Environ. Process. (2017) 4:663–682
DOI 10.1007/s40710-017-0255-6

ORIGINAL ARTICLE

Processes and Status of Land Degradation in a Plateau Fringe Region of Tropical Environment

Avijit Mahala [1]

Received: 15 February 2017 / Accepted: 11 July 2017 / Published online: 20 July 2017

Abstract The concept of land degradation means a temporary or permanent long-term decline in an ecosystem function and its productive capacity. Land degradation is the result of numerous factors or a combination thereof, including physical (climate change, soil degradation) as well as anthropogenic activities such as unsustainable land management practices. The present study primarily concerns the processes and status of land degradation in a part of the eastern Chotanagpur Plateau, India. The basin falls under the transitional zone, is undulating in nature and situated between the Chotanagpur Plateau area in the west and the greater Ganga plain area in the east. Largely, the basin falls under the Ganga River system. The major part of the population (>70%) of the area is dependent on agriculture which is largely affected by land degradation as well as soil erosion processes. The status of land degradation is estimated from different physical factors (geology, soil, geomorphology, slope, relief, groundwater, drainage density, rainfall intensity, green biomass cover) as well as anthropogenic factors (land use land cover change, population pressure on agricultural land, deforestation, irrigation intensity etc.). All these factors have been weighted with considerable importance to show the resultant varying intensities of land degradation. The different factor weighted raster has been multiplied in the GIS environment. The different vulnerable land degradation areas have been identified on the basis of the final weighted value. It has been shown that the upper reaches of the basin is considerably more prone to degradation due to its rugged topography, poor soil development and high drainage density. In the lower reaches of the Silabati River, the left bank is characterized by a high degreee of slope whereas the right bank shows intensive agricultural density, which couple up, to cause medium to high degree of land degradation vulnerability.

Keywords Land degradation · Soil degradation · Anthropogenic activities · Eastern Chotanagpur plateau · Irrigation intensity · Weighted multiplication · Land degradation vulnerability

✉ Avijit Mahala
mahala.avijit@gmail.com

[1] Centre for Study of Regional Development, Jawaharlal Nehru University, New Delhi 110067, India

1 Introduction

The concept of land degradation refers to a temporary or permanent long-term decline in a functioning ecosystem and in its productive capacity. Land degradation (characterized by soil salinity, acidity, erosion) can be explained as the decline in the quality of land, resulting from a gross discrepancy between a particular quality or nature of land and its subsequent (here, erroneous) use. It may further, also refer to the destruction of the health of that particular terrestrial ecosystem, thus affecting the natural ecological processes, associated biodiversity, and ecosystem resilience in totality. It can also be explained by the consequent change in the characteristic features of the forest, pastures and woodland (present there), culminating in the loss or reduction of biological or economic productivity. Globally, about 30% of the total forest area, 10% of grasslands and 20% of cultivated land across the world is suffering from land degradation related problems, and an estimated 1.5 billion people associated, are affected by it. Degradation encompasses deforestation (both tropical and temperate) and dryland desertification. Almost 75% of dry land in the world is facing the problem of severe desertification. The various types of land degradation problems include water erosion, wind erosion, loss of soil fertility, water logging, salinization, lowering of the water table, deforestation, forest degradation, rangeland degradation and soil pollution.

In developing countries, the physical processes of land degradation are accelerated by different anthropogenic processes (Feoli et al. 2002). The seasonality of rain, slope gradient, plant cover and land-use intensity are important indicators of land degradation worldwide (Zuquette and Pejon 2004). The different reasons of land degradation include clearing of vegetation cover, soil erosion by wind or water, soil types, changing of topographies, pollution, drought and flood, unsuitable agriculture practice, urban expansion or natural habitat alteration, agricultural expansion and forest habitat destruction (Ayoub 1998). Soil carbon sequestration, methane and nitrous oxide emission, eutrophication and soil acidification can also be noted as prominent processes of land degradation in different countries (Oostrum 2015). Land degradation and soil degradation are synonymous terms. Soil salinity, sodicity, acidity and erosion are also some of the common land degradation processes (Guillaume et al. 2016). Natural soil erosion by wind, water, coastal areas erosion, mass movement, salt-affected soil, desertification, decline in nutrient, organic matter, structure and acidification are other common types of soil degradation. Therefore, changes in land use land cover (LULC) and the phenomena of land degradation are seen to be highly correlated (Tolessa et al. 2017).

The pre-colonial developing countries have changed their land use patterns quite rapidly (Dewan and Yamaguchi 2009). The general transformation from dense forest to open or deforested land and continuous expansion of agricultural land has caused degradation worldwide (Fares et al. 2014). LULC change and allied land degradation has also increased in the Mediterranean region (Bajocco et al. 2012). According to the 'Food and Agriculture Organization' (FAO), this ensues a 'vicious cycle of erosion' where an ever-increasing population causes reduction in per capita land resources. With the hike in population, improper land usage and unsustainable management invariably leads to land degradation. Ultimately, land degradation causes reduction in productivity. Therefore, in such cases, increase in population and poverty go simultaneously. The effect of land degradation includes decline in the chemical, physical and biological properties of the soil (Karamesouti et al. 2015). The results of which are: depletion of the biodiversity, reduction in the availability of potable water, retreat in the level of present surface water, decline of aquifers due to lack of river water recharge resulting in lessened crop yields, famine, water and food insecurity. Conversely, this inflicts conflicts over access to existent limited resources, resulting into mass migration of the village population. Land degradation processes are the combined phenomena of physical and anthropogenic processes (Salvati and Zitti 2009). When we look at the global cost of land degradation, LULC (especially in sub-Saharan Africa) accounts for 26% of the global cost of land degradation. The tangible losses account for 46% of the total land degradation cost and the rest are due to losses in ecosystem services. The economic loss of land degradation has also sharply increased in newly developing countries like Bhutan. The cost of soil fertility, mining is estimated to be around 0.07% of the total global GDP. Forest or vegetal degradation accounts for the highest cost of land degradation leading up to about 29% of total cost. Others consist of crop land (23%), grassland (17%), urban land (13%), sub-urban (9%) and bare land (7%). In most of countries, the cost of action against land degradation is lower. Rapid change in LULC characteristics has been noticed in the post-independent years in developing countries of tropical and subtropical areas (Brandt and Townsend 2006). Rapid population growth, agricultural expansion, and deforestation are the common LULC change characteristics in tropical Africa (Nigeria, Zimbabwe, Sudan) tropical America (Caribbean countries, Brazil, Chile, Peru) and tropical Asia (India, Malaysia, Myanmar, Thailand, etc.) which increase land degradation (Fares et al. 2014). Global Assessment of Soil Degradation (GLASOD) has estimated that nearly 2 billion ha of land (22% of cropland, pasture, forest, woodland) has been degraded since mid-century in the developing countries (Scherr and Yadav 1997). Land use change in ecosystem services has also increased in developing countries (Tolessa et al. 2017).

According to different sources, the total area under desertification (arid, semi-arid, dry subhumid) in India is 228 × 10^6 ha. or 69% of the total geographical area (Ministry of Environment and Forestry, 2011). The different processes of land degradation that have been observed in India include vegetation degradation, water erosion, wind erosion, salinity and waterlogging. The percent changes in the status of land degradation in India are water erosion (10.21%), water degradation (9.63%), wind/aeolian degradation (5.34%), frost shattering (3.1%), salinity/alkalinity (1.6%), mass movement (1.35%), water logging (0.3%), rocky/barren areas (0.5%), others (0.04%) (Ministry of Environment and Forestry 2011). For instance, the Himalayan states are prone to frost shattering, glacial related degradation (the melting of high snow caps), while in northeast India water erosion of soil and vegetal degradation are prominent. The midland peninsular plateaus face degradation due to mining, soil erosion and forest degradation. The arid north-western area is prone to desertification. The river plain areas face irrigation-salinization, erosion and vegetal degradation. Total estimated cost of land degradation in India is about 1.40% of the country's GDP, 3.95% of AGDP, which amounts up to Rs. 25,944 million or US$401,610,006.72 (Reddy 2003). In West Bengal, degradation has affected 30.10% of the total geographical area. Water erosion in agricultural land and gradual scarcity of vegetal green cover are some of the main processes of land degradation. In the eastern part of India, the eastern Chotanagpur plateau fringe, namely the Purulia, Bankura, and Paschim Medinipore districts of West Bengal are most affected by degradation. Water-related high degree of rill and gully erosion (Shit et al. 2015), forest degradation, rapid irrigation and agricultural expansion are the common processes of land degradation in this area. The pre-Cambrian granite gneiss geology (Gour et al. 2014), laterite soil, undulating topography, high relief and slope, declining groundwater (Bhunia et al. 2012), high drainage density (Shit and Maiti 2012) and increasing aridity (P/PET) are the common physical factors that cause land degradation. High population pressure and greater dependency on agricultural land, i.e., lower availability of cultivable land are the major anthropogenic factors for degradation. The Silabati basin, which bears all of the above characteristics, is one of the important river basins of the area and a detailed study of it would give an insight into the way degradation has crept into the scenario.

The present study presents an effort to understand the processes leading to land degradation in a plateau fringe environment. In this environment, physical and anthropogenic settings give rise to definite characteristics. The present status of the land degradation bears the traces of the different processes that have acted on it.

The present study has been conducted in an attempt to fulfill two basic objectives:

- To understand the different processes of land degradation in a plateau fringe region of tropical environment; and
- To understand the different land degradation vulnerability of the region due to these processes.

2 Location and Description of Study Area

The Silabati basin which is a part of the Chotanagpur plateau, has been selected for this current land degradation study (Fig. 1). This basin characteristically is a part of the Chotanagpur plateau, India. The granite gneiss geological formation, undulating plateau upland with inter-fluvial lateritic upland, eastern flowing river system, low to medium precipitation (100–140 cm), high temperature (35–40 °C), and tropical dry deciduous forest cover make the Silabati basin a homogeneous physical unit. The anthropogenic characteristics (population

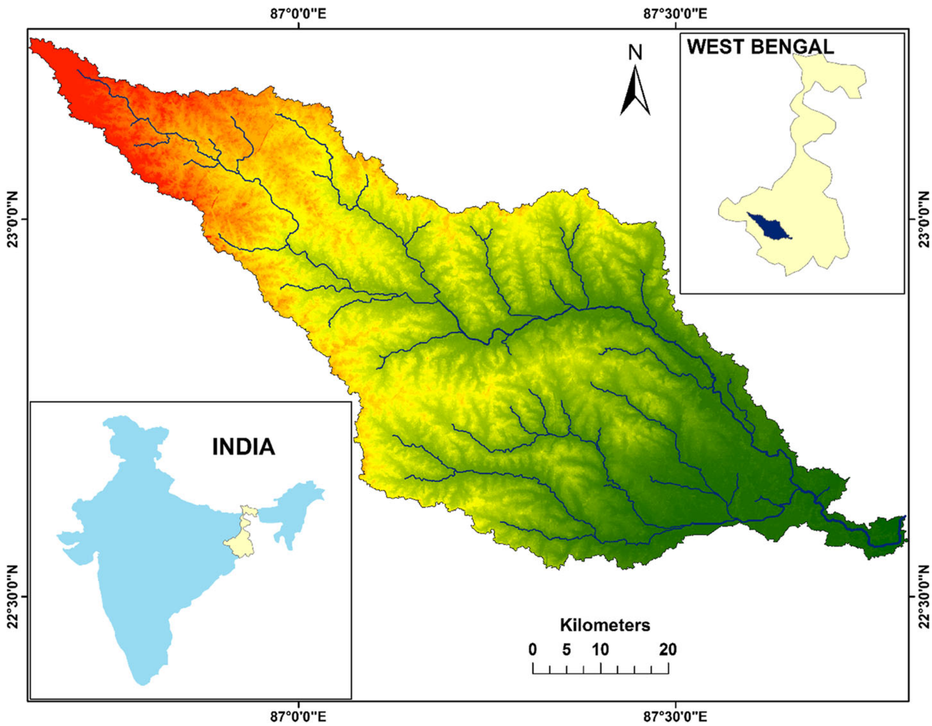

Fig. 1 Location map of Silabati basin

density, agricultural dependent population, percentage of agriculture land, livelihood, cropping pattern) are also representative of Chotanagpur plateau. Due to these unique physical and anthropogenic characteristics, the Silabati basin has been selected for land degradation study as a plateau fringe unit of tropical environment. The water-related rill and gully erosion, drainage-water erosion, forest-vegetal degradation and degradation related to agricultural expansion are the major land degradation processes in this region.

3 Materials and Methods

Different indicators have been studied on a worldwide level to understand the land degradation processes. Spectral characteristics of different objects like vegetation leaf, bare soil has been used to access desertification worldwide (Chabrillat 2016). But this method has limited use in land degradation factor or process analysis. Modersat data has been used to access the land degradation in the Arabian area (Faour and Council 2016). The method is limited only to the study of the physical phenomena. The Airborne laser scanning is a very important instrument to study the different land degradation processes (Avni 2016). But as pointed out above, it also has its limitations. The grazing land degradation can be assessed through the study of different water stress related factors (Coelho 2014). This method is only limited to the temperate region. In semi-arid areas, land degradation can be assessed through ecosystem services (Ravera et al. 2016). However, this method is not applicable in the plateau fringe areas. Desertification in arid regions can also be estimated through soil moisture, NDVI and rainfall characteristics (Ibrahim et al. 2015). Physical features like, geology, soil, relief, slope, physiography, groundwater, surface water (drainage density/drainage frequency), rainfall, aridity (P/PET), vegetation cover have largely influenced the land degradation processes in a plateau fringe region. This study aims to assess land degradation risk through Geographical Information Systems (GIS) (El-gammal et al. 2015). The study area, namely Silabati basin, has distinguishable physical characteristics, like dissected and undulating plateau over granite gneiss geology with shallow soil depth, high aridity and low vegetation cover in the entire basin. Different physical processes like, geology, geomorphology, soil, groundwater, surface water (drainage density/ drainage frequency), rainfall, aridity (P/PET) and vegetation cover have been studied for the Silabati basin individually (Table 1). All these factors delineates land degradation and inter-dependent to each other. The different weighted rasters (ranging from 100 to 200; 100 = minimum degradation, 200 = maximum degradation) for various physical factors of the basin has been created separately. The weighted value for different rasters have been assigned according to the land degradation potentiality of the concerned variable. To sum it up, weighted rasters of all the physical factors of Silabati basin have been multiplied through Arc GIS raster calculator function. The output raster shows the physical vulnerability index of land degradation in the basin.

$$\textbf{Physical vulnerability index of land degradation} = \left(\textbf{Geology} * \textbf{Soil} * \textbf{Relief} * \textbf{Slope} * \textbf{Geomorphology} * \textbf{Groundwater} * \textbf{Drainage density} * \textbf{Climate} * \textbf{Vegetation}\right)\hat{}\ \mathbf{1/9} \quad (1)$$

The various anthropogenic factors determine the land degradation processes. The GIS based approach for desertification risk assessment is highly popular worldwide (Ladisa et al. 2012). In spite of the wide popularity of this method, most of the studies have yielded limited results. In temperate areas, the authors excluded different population pressure related factors like,

Table 1 Data sources and techniques of physical processes of land degradation study

Physical factors	Data types	Techniques
Geology	Map of "Geological Survey of India."	Vector mapping for different geological characteristics
Soil	Map of "National Bureau of Soil Science"	Vector mapping for different soil groups
Relief	ASTER DEM 30 m.USGS Earth Explorer	Relief raster creation for different relief classes
Slope	ASTER DEM 30 m.USGS Earth Explorer	Slope(θ) raster creation for different slope categories
Physiography	ASTER DEM 30 m.USGS Earth explorer	Vector mapping for different physiographic unit
Groundwater	Mbgl data of "Central ground water board, India"	Mbgl raster creation for different availability classes
Drainage density	ASTER DEM 30 m.USGS Earth Explorer	Drainage density raster creation by (drainage length/Sq.km)
Climate	Daily temp. & rainfall data of "Indian Meteorological Dept."	Aridity(P/PET)raster creation for different aridity classes
Vegetation cover	Landsat8 OLI image USGS Earth Explorer	NDVI raster creation for different vegetation cover areas

population density and dependent population. However, these factors are of considerable importance in the tropical environment. In some studies the anthropogenic factor induced land degradation processes have been assessed only through land use and land cover studies (Hill et al. 2008). But the changes in land use and land cover are not disconnected individual phenomena. It is related and tied to other decisive factors as well. In some temperate areas, land use and land cover changes can heavily impact land degradation (Arnau-rosalen 2007). But this condition does not prevail in plateau region of the tropical environment. Large agricultural land, rapid deforestation and ever increasing population density of studied area are the major causes of land degradation. Different Anthropogenic factors for land degradation like, population density, agriculture dependent population, forest cover, agricultural land use, double cropping, the expanse of irrigation and uncultivable land have been studied for Silabati basin at a village level with a different approach (Table 2). All these factors influenced land degradation as well as interdependent to each other. Vector maps at village level of the basin for all anthropogenic characteristics have been prepared. The different weighted raster (ranging from 100 to 200; 100 = minimum degradation, 200 = maximum degradation) for different anthropogenic factors of the basin has been created according to land degradation potentiality. Finally, weighted rasters of all anthropogenic factors of Silabati basin has been multiplied through Arc GIS raster calculator function. The output raster shows the anthropogenic vulnerability index of land degradation of the basin.

$$\textbf{Anthropogenic vulnerability index for land degradation} = \Big(\textbf{Land use land cover} * \textbf{population density} * \textbf{agricultural population} * \textbf{dependent population} * \textbf{deforestation} * \textbf{agriculture land} * \textbf{double cropping land} * \textbf{irrigated land} * \textbf{uncultivated land}\Big)\hat{}\,\textbf{1}\Big/\textbf{9} \tag{2}$$

Land degradation vulnerability depends on both Physical and Anthropogenic vulnerability. In the environment, the physical processes of degradation are accelerated by anthropogenic

Table 2 Data source and techniques of anthropogenic processes of land degradation study

Anthropogenic factors	Data types	Techniques
PCA analysis	Primary census abstract and village directory-2011, Census of India	Descriptive statistics, correlation, pattern metrics for different socio-economic data
Land use Landover	Landsat-8 OLI (11 bands) USGS Earth Explorer	Land use land covers classification by supervised techniques
Population density	Village directory-2011, Census of India	Total Population/area
Agriculture population	Primary census abstract-2011, Census of India	Main and marginal cultivator and agriculture labor population/total working population*100
Dependent population	Primary census abstract-2011, Census of India	Non-working population/ total population*100
Forest cover	Village directory-2011, Census of India	Forest land/total area*100
Agriculture land	Village directory-2011, Census of India	Irrigated and unirrigated land/ total area*100
Double cropping land	Village directory-2011, Census of India	Irrigated land/agriculture land*100
Irrigated land	Village directory-2011, Census of India	Irrigated land/agriculture land*100
Uncultivated land	Village directory-2011, Census of India	Area not available for cultivation and cultivable waste land/area*100

processes and vice-versa. In Silabati basin, these two categories of processes have resulted into land degradation. The previously created raster - Physical vulnerability index of land degradation has been multiplied with anthropogenic vulnerability index of land degradation. The output raster has shown the status of land degradation vulnerability in the basin.

$$\textbf{Land degradation vulnerability} = \left(\textbf{A.Physical vulnerability index for land degradation}^{*}\ \textbf{B.Anthropogenicvulnerability index for land degradation}\right)\hat{\ }\mathbf{1}\Big/\mathbf{2} \quad (3)$$

4 Result and Discussion

4.1 Physical Processes of Land Degradation of Silabati Basin

Land degradation is a result of both natural and anthropogenic cause-effect phenomena that is present on a worldwide level (Abu and Tumeizi 2012). Land degradation is the deviation of land quality from a standard one. Studies show that more than half of the global land has been degraded by the action of different physical and anthropogenic processes. Geology, mineralogy, soil, relief, slope, geomorphology, drainage, climate and vegetation are the various physical factors that control the land quality. Different regions of the earth are dominated by different physical factors of land degradation.

Geology Geological formations and related mineralogy largely control the quality of land. The land surface condition, i.e., relief, slope and geomorphology are also controlled by geology. Soil, groundwater storage, drainage condition and available minerals depend on the geology of the region which indirectly controls the total land degradation processes. The underlying geology of mountain and plateau areas are mainly responsible for land hindrance. The upper basin of Silabati river is dominated by granite gneiss geology which causes hindrances in soil development (Fig. 2a). The undulating plateau and long ridges cause land hindrance in upper reaches of the basin. The lateritic geology of middle basin causes intense rill and gully erosion. The lower reach is dominated by lateritic geology with primary and secondary development as well as sediment geology. The areas with lateritic geological formations bear the ill effects of soil erosion.

Soils Soil or the interactive zone of biosphere and lithosphere, is an important factor in delineating land degradation. Soil degradation falls largely under land resource scarcity

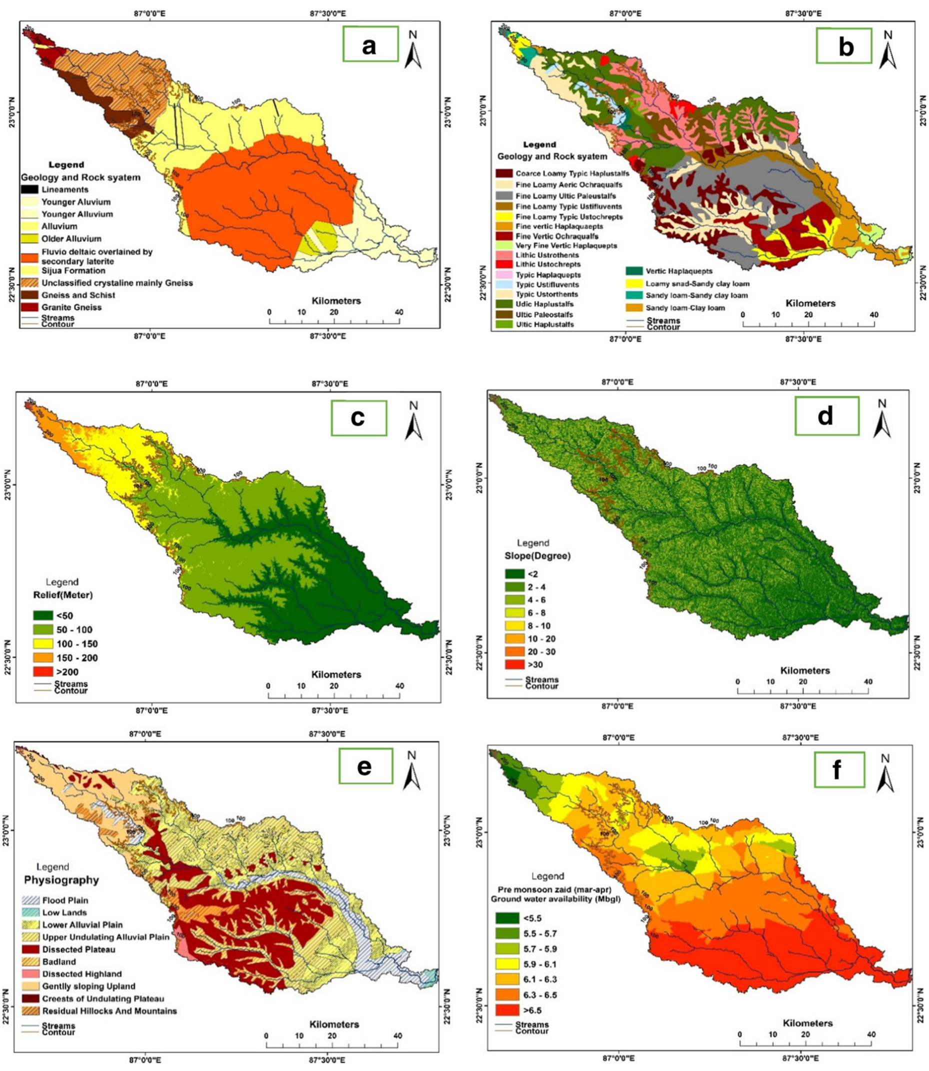

Fig. 2 Physical factors and vulnerability of land degradation of Silabati basin **a.** Geology **b.** Soil **c.** Relief **d.** Slope **e.** Geomorphology **f.** Groundwater (Mbgl) **g.** Drainage density **h.** Aridity (P/PET). **i.** Green biomass cover and **j.** Environmental vulnerability index

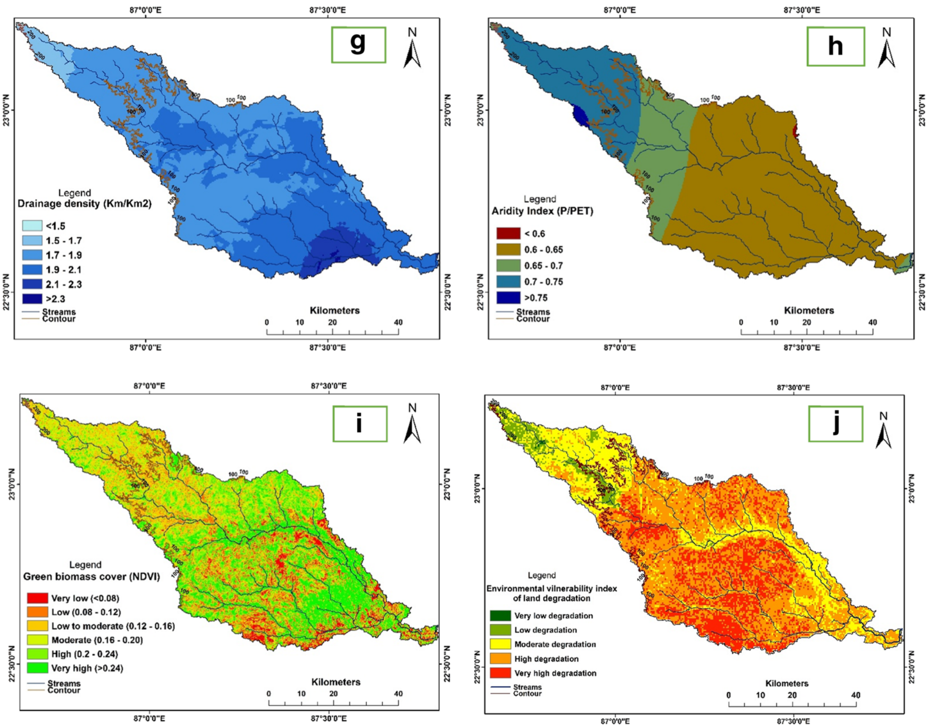

Fig. 2 (continued)

(Guillaume et al. 2016). Land use and land degradation processes affect soil resources (Karamesouti et al. 2015). The soil and land degradation occurs hand to hand, soil degradation promotes land degradation and on the other hand land degradation causes soil to degrade (Hao et al. 2009). The physical characteristics of soil, i.e., soil texture, soil structure, color and temperature determine the land productivity (Franzmeier 1994; Askari et al. 2015). Soil moisture loss and related land degradation are important in Sub-Saharan Africa (Ibrahim et al. 2015; Omuto et al. 2011). Human-induced soil erosion is becoming increasingly noticeable in S-E Asia. Low organic matter characterizes coarse-grained soil in the upper basin of study area. Shallow soil profile development, high sand content, and low conductivity are the general characteristics of the said region (Fig. 2b). These characteristics of soil decrease the fertility of the land in the upper reaches of the basin. The middle reaches of the basin are characterized by intense lateritic formation, whereas high soil erosion causes low fertility. The lower basin areas have the problems of water accumulation related soil degradation.

Relief The surface relief is an important factor of physiography of any region in determining the land degradation characteristics. Directly and indirectly, surface relief controls the land productivity of any region. The different relief types of a region have a set of different effects in the process of land degradation. The high relief regions of the tropical as well as extra-tropical areas (Himalayan, Alps, and Andean Mountains) have the potentiality of possible land degradation (Tolessa et al. 2017). Medium to high relief in upper reaches of Silabati basin causes low land productivity (Fig. 2c). Undulating relief in middle-upper reaches has given rise to intense soil erosion.

Slope The slope characteristic of any region determines the stability of the soil materials, delineating land degradation. The high slope areas having a slope of more than 30° has less potentiality to stabilize the soil materials on its surface, and this causes the land to face degradation. High slope in mountains and plateau areas of world (countries like Bhutan, Nepal in Asia) have faced such types land degradation processes. For example, in Silabati basin the high slope of the right bank has a high potentiality of soil erosion (Fig. 2d).

Geomorphology The different geomorphic features and their associative configuration define the land quality. The highly elevated mountainous land with high slope and closely spacing contours create land degradation. Different geomorphological units have region-specific potentiality of land degradation. The mountain geomorphology with high slope, concentric ridge and ridge and valley topography of various ranges like the Himalayas, the Andean, the Alps countries has problems of soil erosion, high landslide susceptibility as well as low soil development (Nyssen et al. 2008). The plateau terrain of central Africa and central Asian countries has faced aridity and low soil fertility related degradation. The lowlands of coastal America and Asia have problems of soil salinity. The residual hillocks and mountains, creating an undulating plateau, and gently sloping upland are the general geomorphic features of upper Silabati basin. These features cause hindrance in the socio-economic development of the area (Fig. 2e). The dissected plateau and upper undulating alluvial plain areas of middle basin cause intense soil erosion. Floodplain area in lower basin faces water accumulation related problems.

Groundwater The presence of an accessible high water table is a primary requirement for land productivity. The imbalance between a renewable source of groundwater and the extraction from it, the shifting of the renewable source of groundwater, and the high extraction of groundwater causes water table decline, which in turn leads to land degradation (Nag and Ghosh 2013). The continuous decline of the groundwater level is expanding from the semi-arid lands of the tropical and extratropical lands of Africa-Asia to the highly intensified agricultural areas of S-E Asia (Shabbir and Ahmad 2015; Hogeboom et al. 2015). Groundwater exploitation and related degradation are also increasing in rich developing countries (Mahmoud and Alazba 2016), like China (Li et al. 2015). Developing countries like India are already experiencing rapid groundwater depletion (Dedewanou et al. 2015). Low depth aquifer, as well as low groundwater recharge due to hard rocks in the upper reaches of the basin, cause decline in groundwater table (Fig. 2f). The continuous decline in groundwater table due to agricultural practices in the lower reaches of the Silabati basin poses a threat to drinking water availability.

Drainage Density The different characteristics of drainage (drainage density, frequency, length, profile, eroding capacity, basin shape and basin forms) determine the erosional characteristics of the region (Frankl et al. 2013). Water erosion and related soil loss are important land degradation processes in European rangeland (Ibáñez et al. 2014). Faulty management affects the soil causing soil erosion and surface runoff in semi-arid regions, increasing land degradation. The high sloped surface with intense contour spacing forms a high-density drainage causing high soil erosion which makes the region degraded (Girmay et al. 2009). The tropical and monsoonal areas of the world have faced intense rill and gully erosion related soil degradation (Frankl et al. 2013). High runoff and associated nutrient loss related land degradation is prominent in the tropical region (Girmay et al. 2009). Tropical semiarid region has faced high runoff water erosion (Cesar et al. 2017). High drainage density, especially in the right bank in the middle reaches of the Silabati basin, has given rise to rill and gully erosion (Fig. 2g). Intense soil erosion, therefore, has resulted in a qualitatively inferior land which has come to dominate the said area. Typical rills and gullies have developed in this region of the basin (Shit and Maiti 2012).

Aridity (P/PET) Rainfall is the most important factor determining the characteristics of desertification responsible for high soil erosion. Climatologists use this variable to calculate the water balance condition through precipitation and evapo-transpiration ratio (P/PET) (Kafle and Bruins 2009). Climate change and allied global warming has resulted into an increase of desertified lands all over the world (Sergio et al. 2015). In India desertification of land has also been on an increase (Ajai et al. 2009). Increasing aridity in desert areas like the Sahara and Gobi poses a threat of greater land degradation (Ayoub 1998). Aridity has also been on an increase in India (Jayasree and Venkatesh 2015). The low value of ‘P/PET’ is a case in point in the lower reaches of Silabati (Fig. 2h). Through the years, the rainfall has continuously declined in these areas of the plateau fringe. Large deforestation and related land use change are the prime factors for increasing aridity. The ecological stress related land degradation prevails in these areas of the basin.

Green Biomass Cover The land covered by greenery is less prone to degradation (Kakembo 2001). Spectral differences are important parameters in assessing green vegetation cover (Higginbottom and Symeonakis 2014). Different high-resolution images (NOAA-AVHRR etc.) shows prominent risk for green vegetation (Maselli et al. 2003). Rapid deforestation and continuous pressure on land has caused low vegetation cover all over the world, especially in the dominantly semi-arid and in developing countries. The Silabati basin shows less green biomass cover in the middle and lower reaches of the basin (Fig. 2i). Large agricultural expansion causes high extraction of green biomass cover in this area of the basin and the resultant low green biomass cover demarcates the ecological stresses of the area.

The different physical factor-induced land degradation vulnerability of Silabati basin has been accessed by multiplication of different factor maps and is presented in Fig. 2j, which shows high vulnerability in the lower and middle reaches of the basin compared to the upper reaches, due to low vegetation cover, deep laterite profile and lowered depth groundwater table etc.

4.2 Anthropogenic Processes of Land Degradation of Silabati Basin

Land Use and Land Cover The land degradation characteristics of any region will be better understood if the land use and land cover characteristics and its changing scenario are examined in detail. The land use and land cover give way to land degradation through direct and indirect processes. For example, the Mediterranean cropland soil gets degraded due to land use and land cover characteristics (Karamesouti et al. 2015). In Africa, increasing population and related LULC change causes degradation (Stéphenne and Lambin 2001). LULC change in Central America especially in the forest land due to habitat and agricultural land is prominent

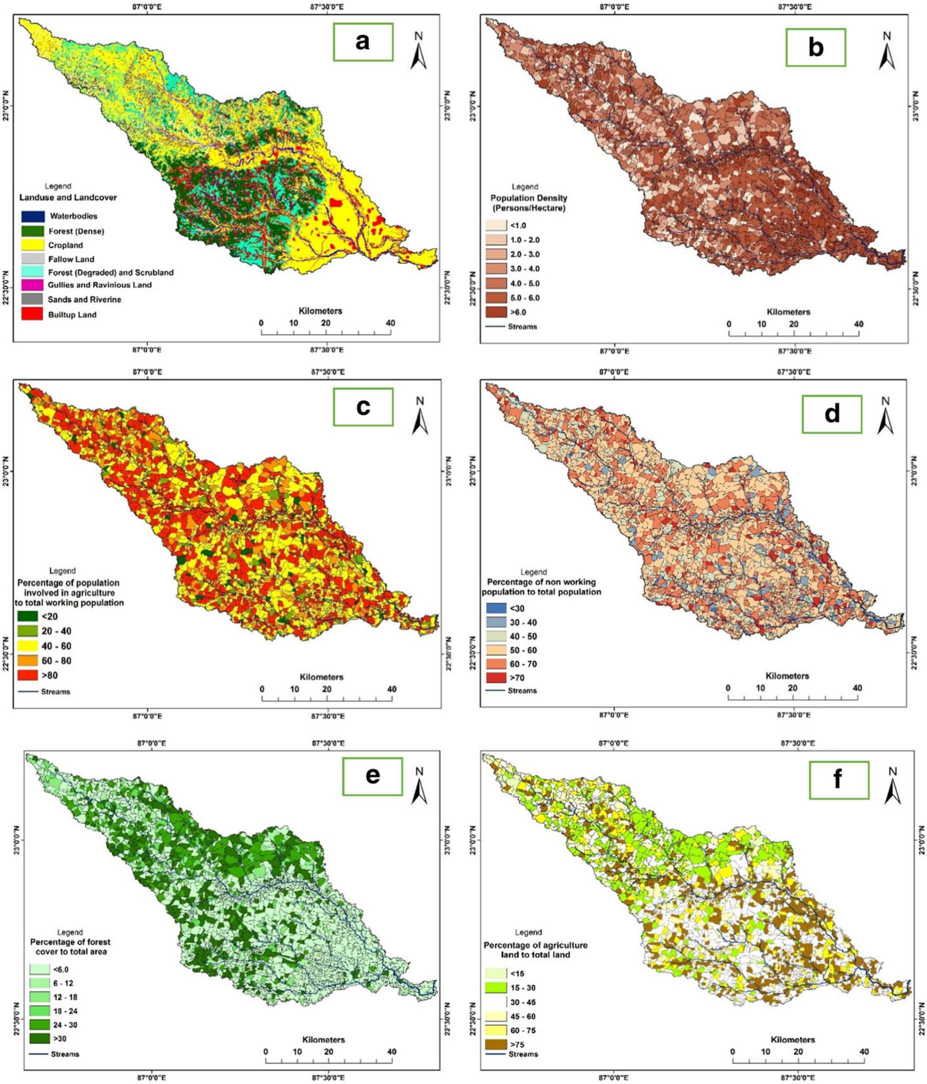

Fig. 3 Anthropogenic factors and vulnerability of land degradation of Silabati basin. **a**. Land use and land cover **b.** Population density **c**. Agriculture population **d**. Dependent population**. e.** Forest cover **f**. Agriculture land **g.** Double cropping land **h.** Irrigated land **i**. Uncultivated land **j.** Socio-economic vulnerability index of land degradation

(Scullion et al. 2014). Mediterranean rangeland has also faced LULC change related degradation (Symeonakis et al. 2007). The continuous expansion of agriculture land in previously occupied forest areas is the most important LULC conversion phenomena in the Silabati basin (Fig. 3a). Forests, left open are emerging in the previously covered dense vegetated forest areas. Continuous urbanization, as well as fallow land expansion, are also important reasons for land degradation in the Silabati basin area. Greater concentration of wasteland, as well as barren land in upper reaches of the basin, causes hindrance in the socio-economic development of the area.

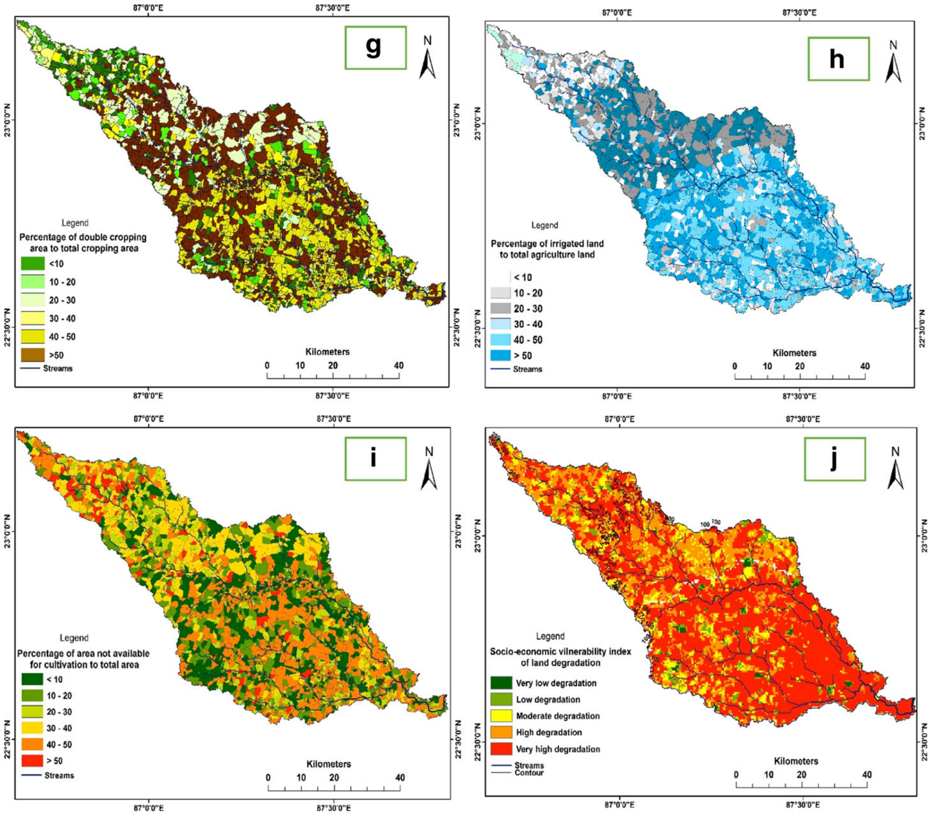

Fig. 3 (continued)

Population Density The environmental consequences of increasing population size are dynamic and nonlinear, non-passive (Harte 2007). The increasing population or the role of population density in environmental degradation can be traced to the pollution of air and water, the earth's climate; soil erosion, fragmentation and elimination of the habitats of plants and animals, depletion of the non-renewable resources, and in the long term depletion of the natural ecosystem of the earth (Harte 2007). In the developing countries of the world (Asia, Africa, S. America) increasing population is the prime responsible factor for land degradation (Scherr 1996; Fei et al. 2015). Economic growth and related increase in population density of sub-Saharan Africa are the prime responsible factors for land degradation. The high fertile areas of the basin in lower reaches cause high population density (Fig. 3b). High population pressure causes land pressure and related ecological stresses. All these factors increase the land degradation vulnerability.

Agricultural Population The part of working population involved in agricultural activities to the total working population is an important indicator for land degradation study. The collective ownership of farmland is no longer common in high agriculture dependent countries. The tenant farmers are less likely to invest in soil conservation and productivity increasing methods in a sharp contrast to the land owners. High agricultural dependency in the third world countries (like S-E Asia) creates land pressure which eventually leads to degradation. The high agriculture dependent population is prevalent all over the basin in the study area (Fig. 3c). Large agriculture dependent population proportionally causes greater land pressure. They extract many resources from the limited land area available, leading to land degradation.

Dependent Population Farmers intensify their agricultural activities on land already in use with increasing needs of food to support a large household and its numerically huge dependent population (Kakembo 2001). The processes are not adapted to the local environment and they may be harmful in terms of long term sustainable resource base, causing land to degrade (Grepperud 1996). Third world countries, like eastern Africa, S-E Asia, have faced such types of problems. Large disguised labor and dependent population of eastern Africa and S-E Asia cause land degradation (Bielli et al. 2011). Silabati basin shows high dependent population all over the basin (Fig. 3d). The area is actually agriculture-dominated area with few small industries. The large dependent population with high sustainable intensive agriculture causes land pressure which ultimately leads to degradation.

Forest Cover Deforestation has occurred in the context of large population increase and expansion of agricultural land to provide food. Increasing population and their immediate need of land are the major causes of deforestation. The different causes of deforestation in developing countries include grazing, shifting cultivation, hunting, subsistence agriculture, etc. In forest and shrubland socio-ecological system community resilience and related land degradation are important worldwide (Kelly et al. 2015). Continuous pressure on land for agriculture and habitat perspective creates deforestation all over the world, especially in the tropical third world countries (Kakembo 2001). For instance, Silabati Basin shows high deforestation all over the basin (Fig. 3e). The low soil development, undulating topography, and agricultural expansion in recent times has caused intense deforestation in upper reaches of the basin. Settlement and agriculture expansion are the major causes of deforestation in the lower reaches of the basin.

Agriculture Land Agricultural development has emerged with a major discourse between environmental degradation and livelihood improvement in Asia (Deshar 2013). In recent times, the increasing use of chemical fertilizers and large irrigation in agricultural land has led to a change in the chemical characteristics of the field (Rahman 2002). Marginalization of agriculture causes land degradation in developing countries (Santamarta et al. 2014). Land system change (from other land use to agriculture land) has accelerated the land degradation processes (Niedertscheider and Erb 2014). Different methods of terrace field cultivation also causes land degradation. The small land holding system of the developing countries (Asia, Africa) increases pressure on land and causes the land to degrade (Waswa et al. 2013). The whole of Silabati basin shows continuous agricultural land expansion (Fig. 3f). Increasing population, continuous pressure on the land and increasing food demand calls for large agriculture expansion of the area. Increasing fertilizer use, irrigation and soil erosion in agricultural areas has caused the land to degrade.

Double Cropping Land Double cropping is fairly common in today's world compared to the practice of single cropping. The high population increase and increasing demands of food causes the single cropping land to be converted into a double cropping land. In the developing parts of the world, in general, the large population mass and their relative dependency on agriculture cause serious pressure on agricultural land. Third world countries are continuously expanding their double cropping areas to feed their large population masses. The fertile lands on river banks of the basin are the major double cropping areas of the Silabati basin (Fig. 3g). Intense irrigation and related salinization are the major land degradation processes in the double cropping areas.

Irrigated Land All countries, developed or developing, have upgraded their development character by increasing the extent of irrigation facility. Arid and semi-arid areas (i.e., Sahara, Gobi, Thar) of the world has also witnessed an increase in the irrigation capacity in order to feed the population. This has led to soil salinity related degradation. In India, large irrigation projects had come in the first phase of economic development. As irrigation increases, the problem of salinization (in a desert region), water logging (in the lowlands) and low microbial activity occur. Channel areas of the Silabati basin are the major irrigated areas of the basin (Fig. 3h). Highland pressure and continuous food demand are the major causes of double cropping and related irrigation in agricultural lands here. The salt content of the soil has also been increasing due to intense irrigation which paves the path for soil degradation.

Uncultivated Land Barren land, fallow land, cultivable waste land all are categorized as uncultivated land. The increasing population pressure needs more and more returns from the land. The uncultivable land is unable to meet these demands, cause desertification (Kosmas et al. 2014). The rising problem of increasing land abandonment and the increase in the extent of uncultivable land has led to a vicious cycle of degraded land production (Barbier 1997). The economic development of any country depends on the uncultivated land ratio to the total land. Undulating plateau, extended plateau ridge, residual hills are the major fallow lands in upper reaches of the Silabati basin (Fig. 3i). Undulating upland and lateritic cap areas are the major uncultivated areas in middle reaches of the basin. All these categories of land decrease the land value and increase land degradation.

Multiplication of different factors, which was discussed above, has assessed the different anthropogenic factor-induced land degradation status of the basin. It shows high vulnerability in lower reaches of the basin (Fig. 3j). High population pressure, large agriculture land, high irrigation in lower reaches of the basin causes high land degradation vulnerability of the basin in comparison to the upper reaches of the basin.

4.3 Land Degradation Vulnerability of Silabati Basin

The multiplication of different rasters of Physical vulnerability index for land degradation and anthropogenic vulnerability index for land degradation has given the result of land degradation vulnerability. All the factor rasters has been created through remote sensing and GIS techniques and limited field checks. The results have been cross-checked from previous studies (Bhunia et al. 2012; Ghosh 2015; Halder 2013; Jha and Kapat 2011). Though there may be some distortion in result from the actual field condition, the major areas of the degraded lands of the basin have been identified. In Silabati basin very high land degradation vulnerability (>150) is seen across the plateau extending (Fig. 4) to the lower reaches of the basin. Sandipan Ghosh et al. (2011) have described how soil erosion has created high gully erosion in these areas. The study of Khatun and Debnath (2014) shows the increasing growth of wastelands in this area of the basin. It covers 770 km^2 or 21.50% (Table 3) of the total area of the basin. The

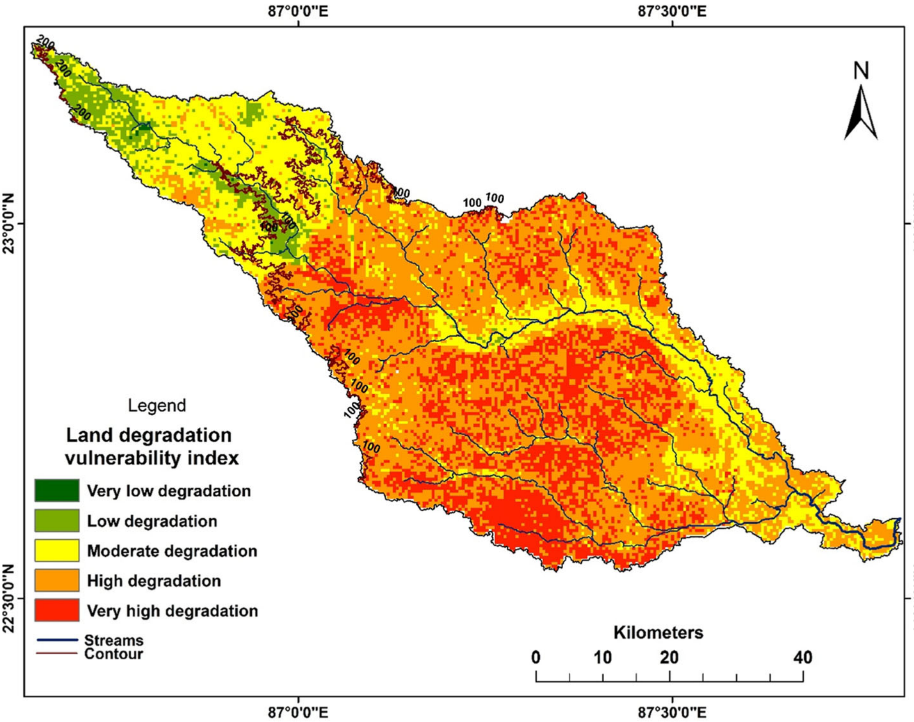

Fig. 4 Land degradation vulnerability of Silabati basin

floodplain areas are prone to soil erosion, low vegetation cover, high population density, agricultural population, and dependent population with intensive agriculture creates very high land degradation vulnerability (Shit et al. 2015). Different anthropogenic factors have created greater vulnerability for land degradation (Khan and Bisai 2013). The high land degradation vulnerability (140–150) (Table 3) areas are concentrated in large in the middle and lower plain areas of the basin. Land use land cover (LULC) change is the prime factor for land degradation vulnerability in this area (Halder 2013). Increasing population and related land use changes are common in these areas which results into land degradation vulnerability. Occasional gully erosion in high slope areas also contribute to land degradation (Ghosh 2015), which covers 1730 km^2 or 48.20% of the total area of the basin. The medium slope with undulating topography, high drainage density and large deforestation creates threats of degradation. The medium land degraded vulnerability area (130–140) covers 910 km^2 or 25.36% of the total area, distributed in upper reaches of the basin. Groundwater decline is a major problem in this

Table 3 Area of different land degradation vulnerability index of Silabati basin

Land degradation vulnerability index	Value	Area (sq.km.)	Area (%)
Very low degradation	<120	3	0.09
Low degradation	121–130	175	4.85
Moderate degradation	131–140	910	25.36
High degradation	141–150	1730	48.20
Very high degradation	>150	770	21.50

area (Nag and Ghosh 2013). Low population pressure decreases the land degradation vulnerability in these areas.

5 Conclusions

Land degradation is a major concern in the present world, especially in the developing countries of Asia and Africa. The tropical world with high population density, continuous expansion of agriculture land, intense deforestation and increasing aridity cause intense land degradation. Extratropical areas have faced land degradation due to intense industrialization related soil pollution, large forest land degradation, increasing soil salinity due to heavy uses of chemicals, etc. The land degradation vulnerability has been assessed by multiplying of different physical and anthropogenic factor maps. Hence, studies have been conducted on remote sensing and secondary data. Results have been cross-checked with previous studies on the same basin. Remote sensing and GIS tools play an important role in generating the factor maps. The results show that the lower reaches of the Silabati basin are prone to high degradation vulnerability due to high population pressure related to anthropogenic factors and existence of undulating laterite cap rocks. It is hard to overcome the physical processes of degradation, but suitable management, like strip cropping and less land pressure can overcome the land degradation vulnerability. The conservationists should implement effective land management strategies in the catchment areas to sustain the environment.

References

Abu HA, Tumeizi A (2012) Land degradation: socioeconomic and environmental causes and consequences in the Eastern Mediterranean. Land Degrad Dev 23(3):216–226. doi:10.1002/ldr.1069

Ajai RR, Arya AS, Dhinwa PS, Pathan SK, Ganesh RK (2009) Desertification/land degradation status mapping of India. Curr Sci 97(10):1478–1483

Arnau-rosalen E (2007) Land use change and land degradation in southeastern Mediterranean Spain. Environ Manag 40(1):80–94. doi:10.1007/s00267-004-0059-0

Askari MS, Cui J, O'Rourke SM, Holden NM (2015) Evaluation of soil structural quality using VIS-NIR spectra. Soil Tillage Res 146:108–117. doi:10.1016/j.still.2014.03.006

Avni Y (2016) Characterization of land degradation processes using airborne laser scanning. Remote Sens Spat Inf Sci XXXVIII:883–888

Ayoub AT (1998) Extent, severity and causative factors of land degradation in the Sudan. J Arid Environ 38(3): 397–409. doi:10.1006/jare.1997.0346

Bajocco S, Angelis AD, Perini L, Ferrara A, Salvati L (2012) The impact of land use/land cover changes on land degradation dynamics: a Mediterranean case study. Environ Manag 49(5):980–989. doi:10.1007/s00267-012-9831-8

Barbier EB (1997) The economic determinants of land degradation in developing countries. Philos Trans R Soc B: Biol Sci 352(1356):891–899. doi:10.1098/rstb.1997.0068

Bhunia GS, Samanta S, Pal DK, Pal B (2012) Assessment of groundwater potential zone in Paschim Medinipur District, West Bengal – a meso-scale study using GIS and remote sensing approach. J Environ Earth Sci 2(5):41–59

Bielli C, Berhanu G, Isaias A, Orasi A (2011) Population growth and environment in Ethiopia: in-depth studies from 1994 population and housing census in Ethiopia. Italian Multi-Bi Research Project ETH/92/P01" 2001 (October): 1–73. http://www.irpps.cnr.it/etiopia/sito/progetto7.htm

Brandt JS, Townsend PA (2006) Land use - land cover conversion, regeneration and degradation in the high elevation Bolivian Andes. Landsc Ecol 21(4):607–623. doi:10.1007/s10980-005-4120-z

Cesar J, Andrade EMD, Henrique P, Medeiros A, João M, Guerreiro S, Araújo H, Palácio DQ (2017) Effect of rainfall characteristics on runoff and water erosion for different land uses in a tropical semiarid region. Water Resour Manag 31(1):173–85. doi:10.1007/s11269-016-1517-1

Chabrillat S (2016) Land degradation indicators : spectral indices. Ann Arid Zone 45(3&4):331–354
Coelho C (2014) Evaluation and selection of indicators for land degradation and desertification monitoring: types of degradation, causes, and implications for management. Environ Manag. doi:10.1007/s00267-013-0110-0
Dedewanou M, Binet S, Rouet JL (2015) Groundwater vulnerability and risk mapping based on residence time distributions: spatial analysis for the estimation of lumped parameters. Water Resour Manag 29: 5489–5504. doi:10.1007/s11269-015-1130-8
Deshar BD (2013) An overview of agricultural degradation in Nepal. Glob J Econ Soc Dev 3(1):1–20
Dewan AM, Yamaguchi Y (2009) Land use and land cover change in greater Dhaka, Bangladesh: using remote sensing to promote sustainable urbanization. Appl Geogr 29(3):390–401. doi:10.1016/j.apgeog.2008.12.005
El-gammal MI, Ali RR, Samra RMA (2015) GIS-based land degradation risk assessment of Damietta governorate, Egypt. Egypt J Basic Appl Sci 2(3):183–189. doi:10.1016/j.ejbas.2015.01.001
Faour G, Council N (2016) Detection and mapping of loong-term land degradation and desertification in Arab Region using Modersat. Lebanese Sci J 15(2):119–131
Fares A, Giri C, Govil K, Hartemink A, Holmgren P, Keita-ouane F, Warren A (2014) Drivers of land use change. States and Trends of the Environment: 1987–2007. Land 1–34
Fei L, Shuwen Z, Jiuchun Y, Kun B, Qing W, Junmei T, Liping C (2015) The effects of population density changes on ecosystem services value: a case study in Western Jilin, China. Ecol Indic 61:328–337. doi:10.1016/j.ecolind.2015.09.033
Feoli E, Vuerich LG, Woldu Z (2002) Processes of environmental degradation and opportunities for rehabilitation in Adwa, Northern Ethiopia. Landsc Ecol 17:315–325
Frankl A, Poesen J, Haile M, Deckers J, Nyssen J (2013) Quantifying long-term changes in gully networks and volumes in dryland environments: the case of Northern Ethiopia. Geomorphology 201:254–263. doi:10.1016/j.geomorph.2013.06.025
Franzmeier DP (1994) Soil color. Geoderma 63(3–4):318. doi:10.1016/0016-7061(94)90080-9
Ghosh S (2015) Mapping and monitoring of the impact of gully erosion in the district of Medinipore (West), West Bengal , India. Int J Novel Res Hum Soc Sci 2(4):73–89
Ghosh S, Maji T, Uday M (2011) Pedo Geomorphic analysis of soil loss in the lateritic region of Rampurhat I block of Birbhum district , West Bengal and Shikaripara block of Dumka district , Jharkhand. Int J Environ Sci 1(7):1734–1751
Girmay G, Singh BR, Nyssen J, Borrosen T (2009) Runoff and sediment-associated nutrient losses under different land uses in Tigray, Northern Ethiopia. J Hydrol 376(1–2):70–80. doi:10.1016/j.jhydrol.2009.07.066
Gour D, Soumendu C, Nilanjana DC (2014) Weathering and mineralogical alteration of granitic rocks in Southern Purulia District, West Bengal, India. Int Res J Earth Sci 2(4):1–12
Grepperud S (1996) Population pressure and land degradation: the case of Ethiopia. J Environ Econ Manag 30(1):18–33. doi:10.1006/jeem.1996.0002
Guillaume T, Mareike A, Damris M, Brümmer B, Kuzyakov Y (2016) Agriculture, ecosystems and environment soil degradation in oil palm and rubber plantations under land resource scarcity. Agric Ecosyst Environ 232: 110–118. doi:10.1016/j.agee.2016.07.002
Halder JC (2013) Land use / land cover and change detection mapping in Binpur- II Block , Paschim Medinipur District, West Bengal: A remote sensing and GIS perspective. IOSR J Hum Soc Sci 8(5):20–31
Hao AM, Watanabe T, Haraguchi T, Nakano Y (2009) Effects of land use on soil physical and chemical properties of sandy land in Horqin, China. From Headwaters to the Ocean: Hydrological Changes and Watershed Management. CRC Press, Kyoto, p 123–127
Harte J (2007) Human population as a dynamic factor in environmental degradation. Popul Environ 28(4–5): 223–236. doi:10.1007/s11111-007-0048-3
Higginbottom T, Symeonakis E (2014) Assessing land degradation and desertification using vegetation index data: current frameworks and future directions. Remote Sens 6(10):9552–9575. doi:10.3390/rs6109552
Hill J, Stellmes M, Udelhoven T, Röder A, Sommer S (2008) Mediterranean desertification and land degradation mapping related land use change syndromes based on satellite observations. Glob Planet Chang 64:146–157. doi:10.1016/j.gloplacha.2008.10.005
Hogeboom RHJ, Oel PRV, Krol MS, Booij MJ (2015) Modelling the influence of groundwater abstractions on the water level of Lake Naivasha, Kenya under data-scarce condition. Water Resour Manage 29:4447–4463. doi:10.1007/s11269-015-1069-9
Ibáñez J, Contador JFL, Schnabel S, Fernández MP, Valderram JM (2014) A model-based integrated assessment of land degradation by water erosion in a valuable Spanish rangeland. Environ Model Softw 55:201–213. doi:10.1016/j.envsoft.2014.01.026
Ibrahim Y, Balzter H, Kaduk J, Tucker C (2015) Land degradation assessment using residual trend analysis of GIMMS NDVI3g, soil moisture and rainfall in Sub-Saharan West Africa from 1982 to 2012. Remote Sens 7(5): 5471–5494. doi:10.3390/rs70505471

Jayasree V, Venkatesh B (2015) Analysis of rainfall in assessing the drought in semi-arid region of Karnataka State, India. Water Resour Manage 29:5613–5630. doi:10.1007/s11269-015-1137-1

Jha VC, Kapat S (2011) Degraded lateritic soils cape and land uses in Birbhum district, West Bengal, India. Soc Nat 23:545-558. doi:10.1590/S1982-45132011000300013

Kafle HK, Bruins HJ (2009) Climatic trends in Israel 1970-2002: warmer and increasing aridity inland. Clim Chang 96(1):63–77. doi:10.1007/s10584-009-9578-2

Kakembo V (2001) Trends in vegetation degradation in relation to land tenure, rainfall, and population changes in Peddie district, Eastern Cape, South Africa. Environ Manag 28(1):39–46. doi:10.1007/s002670010205

Karamesouti M, Detsis V, Kounalaki A, Vasiliou P, Salvati L, Kosmas C (2015) Land-use and land degradation processes affecting soil resources: evidence from a traditional Mediterranean cropland (Greece). Catena 132: 45–55. doi:10.1016/j.catena.2015.04.010

Kelly C, Ferrara A, Wilson GA, Ripullone F, Harmer N, Salvati L (2015) Community resilience and land degradation in forest and shrubland socio-ecological systems: evidence from Gorgoglione, Basilicata, Italy. Land Use Policy 46:11–20. doi:10.1016/j.landusepol.2015.01.026

Khan A., Bisai D (2013) Block level assessment of human vulnerability in Paschim Medinipur District , West Bengal. J Bus Manag Soc Sci Res 2(11): 5–11.

Khatun S, Debnath GC (2014) Identification and mapping of wasteland in Birbhum District , West Bengal. Int J Adv Remote Sens GIS 3(1): 713–722.

Kosmas C, Kairis O, Karavitis C, Acikalin S, Alcalá M, Alfama P, Salvati L (2014) An exploratory analysis of land abandonment drivers in areas prone to desertification. Catena 128:252–261. doi:10.1016/j.catena.2014.02.006

Ladisa G, Todorovic M, Trisorio LG (2012) A GIS-based approach for desertification risk assessment in Apulia region, SE Italy. Phys Chem Earth 49:103–113. doi:10.1016/j.pce.2011.05.007

Li F, Zhao Y, Feng P, Zhang W (2015) Risk assessment of groundwater and its application . part I: risk grading based on the functional zoning of groundwater. Water Resour Manage 29:2697–2714. doi:10.1007/s11269-015-0964-4

Mahmoud SH, Alazba AA (2016) Integrated remote sensing and GIS-based approach for deciphering groundwater potential zones in the central region of Saudi Arabia. Environ Earth Sci 75(4):1–28. doi:10.1007/s12665-015-5156-2

Maselli F, Romanelli S, Bottai L, Zipoli G (2003) Use of NOAA-AVHRR NDVI images for the estimation of dynamic fire risk in Mediterranean areas. Remote Sens Environ 86:187–197. doi:10.1016/S0034-4257(03)00099-3

Ministry of Environment and Forestry (2011) Elucidation of the 4 National Report submitted to UNCCD Secretariat. Ministry of Environment and Forest. GOI 1–121. http://envfor.nic.in/sites/default/files/unccd-report_0.pdf

Nag SK, Ghosh P (2013) Delineation of groundwater potential zone in Chhatna Block, Bankura District, West Bengal, India using remote sensing and GIS techniques. Environ Earth Sci 70(5):2115–2127. doi:10.1007/s12665-012-1713-0

Niedertscheider M, Erb K (2014) Land system change in Italy from 1884 to 2007: analysing the North-South divergence on the basis of an integrated indicator framework. Land Use Policy 39:366–375. doi:10.1016/j.landusepol.2014.01.015

Nyssen J, Poesen J, Haregeweyn N, Parsons T (2008) Environmental change, geomorphic processes and land degradation in tropical highlands. Catena 75(1):1–4. doi:10.1016/j.catena.2008.04.010

Omuto CT, Balint Z, Alim MS (2011) A framework fro national assessment of land degradation in the drylands: A case study of Somalia. Land Degrad Dev 25:105-119. doi:10.1002/ldr.1151

Oostrum V (2015) Key processes and factors to mitigate land degradation. Catena 133:453–454. doi:10.1016/j.catena.2015.07.011

Rahman MH (2002) Agricultural land use and land susceptibility in Bangladesh: an overview. Department of Soil, Water and Environment, Dhaka University. http://globalcommunitywebnet.com/GlobalFiles/agriculturallanduse.pdf

Ravera F, Reed MS, Dougill AJ, Gonzalez L, Tarras D (2016) Land degradation assessment through an ecosystem services lens: Integrating knowledge and methods in pastoral semi-arid systems. J Arid Environ 124:205–213

Reddy VR (2003) Land degradation in India: extent, costs and determinants. Econ Polit Wkly 38(44): 4700–4713

Salvati L, Zitti M (2009) The environmental "risky" region: identifying land degradation processes through integration of socio-economic and ecological indicators in a multivariate regionalization model. Environ Manag 44:888–898. doi:10.1007/s00267-009-9378-5

Santamarta JC, Rodríguez-martín J, Merino C, Arraiza MP (2014) Identification of degraded land in the Canary Islands; Tests and Reviews. IERI Proc 8:77–82. doi:10.1016/j.ieri.2014.09.013

Scherr SJ (1996) Land Degradation in the Developing World : Implications for Food, Agriculture and the Environment to 2020 Vision. International Food Policy Research Institute, Washington

Scherr SJ, Yadav S (1997) Land degradation in the developing world: issues and policy options for 2020. Int Food Policy Res Inst 2020:44

Scullion JJ, Vogt KA, Sienkiewicz AA, Gmur SJ, Trujillo C (2014) Assessing the influence of land-cover change and conflicting land-use authorizations on ecosystem conversion on the forest frontier of Madre de Dios, Peru. Biol Conserv 171:247–258. doi:10.1016/j.biocon.2014.01.036

Sergio M, Serrano V, Cabello D, Miquel TB (2015) Drought variability and land degradation in semiarid regions: assessment using remote sensing data and drought indices. Remote Sens 7:5471–5494. doi:10.3390/rs70505471

Shabbir R, Ahmad SS (2015) Use of geographic information system and water quality index to assess groundwater quality in Rawalpindi and Islamabad. Arab J Sci Eng 40(7):2033–2047. doi:10.1007/s13369-015-1697-7

Shit PK, Maiti R (2012) Rill Hydraulics - An experimental study on gully basin in lateritic upland of Paschim Medinipur, West Bengal, India. J Geogr Geol 4(4):1–11. doi:10.5539/jgg.v4n4p1

Shit PK, Nandi AS, Bhunia GS (2015) Soil erosion risk mapping using RUSLE model on Jhargram sub-division at West Bengal in India. Model Earth Syst Environ 1(3):28. doi:10.1007/s40808-015-0032-3

Stéphenne N, Lambin EF (2001) A dynamic simulation model of land-use changes in Sudano-sahelian countries of Africa (SALU). Agric Ecosyst Environ 85(1–3):145–161. doi:10.1016/S0167-8809(01)00181-5

Symeonakis E, Calvo-Cases A, Arnau-Rosalen E (2007) Land use change and land degradation in southeastern Mediterranean Spain. Environ Manag 40(1):80–94. doi:10.1007/s00267-004-0059-0

Tolessa T, Senbeta F, Kidane M (2017) The impact of land use / land cover change on ecosystem services in the central highlands of Ethiopia. Ecosyst Serv 23:47–54. doi:10.1016/j.ecoser.2016.11.010

Waswa BS, Vlek PLG, Tamene LD, Okoth P, Mbakaya D, Zingore S (2013) Evaluating indicators of land degradation in smallholder farming systems of western Kenya. Geoderma 195-196:192–200. doi:10.1016/j.geoderma.2012.11.007

Zuquette LV, Pejon OJ (2004) Land degradation assessment based on environmental geoindicators in the Fortaleza metropolitan region , state of Ceara, Brazil. Environ Geol 45:408–425. doi:10.1007/s00254-003-0892-0