyar and Muvattupuzha river basins are 0.001–0.01 % (av. 0.005 %) and 0.001–0.06 % (av. 0.022 %), respectively. Like the case of N, the content of P is comparatively low in the Periyar river basin than that in the Chalakudy and Muvattupuzha river basins. This again reiterates the increased fertilizer application in the latter basins. The K values in the brick and tile clay samples of the mining locations vary from 1 to 2.38 % (av. 1.64 %) in the Chalakudy river basin, 1.66 to 2.85 % (av. 2.15 %) in the Periyar river basin and 0.85 to 1.9 % (av. 1.39 %) in Muvattupuzha basin. No marked variation is observed in the content of K in the brick and tile clay samples of these river basins.

Quantity of clay mining

Indiscriminate mining of brick and tile clays is widespread in the lowlands and adjoining parts of the midlands of Central Kerala (Fig. 5) that host one of the fast growing developmental centers in South India, the Kochi City. Estimates show that a total of 0.73 million ty^{-1} of raw clay has been extracted from the wetlands of the study area. Out of the total quantity, a greater portion (66 %) of the clay is extracted from the Periyar river basin and the remaining from the Chalakudy (19 %) and Muvattupuzha (15 %) river basins (Table 2). The clay extracted from the area is used in a variety of ways such as in manufacture of roofing, flooring and decorative tiles, wire cut (mechanically made) and ordinary bricks (manually made), and pottery wares. In the Periyar river basin, mining has spread in 11 local bodies, whereas in the Chalakudy and the Muvattupuzha river basins brick and tile clay extraction is noticed in 9 local bodies each. Altogether, 440 clay-based industrial units utilize the brick and tile clay extracted from the paddy lands of the study area. Out of this, a total of 274 clay-based industrial units are located in the Periyar river basin. The clay-based industrial units in the Chalakudy and Muvattupuzha river basins are comparatively low in number and are 102 and 64, respectively.

In the Chalakudy river basin, about 40 % (54,840 t) of the extracted clay is used for tile manufacturing; after tiles, a great quantity is used for wire cut brick manufacturing

Table 2 Geochemical parameters in the brick and tile earth samples (also see Fig.1) of Chalakudy, Periyar and Muvattupuzha river basins

Location no.	Sand (%)	Silt (%)	Clay (%)	C-org (%)	TN (%)	TP (%)	K (%)
Chalakudy river basin							
1	46.88	24.25	28.71	1.14	0.1	0.07	2.13
2	33.97	33.98	32.15	0.43	0.06	0.12	1.63
3	70.93	12.13	17.06	1.25	0.13	0.02	2.38
4	19.67	24.94	55.38	1.51	0.13	0.04	1.63
5	10.82	27.03	62.21	2.53	0.15	0.05	1.5
6	56.79	23.37	20.48	0.19	0.07	0.04	2.01
7	19.67	23.13	56.87	1.74	0.16	0.04	1.13
8	34.49	41.64	23.44	0.98	0.08	0.08	1.88
9	56.26	12.11	31.60	4.08	0.09	0.02	1.01
10	41.49	17.34	41.16	1.78	0.15	0.06	1.13
Periyar river basin							
11	2.09	64.41	33.5	1.2	0.01	0.00	2.4
12	23.54	39.44	37.01	2.52	0.02	0.01	2.02
13	15.01	45.4	39.5	1.45	0.01	0.00	2.24
14	26.44	36.55	37.01	1.57	0.01	0.00	2.14
15	5.42	54.55	40.02	2.76	0.02	0.01	1.88
16	5.11	51.88	43.01	1.56	0.01	0.00	2.38
17	6.19	72.31	21.5	2.12	0.02	0.01	2.01
18	24.5	38.8	36.7	1.82	0.02	0.01	2.85
19	24.53	38.45	37.02	1.51	0.01	0.00	1.66
20	18.63	42.5	38.87	1.62	0.01	0.01	1.95
Muvattupuzha river basin							
21	60.93	22.12	17.06	1.35	0.02	0.001	1.41
22	19.6	25.17	55.23	1.72	0.04	0.01	1.2
23	23.54	37.44	39.01	1.61	0.05	0.01	1.30
24	56.26	12.11	31.6	0.98	0.04	0.03	0.95
25	46.88	24.25	28.71	0.62	0.01	0.01	0.72
26	10.82	27.03	62.21	2.3	0.13	0.06	1.51
27	16.19	62.31	21.5	2.12	0.04	0.05	1.45
28	41.49	17.34	41.16	0.59	0.01	0.01	0.62
29	24.53	38.45	37.02	1.31	0.03	0.02	0.93
30	26.5	36.41	37.08	1.25	0.03	0.02	0.95

(53,640 t), which is followed successively by tile-cum-wire cut brick manufacturing (15,260 t) and ordinary (manually made) bricks (12,060 t). At present, only a meager quantity of clay is used by the traditional laborers of the area for making pottery wares. In the Periyar river basin, about 227,315 t of clay has been used by the tile industrial units. The use of raw clays by the wire cut brick units, tile-cum-wire cut brick units and ordinary brick units is 193,500, 32,400 and 30,000 t, respectively. In the Muvattupuzha river basin, no tile manufacturing units are located, instead the entire clay resource of the basin is used by the wire cut (45,000) and ordinary (50,000) brick making units. The increased use of raw clays for brick manufacturing is directly related to the pace of building activity in the Kochi City and its satellite townships.

Land use changes and anthropogenic erosion of nutrients

The impact of brick and tile clay mining from the paddy lands and other forms of wetlands are often underestimated. But it is a fact that uncontrolled mining of brick and tile clays would definitely aggravate environmental degradation in addition to creating problems in the food security of the area. Due to continued and unabated mining, pits of different dimensions are formed in the affected area. On many occasions, extensive areas will be converted into waterlogged areas hindering the traditional agricultural practice in the area. Added to these are the problems in the removal of fertile soil along with its naturally evolved nutrients. It is estimated that 729,695 ty^{-1} of brick and tile

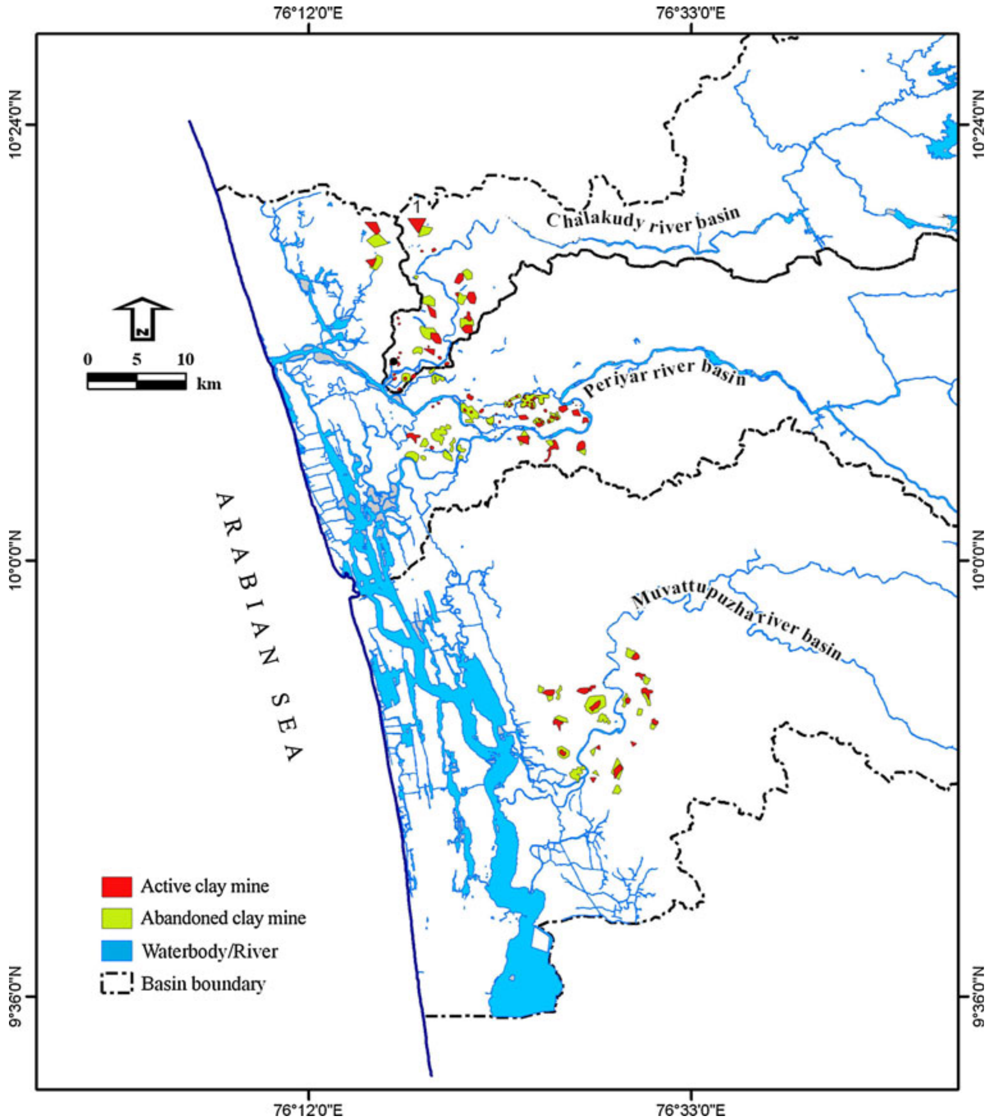


Fig. 5 Major clay mining areas of the study area

clay is extracted from the paddy lands and other wetlands in the lowlands and midlands of the study area. Out of this, 135,975 ty^{-1} ($\sim$18 %) is extracted from the Chalakudy river basin, 483,820 ty^{-1} ($\sim$66 %) from the Periyar river basin and 109,900 ty^{-1} ($\sim$15 %) from the Muvattupuzha river basin. From this, it is evident that a major proportion of brick and tile clay is scooped out from Periyar river basin which is located close to the major developmental center, the Kochi City. Further, the Periyar river basin has extensive wetland areas with high quantity brick and tile clays compared to the other two river basins. Indiscriminate mining of topsoil for the manufacture of bricks and tiles from the paddy lands/wetlands results in many socio-environmental problems. One of the major problems is the man-made erosion of fertile topsoil and subsequent shrinkage of agricultural lands. Major nutrients such as nitrogen, phosphorus and potassium are lost forever from the wetlands/agricultural lands due to brick and tile making. Geochemical analysis reveals that the tile and brick clay contain 0.55 mg/g of N, 0.27 mg/g of P, 17.3 mg/g of K and 15.9 mg/g of C-org, on an average level. In other words, through clay mining and manufacturing of clay articles, 210 ty^{-1} of N, 96 ty^{-1} of P, 9,352 ty^{-1} of K and 9,879 ty^{-1} of C-org have been eroded from the paddy land/wetlands. The respective figures of nutrients estimated for the individual basins are shown in Table 3. As the bricks and tiles are used for building constructions, this human-imposed erosion of nutrients will not be regenerated back to use for human life time.

Discussion

In the past few decades, the demand for natural resources is increasing exponentially in many parts of the world. The prominent factors that are responsible for environmental

Table 3 Details of the quantity of clay and the erosion of nutrients from the wetlands of the study area

Sl.No	River basin	Quantity of clay (ty^{-1})	Nutrient loss (ty^{-1})			
			C-org	N	P	K
1	Chalakudy	135,975	1,696	121	58	1,783
2	Periyar	483,820	7,005	54	19	6,347
3	Muvattupuzha	109,900	1,178	35	19	1,222
Total		729,695	9,879	210	96	9,352

changes caused by brick and tile clay mining are rise in population and standard of living of the people of the area (Galero et al. 1998; Padmalal et al. 2008; Sanfeliu and Jordán 2009). Standard of living is usually measured in terms of economic growth. In Kerala, these driving forces have become a major causative factor for excessive extraction of brick and tile clays since the second half of the 1970s. Figure 6 shows the decadal addition of houses and population growth in the state during the last century. The rise in foreign remittance was one of the most influential factors responsible for the increase in the number of dwelling places (Padmalal et al. 2010a, b), which was responsible for the rise in the demand of construction materials in the region. Some of the other factors favorable for enhanced clay extraction from paddy lands are rise in the export of clay articles to neighboring states, uneconomic paddy cultivation, exponential rise in foreign remitence, investments of a major portion of the savings in construction and renovation of buildings, etc. The problems will be aggravated further as the region is readying to host many mega development projects in the coming years (Padmalal et al. 2008).

The exponential rise in the number of households in the region consequent to increase in population with small household number in the developing economic regime of the region has, no doubt, promoted the per capita utilization of natural resources, especially with regard to building materials. More recently, scholars all over the world have acknowledged that the number of households has a key role in determining the resource consumption pattern of a region (Jiang 1999; Keilman 2003; Liu et al. 2003). Even if the size of a population remains constant, more households imply larger demand for resources (Keilman 2003). As per the studies of Nair (1994a, b, 1998), a substantial part of the money received in the form of foreign remittances in Kerala in the southwestern coast of India has been invested for building constructions and/or renovation over the years. The growing use of bricks for walling, which offers advantages over other types of building blocks, has also become a factor for aggravating clay mining from the wetland systems of Kerala.

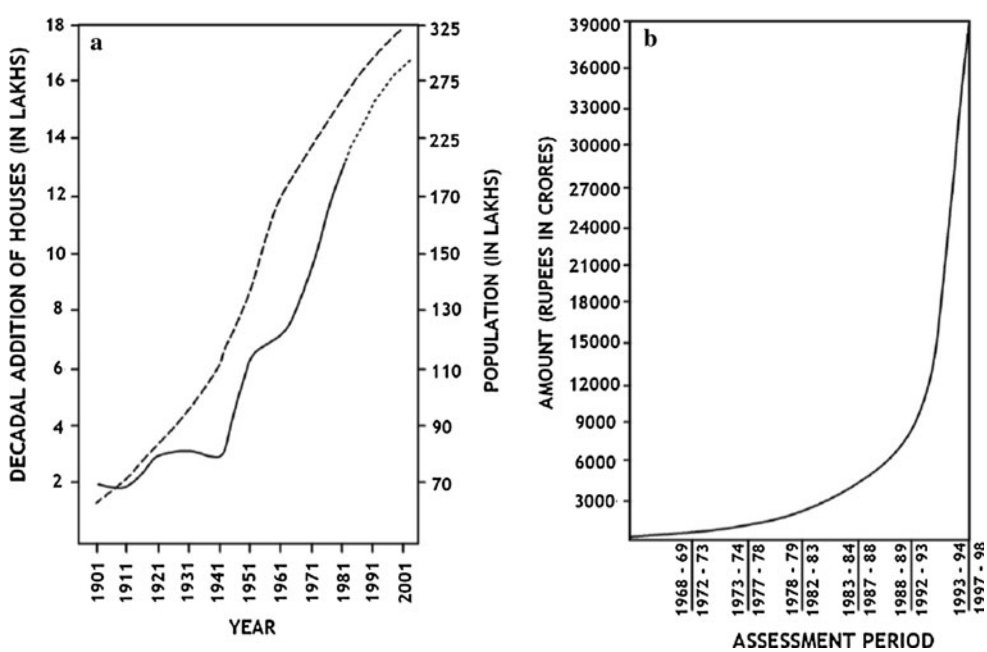


Fig. 6 **a** The population growth curve and decadal addition of occupied houses during the period 1901–2001 (modified after Harilal and Andrews 2000); **b** foreign remittance of Kerala during the period 1968/1969 to 1997/1998 (update after Nair 1994a, b)

Conclusions and recommendations

Indiscriminate mining of brick and tile clays from the Chalakudy, Periyar and Muvattupuzha river basins in the southwest coast of India for meeting the raw material demands for the numerous brick kilns and tile factories adjoining the development center Kochi City causes severe socioeconomic and environmental problems. Excessive removal of clays either creates vast areas of fallow lands unsuitable for any agricultural activities due to the loss of soil cover or extensive waterlogging. Mining of clays several meters below the prescribed levels, pumping out of water from the pits for further mining, etc., can cause lowering of water table and water shortage problems near mining areas. The revenue from clay mining is meager, but at the same time the additional expenditure incurred to meet the freshwater requirements of the people living in areas adjacent to mining sites is increasing year after year. In short, indiscriminate clay mining, unscientific planning and developments, insufficient guidelines, inadequate enforcing mechanisms and lack of awareness of environmental and economic issues involved in the activity are the major challenges in regulating clay mining and setting developmental targets for clay-based industrial units. The following are some of the recommendations drawn from the study:

1. Limit the extraction of brick and tile clays within the natural resilience of the wetland ecosystem.
2. Use raw clays for the manufacture of value-added products like pottery wares including flower pots and other articles for indoor and outdoor decoration.
3. Evolve new building blocks that consume only low quantities of floodplain clays.
4. Regulate random mining and allow only location-specific extraction of the clay resource under well laid up guidelines.
5. Prohibit mining below the level of the local water table (with reference to the water table condition of summer season).
6. Convert the mined and abandoned areas into fish farm ponds or irrigation ponds. The possibility of freshwater pisciculture may be explored through R&D activities.
7. Create awareness among the public to use laterite blocks or other alternatives to clay bricks for construction purposes. Consider recycling of building materials to the maximum possible extent.

Acknowledgments We are indebted to Dr. N. P. Kurian, Director, Centre for Earth Science Studies (CESS, Thiruvananthapuram) for encouragements and also for extending necessary facilities for carrying out this study. We are grateful to Dr. K. N. Nair, Director, CDS and program co-ordinator, KRPLLD for constant support and encouragements. Financial assistance from KRPLLD (to DP and KM) and University of Kerala (to SV and BB) are also acknowledged. SV and BB thank Prof. (Dr.) V. Sobha, Department of Environmental Sciences, University of Kerala for encouragements and supports. We are thankful to the anonymous reviewers for their critical suggestions, which improved the scope of the paper.

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