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Land Degradation Mapping in Singhanhalli-Bogur Micro-watershed in Northern Transition Zone of Karnataka through Remote Sensing and GIS Techniques

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Abstract

The study was undertaken to identify and map areas affected by various land degradation through remote sensing and GIS techniques. The study revealed that the major process of land degradation is water erosion. Three types of water erosion, namely sheet, rill and gully erosion were prevalent in different land forms. Sheet erosion accounted for 77.2 %, rill erosion 6.7 % and gully erosion 16.2 % of the study area. The lowlands, majority of which area was under agriculture land use, was observed to be sheet eroded with severity ranging from slight to severe which was attributed to overcutting of vegetation, overgrazing and agricultural activities. Rill erosion was prevalent in undulating midlands under agriculture and open scrub land uses, whereas gully erosion occurred in agriculture and open scrub lands. The moderately degraded lands were observed in all land uses but they were more prominent in agriculture lands on moderate slopes. The severely degraded lands were observed on moderate-to-steep slopes in undulating midlands and uplands. The adoption of soil and water conservation measures was recommended for improve soil productivity and sustaining agricultural production at higher levels. In addition, watershed programmes should be undertaken considering the summarized priority for land treatment.

Key words: Land degradation, Soil Erosion, Singhanhalli-Bogur, Soil Conservation, Microwatershed

Introduction

Land degradation is the "temporary or permanent reduction in the productive capacity of a land as a result of human action". The processes of land degradation have posed a worrisome threat to food security at a time of continuous population growth especially in developing countries. At present, about 20 million km² of land worldwide are affected by reduced productivity due to land degradation. About 21 per cent of the arable area even show signs of strong and extreme degradation; these are "largely, and for most practical purposes irreversibly, destroyed" [1]. Soil erosion by wind and water is the most damaging and widespread form of land degradation and accounts for about 83 per cent of the global degraded land.

As much as 56 per cent of the degraded land is affected by water erosion alone. In India, the problems of land degradation are prevalent in many forms. About 146.8 million ha area is suffering from various kinds of land degradation. This includes 93.7 million ha due to water erosion, 9.5 million ha due to wind erosion and 14.3 million ha due to water logging/flooding [2]. According to [3], India loses about 5334 million tonnes of soil annually due to various reasons.

In recent years, as part of environment and land degradation assessment policy for sustainable agriculture and development, soil erosion has increasingly being recognized as a hazard which is more serious in mountain areas [4]. Land resources available for agriculture are shrinking in India. Most of the soils in rainfed regions are at the verge of degradation having low cropping intensity, relatively low organic matter status, poor soil physical health, low fertility, etc. [5]. Soil erosion is a major process of land degradation and is generally associated with agricultural practices which leads to decline in soil fertility and a series of negative environmental impacts and has become a threat to sustainable agricultural production and water quality in many countries. Singhanhalli-Bogur microwatershed is highly affected by water erosion due to high rates of deforestation and unsustainable land use practices which have intensified due to poor socio-economic status of inhabitants. In addition, the demography in this area is characterized by high poverty, rapid population growth and high illiteracy rates. As a result, this area has undergone several changes in forest/land use as a result of human influence causing degradation of soil resources. Despite these conditions, no research has been conducted to assess land degradation in the study area. Hence, the present study was undertaken in order to identify and map land degradation types by remote sensing and GIS techniques.

Materials and Methods

Description of the study area

Singhanhalli-Bogur micro-watershed is located between 15°31'30.30" to 15°34'49.45" N latitude and 74°50'47.46" to 74°53'35.67" E longitude in Dharwad taluk of Dharwad district in the northern transition zone of Karnataka, India (Fig. 1). The area lies in the Decca plateau in the hot semi-arid agro-ecological region 6 (K4D2) and sub-region 6.4, having medium to high available water content (AWC) with a length of growing period (LPG) of 150-180 days.

The climate is characterized by hot and humid summer and mild and dry winter. The study area receives an annual average rainfall of 755.2 mm, which distributed over May to October and annual temperature ranging from 24 - 28 °C. The study area is classified as having Ustic Soil Moisture and Isohyperthermic soil temperature regimes [6]. The highest elevation is 754 m above mean sea level and the relief is very gently to strongly sloping. The general slope is towards the northeast, southeast and southwest but it is more in the southwest direction. The drainage pattern is parallel.

Soils are derived from chlorite schist with shale as dominant parent material containing banded iron oxide quartzite. The soils are coarse textured and shallow at the higher elevations but gradually fineness and depth increases towards the lower elevations. The main soil types are black and red soils but the red soils are in higher proportion than the black soils. The natural vegetation mainly comprised of trees and shrubs including Acacia (*Acacia auruculiformis*), Neem (*Azadirachta indica*) and Eucalyptus (*Eucalyptus sideroxylon* and *Eucalyptus regnana*).

Source of data

For the mapping of land degradation, the Manual on "Nation-wide Mapping of Land Degradation using Multi-temporal Satellite Data in India" [7] was followed. For delineation and mapping of land degradation classes, IRS P6 LISS-IV image of 2010, acquired from the National Remote Sensing Centre (NRSC), Hyderabad was used. Survey of India toposheet on a 1:50000 scale (No. 48 I/14) was used for field traversing. The flow chart of methodology is presented in Fig. 2.

Ground truth data collection and verification

Satellite image data of IRS P6 LISS-IV was used to address spatial and temporal variability of land degradation. Later, on-screen visual interpretation of different land degradation classes on satellite data showing FCC was done by adopting standard visual interpretation techniques. Sample points were identified for various land degradation classes from interpreted map for ground truth collection and for accuracy assessment. Soil samples were collected from 0-20 cm depth on an 8'x8' grid using a hand held GPS device for recording the latitude-longitude position of the sample points. During the field work, the relationship between image elements (i.e. tone, shape, size, pattern, texture, shadow, and association) and tentatively identified land degradation classes that were delineated during preliminary interpretation were established using visual interpretation techniques. The preliminarily interpreted land degradation maps were finalized in light of ground truth data and soil analysis data to arrive at the final map.

Data preparation and geo-rectification

Data preparation was a primary requirement for interpretation and subsequent analysis. IRS P6 LISS-IV satellite image data provided by NRSC was used for mapping the land degradation classes. The topographic map of the study area was digitized and geo-referenced to a map coordinate system so as to generate spatial information and subsequent use in a GIS environment.

Image enhancement and interpretation

Image enhancement was done essentially for improving the image contrast for better delineation of land degradation types. Image radiometry characteristically varies from one scene to another. Hence, standardization of enhancement was achieved dependent upon the major earth surface elements and the degraded land types that were to be delineated. Image interpretation is defined as the "act of examining images for the purpose of identifying objects or surface features and judging their significance". An image interpretation key for the study area was designed prior to image interpretation, which was further refined in the course of image interpretation. The image interpretation key developed for the study area included collection of annotated/captioned images illustrating features and a graphic or textural description of the systematically recognized image features as recommended by [8]. However, for delineation of severity, the local factors affecting degradation and ground truth were considered along with satellite images.

Interpretation of land degradation types

Using the interpretation key prepared, land degradation classes were delineated by using onscreen image and visual image interpretation procedures. To do this, the various objects on the image were identified and delineated on the image using visual image interpretation based on their tone, shape, size, pattern, texture, shadow, and association. Next, the image was opened in ArcGIS Map and as was done in the case of visual image interpretation, the objects on the image were identified and delineated as polygons. These two sets of objects delineated through visual and on-screen image interpretations were closely compared and the boundaries were refined in ArcGIS Map. These refined polygons represented that various land degradation types in the study area.

Final map preparation and degraded area estimation

The land degradation map was finalized based on ground truth observations and visual interpretations. The map was rechecked for topological and labelling errors. Base map features were overlain and land degradation map was generated on a layout consisting of the title, legend, index map, scale bar and north arrow. Area extent for each land degradation type was calculated.

Results and Discussion

No matter the type of soil erosion in any given location, the consequences, in terms of what is relevant to soil conservation, are two-fold: 1) general decrease in soil fertility (as a result of the action of sheet and/or wind erosion) and 2) diminution of cultivable land as a result of the occurrence and expansion of gullies. The latter consequence has wider implications which include displacement of population following loss of residential houses and farm crops changes in the topography and hydrology of affected areas and disruption of roads [9].

The results of the study indicated that the major process of land degradation in the study area was water erosion. In total, eleven land degradation mapping units were identified and mapped (Table 1 and Fig. 1). Three types of water erosion were identified, namely sheet, rill and gully erosion (Tables 1 and 2). During traversing of the study area, however, other types of land degradation like stony wastes and rocky outcrops were observed but these were negligible because they occur in only very few smaller patches and therefore, their effect in degradation mapping can be ignored [7].

The severity of each water erosion type varied depending on several features such as soil type and properties, slope, land form, land use, etc. The severity of sheet erosion ranged from slight to moderate and severe; rill erosion ranged from slight to moderate, whereas gully erosion ranged from severe to very severe. Similar findings have been reported by [10].

In the lowlands, majority of which area was under agriculture land use, the major type of land degradation was sheet erosion with severity ranging from slight to severe. The prevalence of sheet erosion might be due to overcutting of vegetation, overgrazing and unstainable agricultural activities. It was observed that most of the vegetation removals are not followed by good management practices in the study area. In addition, in agriculture land, the soil cover was not sufficient to withstand the erosive nature of the rainfall especially during the off-season periods. The human components in soil erosion are connected mostly with agricultural practices and other land use activities [1]. Agricultural practices in the majority of farming systems were observed to generally involve the destruction of vegetation by clearing the land for cultivation and by forest fires. These activities might have caused great change in the relative proportions of infiltration and runoff, with the dangers of erosion increasing with increased destruction of vegetation and hence reducing infiltration and increasing runoff [9].

Rill erosion was prevalent in undulating midlands under agriculture and open scrub land uses, whereas gully erosion was prevalent in agriculture and open scrub lands. In open scrubs, land degradation ranged from rill to gully erosion. Sheet erosion accounted for 77.0 per cent; rill erosion 6.7 per cent and gully erosion accounts for 16.3 per cent of land degradation in the study area. About 268.7 ha of study area were under slight erosion, 282.8 ha under moderate erosion, 183.8 ha under severe erosion and 10.2 ha under very severe erosion. With regards to land form/physiography, it was observed that 154.4 ha (20.5 %), 202.2 (27.3) and 389.0 ha (52.2 %) of lowlands, undulating midlands and uplands respectively were undergoing various types of land degradation, whereas based on land uses, 452.2 ha (60.4 %) of agricultural land; 9.5 ha (1.1 %) of forest; 213.6 ha (30.2 %) of plantation and 70.2 ha (8.3 %) of open scrub were under various types of degradation (Table 2). The indirect effect of climate on soil erosion was manifested through the medium of vegetation. Areas under effective cover of vegetation were more prone to sliding and slumping (provided that the gradient is steep enough) as they were characterized more by infiltration than by surface runoff, while bare surfaces encouraged runoff resulting to sheet and rill erosion and gullying.

The moderately degraded lands were observed in all land uses but they were more prominent in agriculture and forest on moderate slopes. The agriculture areas appeared grey-to-dark grey in tone; medium to coarse in texture and irregular in pattern on gently to moderately steep slopes from the satellite image, whereas forests were red-to-bright red in tone; smooth in texture and irregular in pattern especially on higher slopes. This was the most dominant land degradation category occupying about one third of the study area of the microwatershed i.e., 282.8 ha, which is 37.9 per cent of the total area. [11] obtained similar results in the Upper Catchment of River Tons.

The severely degraded lands were observed on moderate-to-steep slopes on undulating midlands and uplands. Depending on the slope, these patches appeared light brown in tone; smooth –to-medium and medium-to-coarse-to-fine texture and irregular in pattern. It was observed that this category of land degradation occupied 183.8 ha, which was 24.7 per cent of the study area. The very severely degraded lands which included gullies were light yellowish-to-brown-to-cyan in tone; medium-to-coarse in texture and irregular in pattern on moderately steep-to-steep slopes in undulating midlands and uplands. As evident from results stated in Table 2, this category of land degradation occupied 10.2 ha, which was 1.4 per cent of the study area. This could be attributed to inadequate cover of vegetation on steeper slopes [10]. Surface configuration (relief/slope) aids runoff, sheet erosion and gullying. Sheet erosion was common over fairly uniform and gentle slopes, while gullying was more characteristic of steeper slopes. It was observed, however, that gullying also takes place on very gentle slopes and this was even more common on such gentle slopes than on very steep ones. For one thing, runoff requires such gentle slopes to be concentrated and concentrated runoff is a prerequisite for gullying [9].

The findings of the study revealed that water erosion in the cultivated and other disturbed areas was a major process leading to land degradation in the study area. This emphasizes the importance of soil and the need for conservation practices not only to sustain the production but also to minimize the process of siltation of downstream reservoirs in the study area. The removal of land covers on high slopes and cultivation without proper soil conservation measures might have led to severe erosion and uprooting of trees. Normally, gullies and large-scale soil movement could be eminent under such conditions. This calls for effective anti-degradation measures to be adopted in the study area.

Priority for land treatment in Singhanhalli-Bogur microwatershed

Even with similar climatic, topographic and vegetative conditions, different soils may erode at different rates. These differences in erosion rates may be tenfold and are caused by differences in soil characteristics. Based on the findings of the study, priority for land treatment was suggested as given in Table 3. Priority fixing was done on the basis of type and severity of degradation. The three major types of land degradation in the study area were sheet, rill and gully erosion. Within these three types of land degradation, highest priorities for soil conservation treatments were given to mapping units having gullies that were very severe and lowest priority to mapping units with sheet erosion that were slight.

Based on these assumptions, the following prioritization model for land treatment has been suggested for the study area:

- Mapping units with very severe gully erosion should be given priority I;
- Mapping units with severe gully erosion should be given priority II;
- Mapping units with moderate gully erosion should be given priority III;
- Mapping units with moderate rill erosion should be given priority IV;
- Mapping units with slight rill erosion should be given priority V;
- Mapping units with severe sheet erosion should be given priority VI;
- Mapping units with moderate sheet erosion should be given priority VII; and
- Mapping units with slight sheet erosion should be given priority VIII.

Conclusion

The major process of land degradation in the study area was water erosion. Three types of water erosion, namely sheet, rill and gully erosion are prevalent in different land forms in the study area. The lowlands are slight to severely sheet eroded due to overcutting of vegetation, overgrazing and unstainable agricultural activities. Rill erosion was prevalent in undulating midlands under agriculture and open scrub land uses, whereas gully erosion was prevalent in agriculture and open scrub lands. The moderately degraded lands were observed in all land uses but they were more prominent in agriculture and forest on moderate slopes. The severely degraded lands, which were attributed to less vegetation cover, were observed on moderate-to-steep slopes in undulating midlands and uplands. The soil loss can be brought to within the safe limit if watershed development programmes are implemented successfully by following the suggested prioritization model and adoption of scientific farming in safer zones. Singhanhalli-Bogur microwatershed was observed to be one of the few micro-watersheds in Karnataka state where diversification of crops by farmers is increasing embraced and the area could be highly suitable for various types of agroforestry. This effort by farmers to diversify their farming systems should be given attention by concerned authorities so that the essence of diversification would aim at providing a permanent cover to the land surface. Presently, the average annual yield of major crops in the study area seemed lower than surrounding areas. The adoption of soil and water conservation measures would improve the soil productivity and help in sustaining the agricultural production at higher levels in the study area. Watershed programmes should be undertaken considering the summarized priority for land treatment.

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Table 1. Land degradation mapping units and their extent of coverage

Land degradation mapping unit	Area	
	(ha)	% of study area
Wsh010201	132.5	17.8
Wsh010301	107.0	14.4
Wsh010302	21.7	2.9
Wsh020201	210.5	28.2
Wsh030301	103.1	13.7
Wri010301	24.5	3.3
Wri010304	14.8	2.0
Wri020201	10.5	1.4
Wgu020301	10.1	1.4
Wgu030101	79.9	10.7
Wgu040104	30.9	4.2

Interpretation of land degradation mapping units

Mapping unit	Degradation type	Severity	Land form	Land use
Wsh010201	Sheet erosion (sh)	Slight (01)	Undulating (02)	Agriculture (01)
Wsh010301	Sheet erosion (sh)	Slight (01)	Lowland (03)	Agriculture (01)
Wsh010302	Sheet erosion (sh)	Slight (01)	Lowland (03)	Forest (02)
Wsh020201	Sheet erosion (sh)	Moderate (02)	Undulating (02)	Agriculture (01)
Wsh030301	Sheet erosion (sh)	Severe (03)	Lowland (03)	Agriculture (01)
Wri010301	Rill erosion (ri)	Slight (01)	Lowland (03)	Agriculture (01)
Wri010304	Rill erosion (ri)	Slight (01)	Lowland (03)	Open scrub (04)
Wri020201	Rill erosion (ri)	Moderate (02)	Undulating (02)	Agriculture (01)
Wgu020301	Gullies (gu)	Moderate (02)	Lowland (03)	Agriculture (01)
Wgu030101	Gullies (gu)	Severe (03)	Upland (01)	Agriculture (01)
Wgu040104	Gullies (gu)	Very severe (04)	Upland (01)	Open scrub (04)

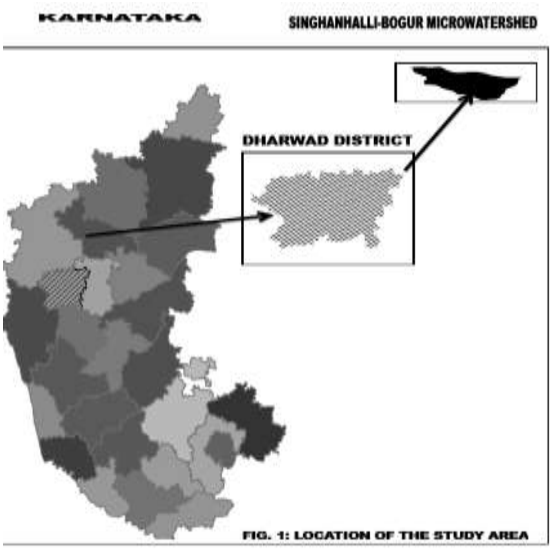

FIG. 1: LOCATION OF THE STUDY AREA

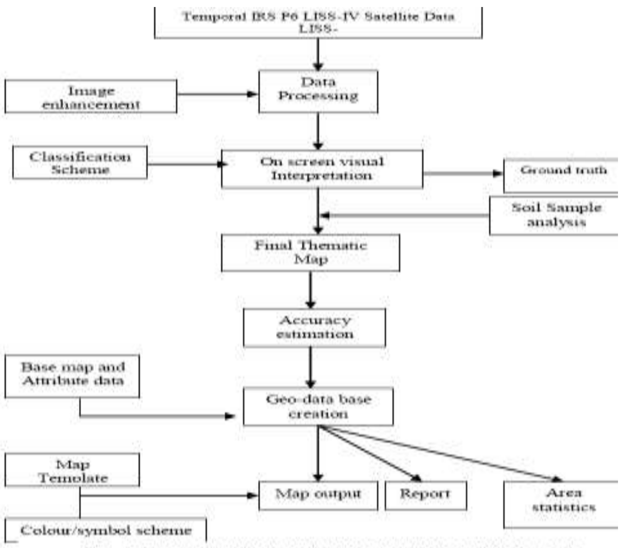

FIG. 2: FLOW CHART OF METHODOLOGY FOR MAPPING LAND

Table 2. Status of land degradation in Singhanhalli-Bogur micro-watershed

Type-wise land degradation

Type of erosion	Area (ha)	%
Sheet	573.9	77.0
Rill	49.7	6.7
Gully	121.9	16.3
Total	745.5	100

Severity-wise land degradation

Severity/degree	Area (ha)	%
Slight	268.7	36.0
Moderate	282.8	37.9
Severe	183.8	24.7
Very severe	10.2	1.4
Total	745.5	100

Landform-wise land degradation

Type of land form/physiography	Area (ha)	%
Lowland	154.3	20.5
Undulating midland	202.2	27.3
Upland	389.0	52.2
Total	745.5	100

Landuse-wise land degradation

Type of land use	Type of land degradation						Total (ha)	%
	Sheet erosion		Rill erosion		Gully erosion			
	Area (ha)	%	Area (ha)	%	Area (ha)	%		
Agriculture	276.0	44.8	34.8	4.7	81.0	10.9	452.2	60.4
Forest	8.4	1.1	-	-	-	-	9.5	1.1
Plantation	171.1	28.5	12.3	1.7	-	-	213.6	30.2
Open scrub	19.6	2.7	2.5	0.3	39.8	5.3	70.2	8.3
Total	475.1	77.1	49.6	6.7	120.8	16.2	745.5	100

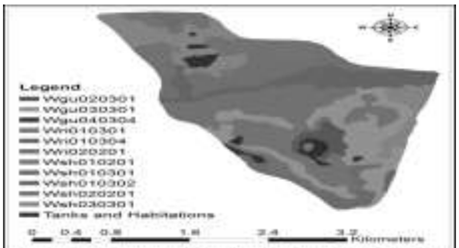

Fig. 1: Land degradation mapping units of Singhanhalli-Bogur microwater

Table 3.Priority for land treatment in Singhanhalli-Bogur microwatershed

Land degradation mapping unit	Priority for land treatment (Ranking)
Wgu040304	I
Wgu030301	II
Wgu020301	III
Wri020201	IV
Wri010301	V
Wri010304	V
Wsh030301	VI
Wsh020201	VII
Wsh010201	VIII
Wsh010301	VIII
Wsh010302	VIII