



# Environmental impact of quarrying of building stones and laterite blocks: a comparative study of two river basins in Southern Western Ghats, India

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## Abstract

Mining and quarrying for minor minerals impart significant economic, environmental and social impacts in and around the affected areas. The problem is severe in the small river catchments as the effective area available for assimilating negative impacts of the activity is minimal, compared to large river basins. To address these issues, an investigation has been carried out in two river basins of southern Western Ghats (India)—the Netravati–Gurpur and Periyar–Chalakydy river basins. Both these basins host two important port cities of south India—Kochi and Mangalore. The study reveals that about  $6.75 \times 10^6 \text{ ty}^{-1}$  of hard rocks are being extracted in the Netravati–Gurpur basin through 64 quarries. At the same time, the total number of quarries and extracted amounts in the Periyar–Chalakydy river basin are 525 and  $10.47 \times 10^6 \text{ ty}^{-1}$ , respectively. Many hillocks in the region are turned to a cluster of ugly scars, degrading the ecology and aesthetics of the area. Lowering of water table, modification or disappearance of natural drainages and environmental pollution are some of the other observations noticed in the area. The environmental impacts of laterite quarrying are comparatively less than that of rock quarrying as removal of the hard laterite cap rock enhances water percolation and makes the area more irrigable for agriculture. The study stresses the need for environment-friendly quarrying alternatives with stringent guidelines to improve the overall environmental quality of the area on one hand and to meet the developmental requirements on the other.

**Keywords** Mining and quarrying · Laterite and hard rock quarrying · Sustainable development

## Introduction

India has a long history of minor mineral extraction for different purposes including building constructions and other types of developmental initiatives. The magnitude and intensity of the mineral extraction shows an exponential increase in the past few decades on account of rapid economic developments and consequent expansion of urban areas (Padmalal and Maya 2014). Population explosion, economic liberalization and innovations in building technologies have made marked changes in the minor mineral extraction scenario of the country. For most developing countries, mining is

an indispensable activity, and it is projected that by 2050, the demand for base materials will be several times higher than the current demand (Halada et al. 2008). During the course of history, man has exploited the natural resources to sustain the needs and demands of the growing population. The exploitation of natural resources has been the core that supported the social and economic development processes of many countries. Though urban centres of the world cover only 2% of the total land surface, the activities within these centres consume over 75% of the global natural resource share. Enduring urbanization will increase the material demand for building construction, roads, landscapes, etc., (UNEP 2013) and an unconditional supply of natural resources is essential to meet this demand (Kobayashi et al. 2014). At the same time, unscientific extraction of resources in its wake could significantly degrade the environment far below its natural resilience capability.

Human wealth depends on the assured supply of natural resources to satisfy basic necessities. Irrespective of the scale of development, the natural resource base continues

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to support the technological and infrastructural growth of nations. If properly integrated into regional development plans and appropriate conservation strategies are adopted, the natural resource-related investments can help alleviate poverty and foster improvements in health and education sectors and ultimately the standard of living of people (Munasinghe 1992; MMSD 2002). Management plans for such activities must be done based on the carrying capacity of the ecosystems that sustains life and greenery of the area.

Land utilization and modifications associated with economic growth have largely impaired the health and uniqueness of natural ecosystems (Malmqvist and Rundle 2002; Padmalal et al. 2008; Maya et al. 2015). The region in and around Western Ghats, the most ecologically sensitive area with high population density near its boundaries, hosts a variety of diverse socio-environmental elements. The situation of mining/quarrying within the ecosystem is often alarming, and, in many of the occasions, the existing rules and regulations seem inadequate to contain the ill effects of the said activities. The human activities portray a significant signature on the region by modifying its morphology, processes and ecosystems, an observation also made elsewhere (Ellis 2011; Tarolli and Sofia 2016). Apart from many environmental adversities, quarrying operations could also affect the very existence of ecosystems and also the hydrogeological conditions of the area to a greater extent (Khawlie et al. 1999; Shaban et al. 2007; Darwish et al. 2011).

In recent years, many studies have been conducted in the mining/quarrying sectors to understand the environmental consequences of the activity. However, studies on the extraction of minor minerals, especially, hard rock and laterite quarrying and their impact on different environmental components are uncommon. An important study in this angle made by Vedeil et al. (2007) dealt with the effect of rapid urbanization in Lebanon city during the period 1990–2000. The period witnessed an increased requirement of construction materials to meet the exponential rise in construction works, a process that led to creation of hundreds of quarry scars across the territory. However, the environmental impact of mining and quarrying is extensively analysed and discussed with related works. Granite quarry mapping in Kerala (India) by Sajeev and Alex (2017) presented the information on granite quarries in the region, and Sajinkumar et al. (2014) have made a study to understand the effect of quarrying on the slope stability of Western Ghats. Darwish et al. (2011) investigated the problems of quarrying especially in regard to dust emission, noise pollution, traffic issues, etc. Although the adversities of mining and quarrying are rampant, no systematic studies have been taken up to address the impact of the activity on various environmental components of life sustaining systems of the area. This is especially true in the case of Western Ghats—the treasure trove of biological diversity in the West coast of

India. Hence, a study has been undertaken herein to take stock of the impacts of mining of minor minerals (especially building materials), on different environmental parameters such as geomorphology, soil and landuse of two river basins that host two fast developing Urban Local Bodies (ULBs) in Southern Western Ghats—the Kochi city (Kerala state) and Mangalore (Karnataka state), as an example.

## Area of study

The Netravati–Gurpur and Periyar–Chalakydy river basins lie in the ecologically sensitive regions of southern Western Ghats of India. The basins cover diverse environmental settings. Both these west flowing river basins are drained by rivers that flow through the two important port cities of India viz, Kochi and Mangalore. Figure 1 depicts the two river basins considered for the present study and the location of hard rock and laterite quarries in the basins.

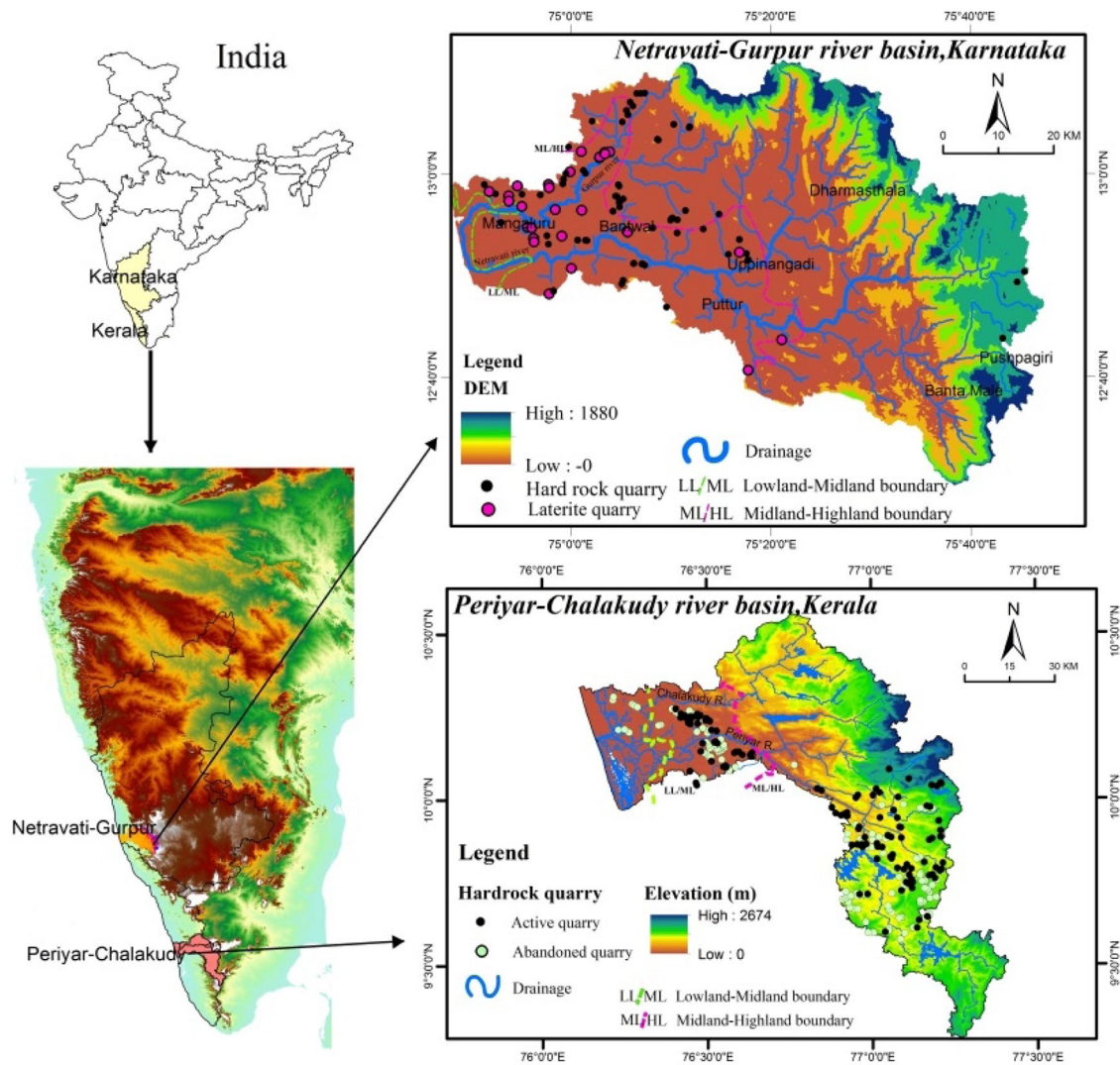
## Environmental settings

The basin areas of the Netravati–Gurpur and Periyar–Chalakydy river basins are 4325 and 7102 km<sup>2</sup> (CWRDM 1995), respectively. The former is drained by a seventh-order river, while the latter is drained by an eighth-order one. Both the river basins drain three distinct physiographic provinces—the highlands (> 75 m), the midlands (8–75 m) and lowlands (< 8 m); (Chattopadhyay and Mahamaya 1995). The highlands of Periyar river basin cover an area of about 4419 km<sup>2</sup> and constitute over 86% of the total basin area. In the case of Netravati–Gurpur river basin, 3175 km<sup>2</sup> area falls within the highlands, which cover about 74% of the total area.

## Geology and soils

Netravati–Gurpur river basins comprise a wide spectrum of rock types from pre-Cambrian crystallines to Pliocene—sub recent laterite capped plateaus and alluvium. The laterites and alluvium are covered over the gneisses and continental type of sedimentary deposits with dolerite and norite dikes (Geological Survey of India 1981; Radhakrishna and Vaidyanadhan 1994; Avinash et al. 2010). The river basins consist of migmatites and granodioritic to tonalitic gneisses of the Peninsular Gneissic Complex with enclaves of high-grade supracrustals (Geological Survey of India 1981; Nair 1990). Highly porous sandy soils, coastal alluvium and red loam soils are found in the basin.

The Periyar–Chalakydy river basins record all the three major geological formations such as Archaean crystalline, Tertiary (Neogene) sediments and Quaternary deposits. Laterite developed over the crystalline basement and sedimentary rocks forms the major cap rock in the area. A major part



**Fig. 1** Location of the study area showing mining and quarrying sites in Netravati–Gurpur and Periyar–Chalakydy river basins

of the basin is composed of Archaean crystallines, charnockite, charnockite gneiss and hornblende biotite gneiss. There are four major soil types in the basin—forest loam, lateritic soil, brown hydromorphic and alluvial soils, in which 60% of the area is covered by forest loam and laterite soils (GSI 1995).

**Terrain characteristics and landuse**

The river basins display diversified terrain characteristics and landuse in the backdrop of the major landform units, viz, the Western Ghats, Munnar-Periyar plateau and the coastal plain (Shiekha 2017). In Periyar–Chalakydy river basin, forest occupies nearly 1500 km<sup>2</sup> (28%) of the basin area, whereas cardamom and settlement with mixed tree crops occupy about 322 km<sup>2</sup> and 2176 km<sup>2</sup> area, respectively. In

the case of Netravati–Gurpur basin, evergreen and deciduous forests occupy about 40% (1759 km<sup>2</sup>) and agriculture plantations cover almost 50% of the total basin area. Both basins, especially in the highlands, fall within the ecologically sensitive zones of the Western Ghats, and nearly 80% of the total area situated in the highlands is susceptible to erosion and mass movement. The Periyar–Chalakydy river basin is characterized by various geomorphological units like denudational structural hills associated with piedmont zone. The upper region is covered by structural hills and isolated hillocks. The highland region comprises forest, agriculture, wasteland and water bodies. Tea and cardamom are the important plantation crops found in the area. The midlands are occupied by agriculture/horticulture plantations. Apart from that, evergreen/semi-evergreen forests are also seen in the midlands.

Geomorphologically, the Netravati–Gurpur drainage basin comprises of three different types of landforms on the basis of origin—coastal origin, denudational origin and structural origin. Three categories are identified in the landforms of coastal origin, younger coastal alluvium, older coastal alluvium and flood plains. Lowlands of the basin support a wide variety of agriculture including paddy and plantations crops. Geomorphic units of denudational origin are comprised of low dissected hills and valleys, moderately dissected hills and valleys and pediment–pediplain complexes that mostly support cash crop plantations like coconut, rubber, arecanut, etc. Landforms of structural origin are comprised of low dissected hills and valleys and moderately dissected hills and valleys. The highland regions are covered with dense forests and plantation crops. Laterite and hard rock quarries are concentrated in the regions of denudational origin like moderately dissected hills and valleys and pediment–pediplain complexes. In the structural origin type landforms dominated areas (like low dissected hills and valleys and moderately dissected valleys), only very few quarries are located and most importantly these are essentially areas under high ecological sensitivity.

## Materials and methods

Extensive field surveys were conducted in the river basins for the collection of relevant data on rock quarrying which include mapping locations of rock quarries, the quantification of resource extraction from each location, number of active and abandoned quarries, labour force involved, aerial extend of quarrying, etc. Select weighing of the loaded vehicles moving out of the mines and quarries, questionnaire surveys with mine operators, labourers, lorry drivers and local people are also performed to collect the required data. Information on employment particulars of the labourers, working and living conditions of the quarry workers as well as the local community, health and safety measures employees, impact on daily life of the local people, etc., were collected through well-structured questionnaire survey methods. In addition, a systematic survey was conducted in the entire study area to map the quarrying sites. Landsat (30 m resolution) images were used to prepare the base map. Field work was then conducted for their confirmation and also to collect other relevant data on the environmental impacts. In ArcGIS software, the band combinations like band 4 for red, band 3 for green and band 2 for blue were used for demarcations. Quarries are easily identifiable as white patches on the satellite images. Geometric correction and ground truth verifications were carried out using the Global Positioning System (GPS), and ancillary data from topographic maps and Google Earth images. Secondary data on population and urbanization trends, important to the study, were collected

from the Census data of the concerned years (1991, 2001 and 2011). This study identifies and addresses the key environmental issues in the study area along with other attributes such as type of mining, location, and extent, environmental interference and socioeconomic conditions. The entire data have been processed in a GIS platform to evaluate the overall environmental quality of the area.

## Results and discussion

### Mining/quarrying

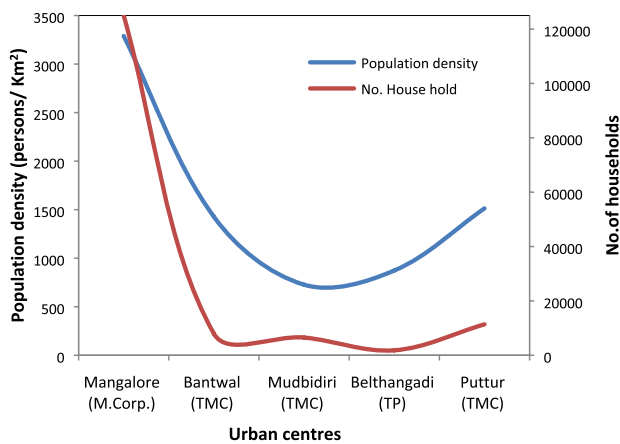
Mining/quarrying for hard rocks and laterite blocks are widely reported in the highlands and midlands of the basins of the Periyar–Chalaky and Netravati–Gurpur rivers in the southern Western Ghats (Fig. 1).

### Hard rock quarrying

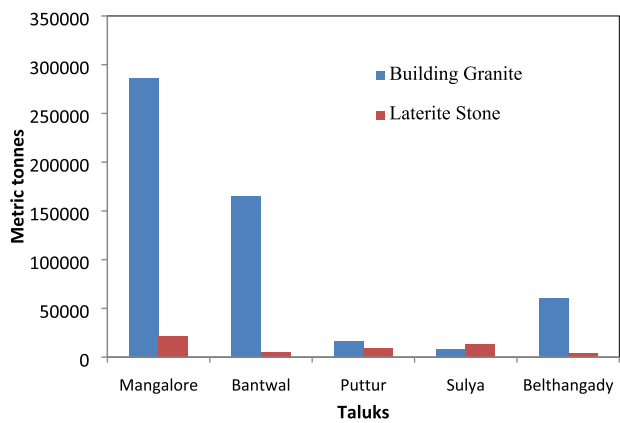
Hard crystalline rocks are quarried as solid block/slabs, or in crushed forms for building constructions. It is one of the strongest building materials known to humans and is readily available in many areas of the world. The hard rock quarries operate generally on the ground, especially along the side of a valley or the side of a hill (Gunn 1993; Gunn and Bailey 1993). The selection of the type of quarry depends on the site topography, ownership boundaries, geological structure and environmental considerations. There are different varieties of rocks spread across the study area with different attributes that make them suitable for specific uses.

Among different taluks in the Netravati–Gurpur river basin, hard rock quarrying is rampant in Mangalore taluk (quantity). A total of 64 hard rock quarries are located within the basin (Fig. 1). The labour force engaged in the hard rock quarrying sector comes to about 1158. Mangalore, the port city of Karnataka state, shows an exponential rise in the rate of urbanization with a marked boom in both population and building constructions (Fig. 2). Quarries in the Mangalore taluk directly cater to the ever expanding developmental needs of the port city.

The production of building aggregates in the different taluks of Dakshina Kannada district shows that Mangalore taluk produces large quantities of building aggregates compared to the rest of the regions (Fig. 3). Urban sprawl with exponential rise in population and households in Mangalore has a direct bearing on natural resource consumption and infrastructure development of the area (Bhagyanagar et al. 2012). It is estimated that about 6.70 million metric tons/year of hard rock is being quarried from the Netravati–Gurpur river basins. The number of abandoned quarries comes to about 19 in the entire basin. Among the three



**Fig. 2** Population density and number of household in different urban centres of Netravati–Gurpur river basin. ( Source: Census, 2011)



**Fig. 3** Production of building aggregates in different taluks Netravati–Gurpur river basin. ( Source: Department of mines and Geology)

physiographic provinces of the basin, hard rock quarrying is rampant in the midland and highland regions (Table 1).

In the case of Periyar–Chalakydy basin, the total number of quarries comes to about 525. Out of these, 137 are active quarries, while 388 are abandoned ones. Physiography-wise analysis reveals that out of the total hard rock quarries, 27 are located in lowlands, 288 in midlands and 210 in highlands. The total labour force engaged in the activity comes to about 1640 persons. The estimated extraction of hard rock from the basins is 10.47 million metric tons/year (Table 1). The number of quarries in the basin has a direct bearing on the level of urbanization and growth of the region in which the activity is being carried out (Maya et al. 2015). The number of hard rock quarries shows wide variations among the two river basins (Fig. 4). However, a higher number of active quarries in the Netravati–Gurpur river basin indicate the intensity of quarrying activity in the basin. Compared to the number of abandoned quarries, active quarries are less in the Periyar–Chalakydy river basin. It is a fact that in both the basins, mining activities are noticed even in ecologically sensitive zones (Figs. 5, 6); however, such sites are comparatively less in the Netravati–Gurpur river basin.

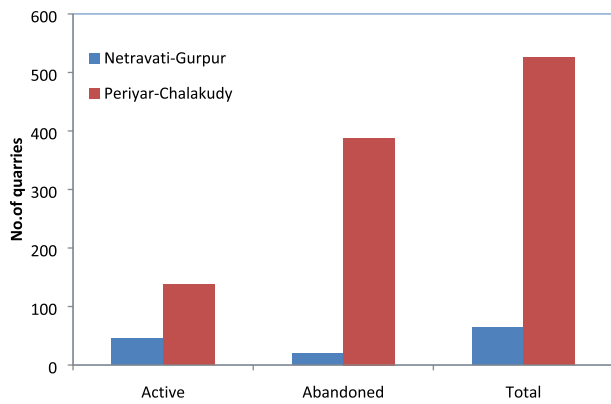
**Laterite quarrying**

A total of 21 laterite quarries are identified in the Netravati–Gurpur river basin. Most of the laterite quarries are mechanized, and on average 25 labourer are employed in each quarry. The intensity of quarrying is higher in Mangalore and Bantwal taluks. Total annual production of laterite blocks from the basin comes to about 42 lakhs (Table 2). Hard laterite blocks are largely used in the building industry. Apart from this, laterite blocks of good quality are also used for lining ponds and tanks in the area. Large scale extraction of laterite has resulted in marked changes in the natural topography and groundwater conditions of the area. Both mechanical and manual cutting of laterite are taking place in the Netravati–Gurpur river basin. In Periyar–Chalakydy

**Table 1** Physiography-wise details of hard rock quarrying in Periyar–Chalakydy and Netravati–Gurpur river basins, Southern Western Ghats

River basins	Physiographic province	Extraction ( $\times 10^6 \text{ ty}^{-1}$ )	No. of quarries		Labour force	Extend of mining ( $\text{km}^2$ )
			Act.Q	Abn.Q		
Periyar–Chalakydy	Lowland	Nil	Nil	27	Nil	0.048
	Midland	8.402	94	194	1179	1.344
	Highland	2.072	43	167	461	0.362
	Total	10.472	137	388	1640	1.754
Netravati–Gurpur	Lowland	–	–	–	–	–
	Midland	1.71	20	16	652	0.54
	Highland	5.04	25	3	506	0.59
	Total	6.75	45	19	1158	1.14

$\text{ty}^{-1}$  tonnes per year, Act.Q. active quarry, Abn.Q. abandoned quarry



**Fig. 4** Hard rock quarrying in Netravati–Gurpur and Periyar–Chalakydy river basins—a comparative evaluation based on the data collected during the field surveys, 2018

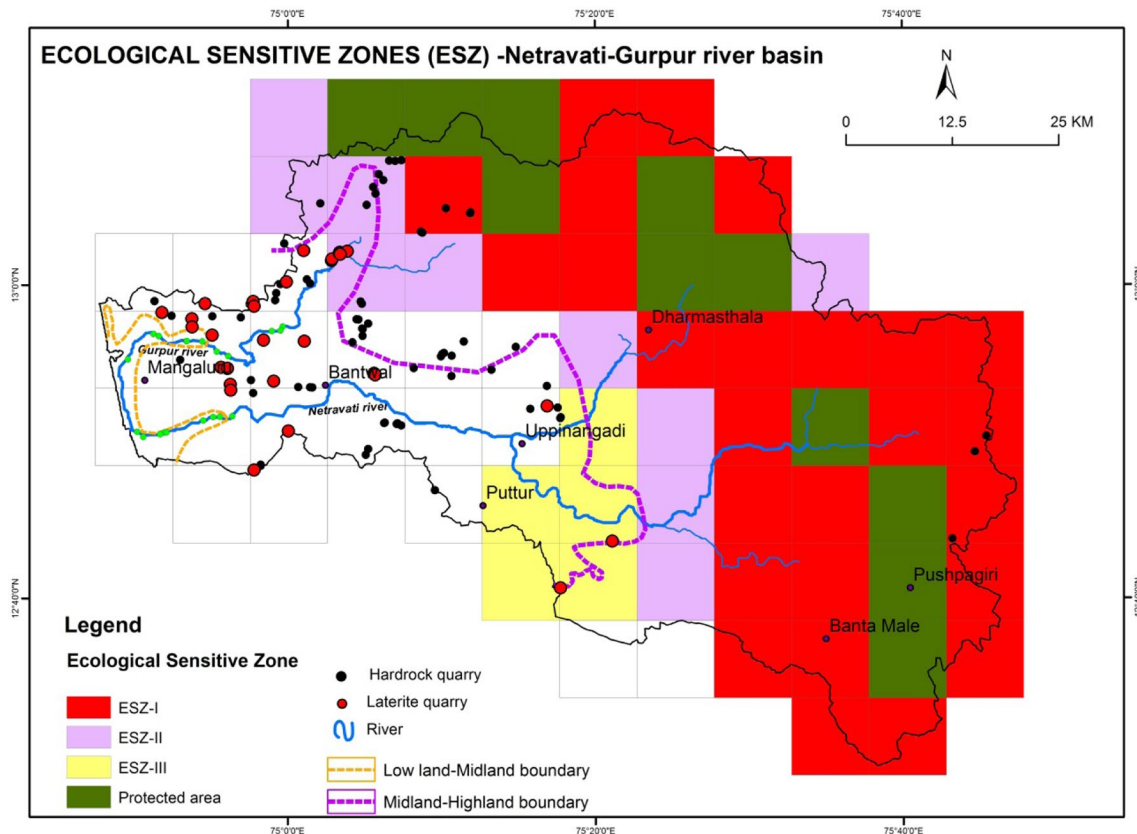
basin, laterite extraction is not reported at present, out a total of six abandoned quarries are cited in the area. This can be because of the wide use of manufactured concrete blocks and burned clay-based bricks for building constructions in the region.

### Impact of mining/quarrying

Mining and quarrying activities can cause many environmental problems in the affected region, especially in their geomorphology, air quality, noise level, landuse/landcover and surface and subsurface water resources (Table 3). Observed impacts of mining in the two basins considered for the present study can be categorized as (1) Impacts on land (2) Impacts on air (3) Impacts on water.

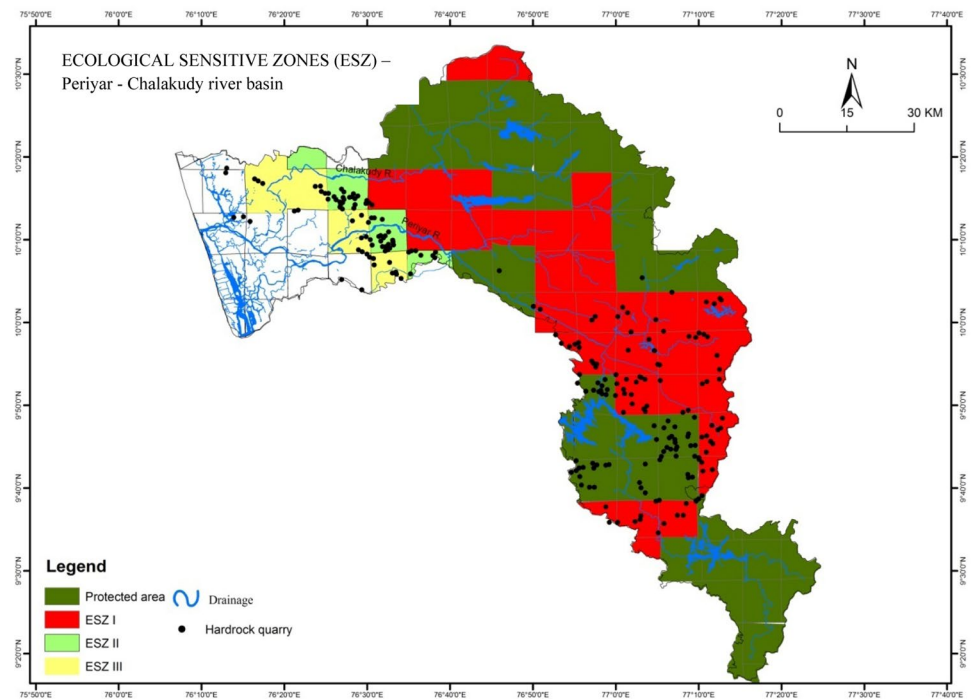
### Impacts on land environment

Large-scale mining and quarrying influence landscape evolution (Haigh 1978; Martín-Duque et al. 2010), sediment transfer (Macklin and Lewin 1989) and thus geomorphology of the whole system (Mossa and James 2013). Hard rock quarrying and laterite cutting in the study area have made critical impacts on geomorphology and landscape in the studied river basins. Most of the hills and hillocks in the region have been levelled down partially or wholly or even turned into a cluster of ugly scars, degrading the ecology and aesthetics of the region to a considerable extent (Fig. 7a).



**Fig. 5** Location of hard rock quarries vis-à-vis the ecologically sensitive zones in Netravati–Gurpur river basin. Note: Gadgil Report (2011) was followed for overlaying ecologically sensitive zones

**Fig. 6** Location of hard rock quarrying vis-à-vis the ecologically sensitive zones in Periyar–Chalakyud river basin. Note: Gadgil Report (2011) was followed for overlaying ecologically sensitive zones



In Netravati–Gurpur river basin, most of the quarries are located on sloping lands with slope gradient below  $18^\circ$ . Based on the existing slope, quarries can be categorised as three (1) low erosion risk for quarries located on level land with slope land less than  $10^\circ$ ; (2) moderate erosion risk for quarries on sloping lands with slope gradient  $10\text{--}18^\circ$  and (3) high erosion risk for quarries located on slopes greater than  $18^\circ$  (Fig. 8). Quarries in this topography frequently cause increased susceptibility to landslides, soil loss and mass movements. Quarries located on steep slopes, particularly those with fragile lithology and restricted drainage are the most exposed to erosion processes and mass movements (Abdallah et al. 2005). Blasting-induced instabilities in the soil apron are noticed in hard rock quarries of Kurnad and Balthila villages (Fig. 7b).

The situation is not different in the river catchments of central Kerala, especially, the Periyar–Chalakyud river basin. In Periyar–Chalakyud basin, rock quarrying is rampant in midlands of Ernakulum district catering the burgeoning development needs of Kochi city. In the basin, most of the quarries operate along the hillside which leads to the formation of pit lakes in the region. In the basin, most of the quarries lie in  $12\text{--}20^\circ$  slopes (Fig. 9). The hillocks in this basin are at the verge of degradation due to intensive quarrying. The situation is critical as many of the quarries that are located near the Ecological Sensitive Zones of the Western Ghats. From the field observations and mapping, it is identified that landuse–land cover changes are prominent in the basin due to widespread quarrying activities (Figs. 10, 11). Construction of roads for transportation of the mined

material, clearing of land for quarrying and operation of crusher units have persuasively created alterations in natural landuse. Blasting in the quarries generates vibrations in the vicinity of the quarry. It is observed that high-intensity vibrations have caused severe damages in the region and hence the increased occurrences of disasters like landslides and landslips in ecologically fragile regions are to be re-looked to discriminate the role of the natural and anthropogenic causes behind the rising incidences of such calamities in the Western Ghats. The impacts of rampant quarrying and related activities have far-reaching consequences on the sustainability of the region. Mining/quarrying threaten large areas of landscape with scarification, debris dumps, soil degradation and widening areas of deforestation.

### Impacts on air environment

The field survey campaign exposed various environmental concerns due to unabated quarrying activities in the study area. Most of the quarries in the region have crusher units attached to them for production of various types of aggregate products. It was observed that the major environmental concerns of the activity are caused by dust emissions and rise in noise levels due to mining-related activities. The primary sources of noise and dust are essentially blasting, crushing, drilling and vehicular movements.

**Noise pollution** The noise level of various operations related to hard rock quarrying is reported by Naik and Ushamalini (2007). Noise level due to blasting operation in various quar-

**Table 2** Details of laterite quarrying in the in Periyar–Chalakyudi and Netravati–Gurpur river basins Southern Western Ghats

River basin	Taluks	No. of quarries			No. of labour	Area of quarries (km <sup>2</sup> )	Rock extraction (× 10 <sup>5</sup> bricks/year)	Appx. depth (m)	Rock type	General landuse
		Act.Q	Abn.Q	Total						
Netravati–Gurpur	Mangalore	7	1	8	160	1.049	20	5–10	Laterite/duricrust	Barren land with hard duricrust, converted to agricultural land
	Batwal	9	2	11	220	0.236	22			
	Puttur	–	2	2	40	0.006	–			
	Total	16	5	21	420	1.29	42			
Periyar–Chalakyudi			6	6						Barren land filled with shrubs

Act.Q active quarry, Abn.Q. abandoned quarry, Appx. Depth approximate depth

**Table 3** Mining and quarrying activities and their consequences in the study area

Physical attributes	Activities	Type of impact	Nature of impact
Geomorphology	Soil excavation, debris dumping, hard rock and laterite quarrying	The terrain is turned into a swarm of ugly scars, degradation of ecosystem, change in natural geo-environmental setting, major long-term impact	Extremely high impact
Air quality	Drilling, blasting, crushing, loading, transportation and debris dumping and soil excavation	Dust emission, dust deposition on canopy cover and reduction in productivity, inhalation of fine particulates and breathing ailments	High impact
Noise level	Soil excavation, drilling, blasting, crushing, loading, transportation and debris dumping	Significant to extreme and continuous grinding sound in the vicinity, machinery noise, impulse noise of moderate to significant levels due to drilling and blasting operations, intermittent loading/unloading traffic noise	High impact
Soil	Soil excavation, quarrying and debris dumping	Slumping, loss of top soil, nutrient depletion and change in soil character, deforestation	Extremely high impact
Landuse	Construction of roads, clearing of land and vegetation, construction of crusher units, quarrying and debris dumping	Change in the natural vegetation, plantation, etc., increase in built up areas, creation of ugly scars in the landscape	Extremely high impact
Groundwater	Quarrying, excavation and blasting	Change in infiltration and recharge processes, increased water use, probable change in porosity	Moderately impact
Surface water	Quarrying and debris dumping, Waste water discharge	Increased runoff and turbidity in water during the rainy season, disappearance of natural drainage system and topography	Moderate impact





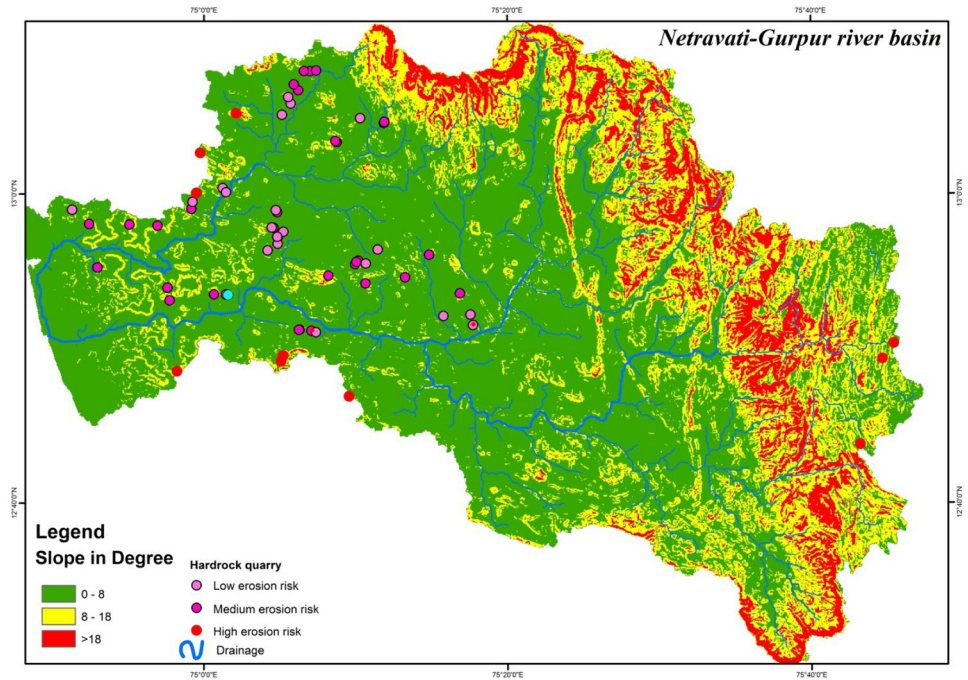
**Fig. 7** Selected scenes from the study area. **a** Rampant hardrock quarrying in the Periyar–Chalakydy river basin. **b** Blasting-induced instabilities in the soil apron over a rock quarry in the Netravati–Gurpur river basin. **c** Pit lake resulted from rock quarry in Belthangadi taluk

ries ranges from 133 to 156 dB. During drilling operations, it ranges from 99 to 116 dB. Similarly, the noise level during crushing is noted to be 92 dB. However, in the case of manual mining, the noise intensity is observed to be less and ranges from 54 to 79 dB. As per Indian Standards for noise level in mines, the level should be less than 85 dB in order to contain the risk to unprotected ears. However, the DGMS (1975), prohibits workers to enter the mines if the noise level is greater than 140 dB. No safety measures/ear protection devices are being used by the workers in the mines/quarries indicating occupational noise health problems in the long run due to continuous exposure to unhealthy noise levels.

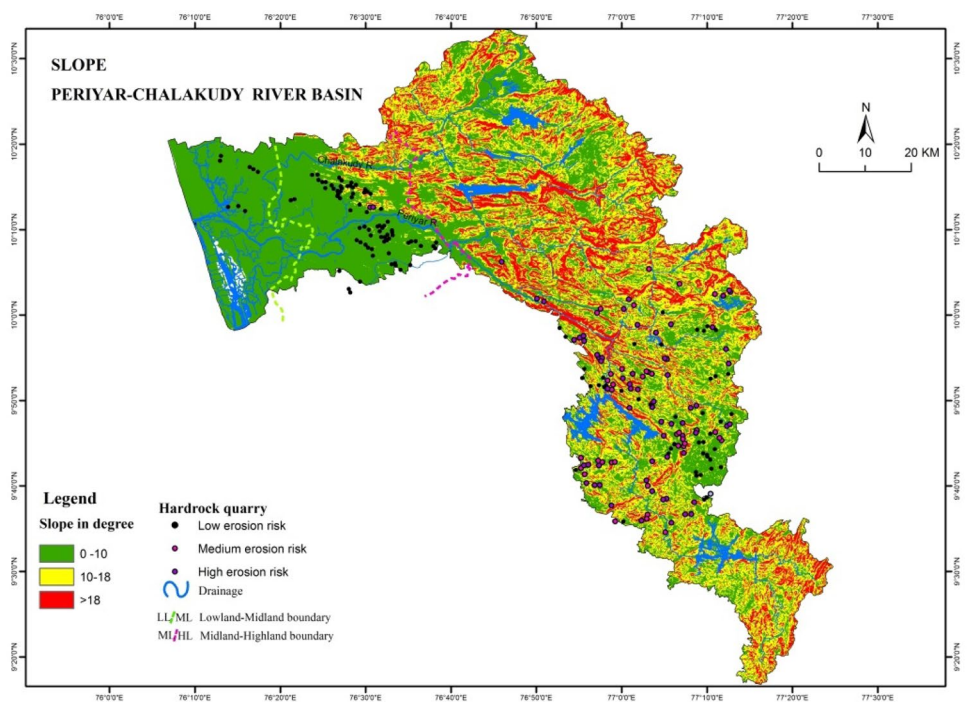
used for irrigation purposes in summer season. **d** A laterite quarry converted to rain water harvesting structure in Netravati–Gurpur river basin

**Dust pollution** Major source of dust is from processing plants such as crushers and loading yards. Most of the quarries are generally situated in uninhabited or less populated regions so the consequences of blasting and crushing are comparatively less in the basins. Careful site selection of quarries, surface treatment of haul roads and careful routing of trucks can help reduce noise and dust pollution from the activity. Impacts of blasting can be mitigated by maintaining blast vibrations within permissible levels (Langer et al. 2004), which will cause health issues to the workers and common people in the adjacent locations. It was noticed that most of the active hard rock quarries are functioning

**Fig. 8** Slope map of the Netravati–Gurpur river basin



**Fig. 9** Slope map of the Periyar–Chalakydy river basin

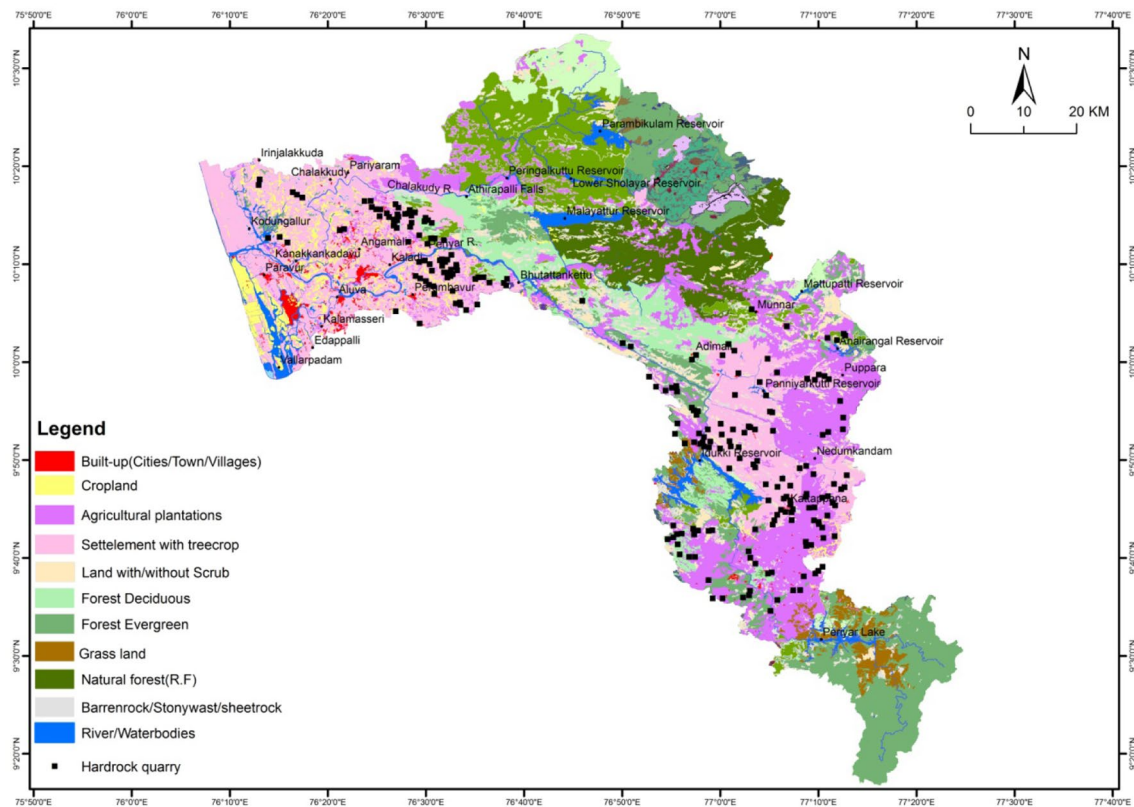


with one or two crusher units near the mining area. Water pollution due to the working of crusher units are noticed in certain places of the study area.

**Impact on water environment**

Indiscriminate mining and quarrying could impose marked changes in the hydrological regime of the area. Most of

the first-order streams are originating from highly elevated regions of the basins; interference in this land system has caused severe implications in the hydrological system of the basins. Modifications or fragmentation in the natural drainages are frequently noticed in the basin which became a major threat to the geo-hydrological settings of the basin. The alteration disrupts contribution of water to the channels, in addition to disturbing the sediment transport and



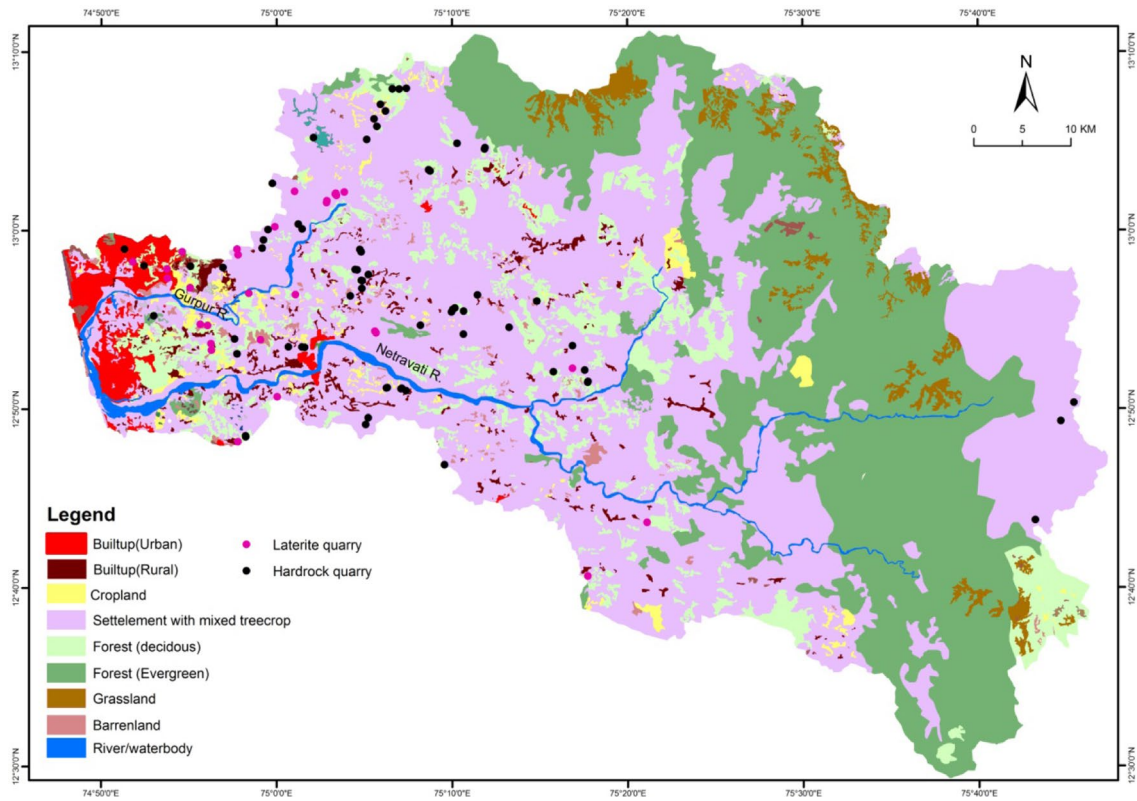
**Fig. 10** Landuse/landcover map of the Periyar–Chalakudy river basin

other natural-ecological conditions of the drainage basins. The situation is clearly noticed in Chemmannar sub-basin of Periyar–Chalakudy river basin (Fig. 12) and Yattinhole sub-basins of Netravati–Gurpur river basin. Detailed studies reveal that nearly ten hard rock quarries in the Periyar river basin are directly imposing changes in its drainage channel. It is noticed that a total of sixteen first-order streams are either blocked or have totally disappeared due to hard rock quarrying in the study area. Changes in the land form units have caused even disappearance of certain natural springs in Netravati–Gurpur river basin. CGWB (2017) reports that groundwater level for the period of 10 years (2006 November–2016 November) shows a fall in water level in Dakshina Kannada district. Out of the 101 observation wells, 80 wells showed a marked declining trend. Quarrying activities without adequate mitigation plans shall be counterproductive and of course, aggravate the situation further.

**Drivers promoting mining and quarrying**

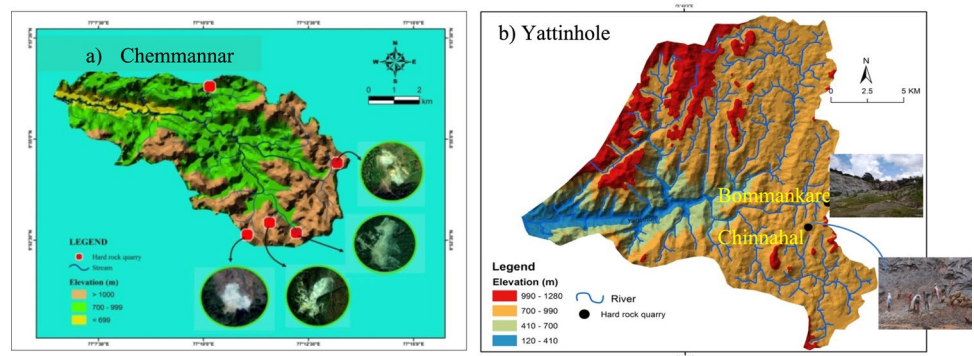
According to the World Population Report, 2014 of the United Nations, the global population is predicted to reach about 11 billion by 2100. The increase in population and urbanization is directly linked to an increase in raw-material demand (Vidal et al. 2013). The urban centres such as Kochi

and Mangalore are forging ahead and are now rated as the fastest growing port cities in the south west coast of India. Recently, both these cities are emerging as epicenters economic development in Kerala and Karnataka states, respectively. Figure 13 presents the population growth in the two urban centres under consideration in the last five decades. Both the urban centres have a sharp increase in population from 1971 to 2011. The study region, Kochi (Municipal Corporation), registered a population of 4.39 lakhs in 1971, and it reached 6.33 lakhs in the year 2011. In Mangalore Corporation, the population grew from 1.95 lakhs in 1971 to 4.99 lakhs in 2011. It is to be noted that even though the population is higher in Kochi, the growth in population is higher in Mangalore. Both cities require improved infrastructural facilities for accommodating the various mega developmental projects that are in the pipeline. This in turn enhanced many times the extraction of different types of construction materials from the outskirts of the respective core development centres. Apart from land, air and biological environments, the activities inevitably affect the socio-economic conditions of the people as well. Therefore, it is extremely important to study the resource extraction trends in regions around development centres to get an in-depth understanding of the long-term feasibility of development initiatives, such as in the study area.



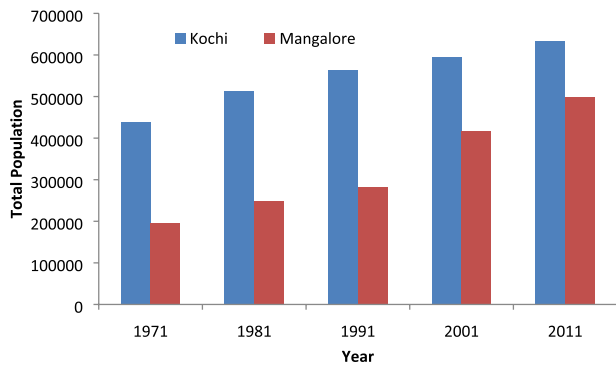
**Fig. 11** Landuse/landcover map of the Netravati–Gurpur river basin

**Fig. 12** Degradation of natural drainage channels due to hard rock quarrying. **a** Chemmannar sub-basin of the Periyar–Chalakydy river basin (source: Maya et al. 2015); **b** Yattinhole sub-basin of Netravati–Gurpur river basin

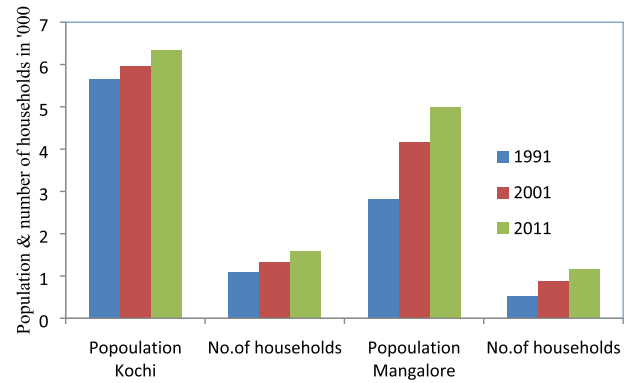


The demand for building stones and aggregate materials will continue to rise on account of the pace of developmental initiatives in the region. The intensity of the mining activities is the highest within 35 km<sup>2</sup> radius of Kochi city (Periyar–Chalakydy basin) where the density of mines often reaches above 30/km<sup>2</sup> (Shiekha 2017). In Netravati–Gurpur river basin, the density of mines is high in the Mangalore–Bantwal belt which is close to the Mangalore city. It is found that nearly 30 mines are located in a square kilometer area in that region. This area generates maximum amount of materials (quantity) to feed the city centre. Nowadays, along with urbanization, it is noted that

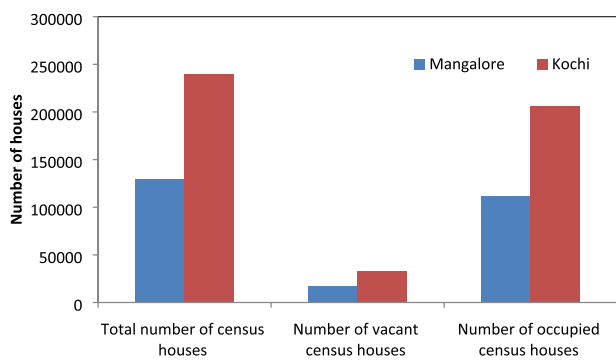
the number of vacant houses is also increasing in the city as people consider houses as an asset for their future and hence, they tend to invest more in construction sector. According to the 2011 census data, about 11% (1.19 million) houses in Kerala lie vacant. While 10% of the houses are found vacant in rural areas, more houses are vacant in urban areas. This is much higher than the national average of 7.5%. In the case of Kochi and Mangalore, as per the 2011 Census report, it is observed that about 14% of the total houses in the urban centres are vacant (Fig. 14). This is one of the most visible negative impacts related to natural resource management and the situation is alarming because it will create an imbalance



**Fig. 13** Population growth in Kochi and Mangalore cities of the study area during 1971–2011 period ( Source: Census reports)



**Fig. 15** Decadal variation of population and number of households in Mangalore and Kochi cities



**Fig. 14** Number of occupied and unoccupied houses in Mangalore and Kochi cities

between the environmental conditions and human needs. Decadal growth of population and number of households in the two urban centres are the contributing factors that impaired the environmental setup severely. Figure 15 indicates the decadal growth of population and household in the two urban centres, Kochi and Mangalore.

**Sustainable development initiatives of mines/quarries**

Natural resources are a vital base for economy and well-being of the people of a country. Sustainable development requires a well-balanced use of natural resources, together with a well balanced consideration of ecology, economy and social justice (Wellmer and Becker-Platen 2002). Discussing on the quantities of mined minerals, Rogic and Matos (2008) highlighted that there has been a constant increase over the years in mineral extractions, mostly for construction materials. However, increases in mineral extraction are concomitant with increases in population, and the overall extraction per person. Given these trends

and the trends in the society, it is important to account for the fact that mining can have a significant impact on catchments, during mining and also for many years after the cessation of the activity (Hancock et al. 2008; Herrera et al. 2010). Urbanisation and development are the prominent factors which control the extent of sustainable development in the study area.

The final stages of the mining cycle, namely mine closure and associated reclamation and rehabilitation of lands earlier utilized for mineral extraction, are, perhaps, the most important aspect for sustainable development in the mineral mining sector (Sheldon et al. 2002). If not properly executed in a holistic manner with sound reclamation practices, the processes in these stages have the potential to establish mining and quarrying as only temporary uses of land. The principles of sustainability require these lands to be returned to some other beneficial use once mining operations are ceased. In both the river basins, compared to hard rock quarries, laterite quarries create less environmental problems in the socio-environmental setting of the region. In a laterite capped region, after resource extraction, the area has the potential to be converted to productive agricultural lands. On the contrary, at present most of the abandoned quarries are remained as wastelands. Today, mine closure normally requires the reclamation and rehabilitation of the land in and around the mine concerned. Reclaimed mine sites may then be returned to their natural state thereby recreating original habitats (such as forests), which will reduce the impact of mining in due course.

Quarrying rocks for use as crushed stone and dimension stone can be accomplished with minimum impacts on the environment provided the entire extraction, processing and transportation are managed properly in concurrence with the regional developmental plan which in turn has to be prepared taking in account the supportive and assimilative capacities of the natural ecosystems. However, if proper precautions are not taken, quarrying can cause irreparable and irreversible

damages to the ecosystem in the long run, leading to drastic increase in costs for environmental compliance.

Recently, a well-advanced sustainable strategy was developed in a few laterite mines of Netravati–Gurpur river basin. In Ganjimutt area, two laterite mines are converted as agricultural plantations and rainwater harvesting structures (Fig. 7d). Large-scale surface quarrying for hard rocks often leads to the creation of pit lakes of variable dimension. In most cases, pit lakes are considered a liability in the mining-hit areas, but when properly executed, the pit lakes left after hard rock quarrying could be used for the meeting the freshwater and agriculture requirements of the people of the area after proper quality analysis (Fig. 7c). Restoration processes are practiced in few hard rock quarries in the study area. In Mogru village, with local initiative, people have converted excavated pits for rainwater harvesting and are used for agricultural purposes. In Kurnad village, a quarry pit is converted to a pond and used for meeting the requirement of water for domestic purposes.

The closure process, therefore, must take care that environmental problems arising during the mining operations and also those likely to arise during the post-closure scenario. Both these cases are to be comprehensively addressed. Also, the socio-economic issues of mine closure and its impact on local communities, workers and their families and the local economy need to be assessed and scientifically managed. Sustainability issues are less in the case of lateritic block cutting as compared to hard rock quarrying. Low-noise producing equipment with dust suppression or collection systems can significantly reduce negative impacts on the environment. Conveyors can be used instead of trucks for the in-pit movement of materials. Another method that can be implemented in the case of abandoned stone quarries located in the outskirts of the city is that they can be used as rainwater harvesting structures after taking necessary precautionary measures.

## Conclusion and suggestion

Urbanization, population growth and related boom in the economy and infrastructure resulted in a hike in the demand for minor minerals. The exploitation of the resource in a defensible manner is necessary for achieving sustainable development. There are only a few quarries in the study area which follow the security and environmental regulations. Intensive mining activity in the basins cause severe environmental degradation issues like land subsidence, soil slumping, pollution, etc. Noise, dust, groundwater and surface water pollution were noticed in certain parts of the study area. Many of the adverse effects such as noise pollution and surface water pollution were observed to be constrained to smaller regions. However, changes in groundwater levels

and changes in landuse and flow pattern can cause long-term effects on the environment. The study warrants the imminent need for a comprehensive scientific plan for the mining and quarrying sector of the study area in particular and similar regions in tropics in general.

Following are a few suggestions for enhancing the overall environmental quality of the area:

1. Coordination among legal and administrative authorities and other stakeholders at different levels to prepare an integrated quarrying/mining policy and implement the same for the sustainable development of the region.
2. Vulnerable areas and suitable locations for quarries are to be determined and appropriate rehabilitation measures are to be taken.
3. Regular wetting (water spraying) of the ground has to be done in dry periods on the roads and the working regions of the quarry to reduce dust pollution during quarrying or transportation of the quarried products.
4. Boundary of excavated areas should be fenced appropriately to avoid accidents/risk to humans.
5. Boundaries of quarry sites that are prone to caving should be strengthened with granite walls or with reinforced concrete structures.
6. Protective measures and health insurance schemes are to be provided to workers and to people living in the buffer zones.
7. All mining and quarrying plans are to be made in compliance with the regional development plan of the area.
8. Awareness campaigns should be conducted at various levels about the impacts of quarrying and levelling of hillocks, present state of hill ecosystems, finite character of the resources, use of alternative materials and immediate need for control measures.

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