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Geomorphological Analysis for Inventory of Degraded Lands in a River Basin of Basaltic Terrain Using Remote Sensing and GIS

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ABSTRACT

In recent years, the use of remotely sensed data and Geographic Information System (GIS) applications has been found increasing in a wide range of resources inventory, mapping, analysis, monitoring and environmental management. Remote sensing data provides an opportunity for better observation and systematic analysis of terrain conditions following the synoptic and multi-spectral coverage. In the present study, the geomorphological analysis reveals that various denudational and depositional landforms have been analysed and mapped. The soil depth ranges from extremely shallow in isolated mounds to very deep in the pediplains. Based on the slope gradient, morphometry, soil depth, vegetation cover and image characteristics of standard FCC imagery of IRS-1D LISS-III data, four categories of eroded lands i.e., very severe, severe, moderate and nil to slight have been identified and mapped. The integrated analysis of slope, geomorphology and degraded lands layers in GIS revealed that the pediplains, rolling plains and subdued plateau are associated with very severe land degradation and accounts for 6.05%, 3.85% and 3.47% of total area respectively. The analysis of percentage of degraded lands at geomorphic sub unit level indicates that severe land degradation process is dominant in the dissected ridges, isolated mounds, escarpments and plateau spurs. The remote sensing data and GIS based detailed geomorphological and degraded lands analysis ensure better understanding of landform-eroded lands relationship and distribution to assess the status of land degradation at micro geomorphic unit for reclamation, geo-environmental planning and management. Similar study also helps in the areas of natural resource management, environmental planning and management, watershed management and hazards monitoring and mitigation.

Introduction

India ranks very high among the developing countries in respect of both in extent and severity of land degradation (Yadav, 1996). The data on the nature, extent and kinds of degraded lands of the country have been projected by various agencies from time to time (National Commission on Agriculture, 1976; Bhumbla and Khare, 1984; Govt. of India, 1994; Sehgal and Abrol, 1994). In India, degraded lands, i.e., eroded lands, salt-affected soils, waterlogged area, ravine lands, area of shifting cultivation and lands affected by toxic elements of industrial

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wastes are either lying waste or are being partially utilized, which are estimated nearly 175 million hectares (Das, 1985). Methods of qualitative assessment of land degradation stressed the need to encompass the combined effects of terrain attributes to identify and demarcate these zones that are relatively under various types of degradation and need priority conservation measures (Rajeev *et al.,* 1985; Gawande, 1989). However, the information on accurate spatial distribution and extent remains major issue in management of degraded lands.

Detailed geomorphological mapping is one of the principle means of studying the morphology, genesis, distribution and age of forms, which in turn helps to interpret the geomorphic history of any evolved landscape. The detailed analysis of landforms is an important aspect of any environmental or resource analysis and planning (Blarzcsynski, 1997). Geomorphological survey is primarily concerned with the classification and mapping of relief forms through differentiation of morphographic patterns with respect to their genesis and processes (Padhi *et al.,* 1994). The synoptic coverage and high precision of remotely sensed data coupled with marked cost effectiveness and time efficiency in data acquisition and analysis procedures have made geomorphological mapping an extremely effective tool for management of natural resources and environment (Srinivasan, 1988).

Until recently, conventional surveys using cadastral maps and topographical sheets had been the traditional processes to assess the land degradation due to erosion. These processes are tedious, time consuming and error prone, especially in rugged or inaccessible terrain (Sujatha *et al.,* 2000). The advent of remote sensing technology has paved the way to gather information about the earth's resources more accurately (Colwel, 1978; Karale *et al.,* 1988). A wide variety of satellite data from Landsat-TM, SPOT and IRS series is available for the preparation of geomorphological and land resources maps at different scales. Analysis of satellite data in conjunction with drainage, lithology, land use/land cover and collateral data, facilitate effective evaluation of geomorphological conditions and status of degraded lands. These data sets in the core of GIS provide an excellent means of spatial data analysis and interpretation. It also provides a powerful mechanism, not only to monitor degraded lands and environmental changes, but also permits the analysis of information of the other environmental variables (Marble *et al.,* 1983). In the present study, an attempt has been made to ascertain the nature, extent and spatial distribution of degraded lands in the river basin of a basaltic terrain based on basin morphometry, geomorphology and land use/land cover conditions using remote sensing and GIS techniques.

Study Area

The study area Vena river basin is located between 20°45' 18" to 21°13' North latitudes and 78°42' to 79°08' 44" East longitudes and is located in western part of Nagpur district, Maharashtra with an area of about 1153 km^2 (8.6 % of the total geographical area of the district) (Fig. 1). The climate is mainly semi-arid (moist) sub-tropical type with mean annual temperature of 27°C and mean annual rainfall of 1120mm.

Methodology

Data Preparation

The IRS-ID LISS-III digital data of the study area was obtained for the period of November 8, 1999 and March 7, 2000. The images were georeferenced in EASI/PACE image analysis system using image to map registration algorithm. The ground control points (GCP's) common to the map and image were identified to register the image at sub-pixel accuracy using second order polynomial transformation. The digitally registered images were subsequently analysed to generate different thematic maps.

Data Generation

Digital Elevation Model (DEM) was

Fig. 1. Location map of the study area

generated from the contour lines and slope was computed in SPANS GIS version 7.0. Various terrain features were analysed using remotely sensed data in conjunction with drainage and contour elevations. Visual interpretation techniques have been followed in generation of lithology (rock types) geomorphology (landforms) and degraded lands thematic maps based on the tone, texture, shape, drainage pattern, color and differential erosion characteristics of the satellite imagery. The lithological analysis of the study area has been carried out through visual interpretation of the satellite data in conjunction with geological map generated by Geological Survey of India (GSI, 1978). Subsequently detailed geomorphic units were delineated with the help of relief, morphometry and image characteristics. The soil depth map of the study area was generated based on the delineated geomorphic units and available soil survey information of Nagpur district (Anonymous, 1990). The land use/land cover information was generated using standard digital image analysis processes and field observation. Besides natural precipitation, the eroded lands in a given location are manifestations of existing

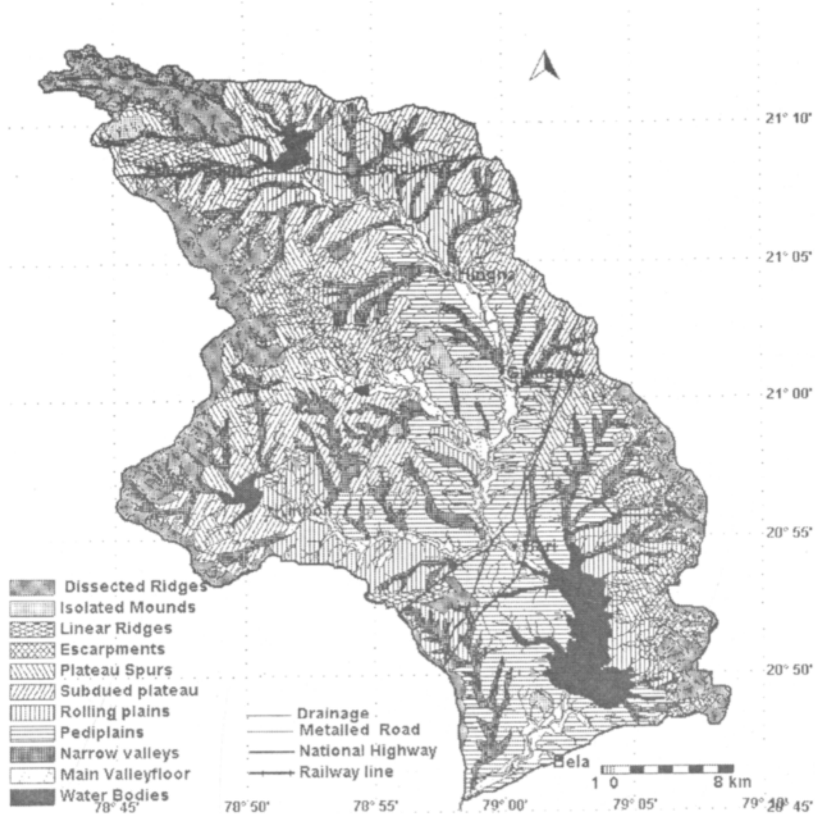

Fig. 2. Geomorphology of Vena basin

slope, drainage conditions, geomorphological processes, soils and land use/land cover conditions. Hence, the image characteristics in association with slope, lithology, geomorphology, morphometry and land use/land cover conditions were taken into consideration in delineation of the degraded lands units with suitable image enhancement techniques in EASI/PACE image analysis system.

Data Analysis in GIS

The digitized vector layers were imported in SPAN GIS version 7.0. The thematic layers of slope, lithology, geomorphology and degraded lands were generated. The geomorphology and degraded lands layers were integrated in GIS using multi-layer overlay analysis technique to find out the status of degraded lands at each geomorphic sub unit. The relationship between degraded land classes and associated parameters of i.e., slope, morphometry, geomorphological processes, soil depth and land use/land cover conditions were analyzed. The selected degraded land units were verified in the ground and found in association with the defined characteristics.

Results and Discussion

Physiography

Three distinct physiographic units of the terrain have been identified based on the analysis of remotely sensed data. Geologically the study

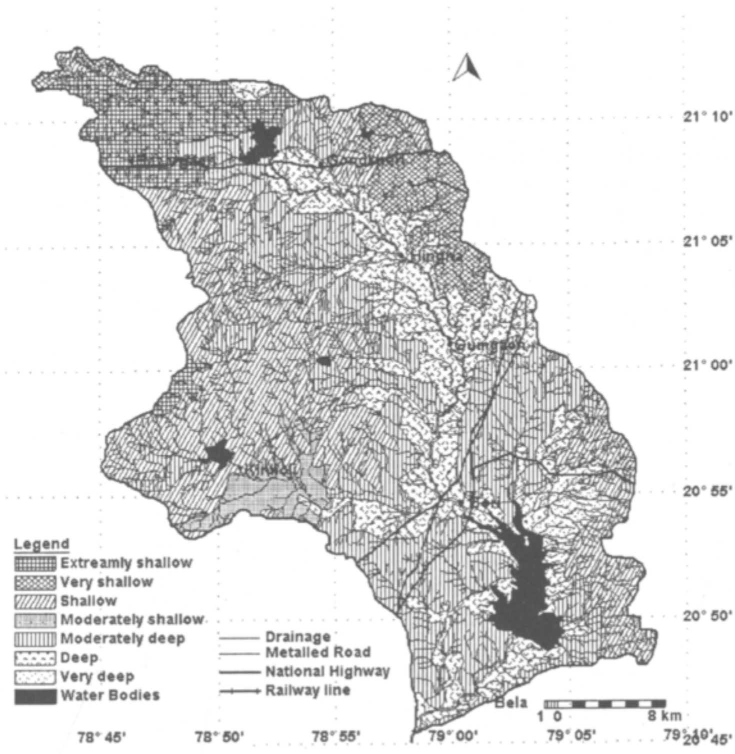

Fig. 3. Soil depth of Vena basin.

area is of basaltic origin and influenced by the actions of various fluvio-morphological processes. Dissected hills of the Deccan lava flow origin are observed in the northern and western and south eastern parts with an elevation ranging from 400 to 520 m above mean sea level (msl). The subdued landscape occupies the intermediate zone of dissected hills and plains with an elevation ranging from 300 to 400 m above msl. The plains are depositional in nature and extend from north to south with an elevation ranging from 240 to 300 m above msl. The isolated mounds are noticed as relict landforms by the actions of various denudational processes.

Slope

The majority of the area is under nearly level to level slopes (0-1%) accounting 52.1% of the study area. The area in association with level plains, occupies the central and southern parts of the area. The foot slopes of the uplands and valley plains in the undulating terrain are having very gentle slopes (1-3%) and accounts for 14.6% of the study area. Gentle slopes (3-5%) coincides with undulating terrain and intermittent valley zones in northern, north-western, western and south-eastern parts with an area of about 7.5% of the study area.

The moderate slope areas (5-10%) are in association with rolling plains and occupies the north-western, western and south-eastern parts with an area of about 9.63%. The strong slopes (10-15%) occupying in the western, north-western and south-eastern parts of the area in association with foot slopes of escarpments and denudational hills with an area of about 4.8%. Steep slope gradients (15-30%) are characterized with dissected ridges, isolated mounds in the western, north-western and south-eastern parts of the area with an area of about 5.9%. The very steep slopes (>30%) are in association with neck of dissected ridges, plateau spurs and escarpments with an area of about 2.1% of the study area. The water bodies are occupied nearly 3.5% of the area of the basin.

Lithology

Deccan basalts

Nearly 90% of the study area is covered by basaltic lava flows. Depending upon the rate of cooling and thickness of the basaltic flow resulted some hard and compact layers. While others are soft, vesicular with minor cavities filled with secondary quartzes, calcite, zeolite, etc. At places, columnar formations are observed in hard compact dark basalts. The terrain consist of sub-rounded to rounded, tabular rock fragments ranging from small pebble to boulders of dark grayish black basalt, gray vesicular basalt in an uncomposed matrix of coarse to fine sand, silt and clay.

Sandstone

The isolated pocket in the northern part of the study area is under sandstone formations. The foot slopes are marked by the development of alluvial and colluvial deposits and consist of coarse fragments admixed with fine sand and silt. It occupies nearly 5.5% of the study area.

Alluvium

The younger alluvium overlaid on the basaltic parent material represents flood plain deposits and are restricted to channel courses and low land areas. Predominantly, it consists of sandy clay soils with unsorted boulders, cobbles and pebbles. Occasionally, the calcareous layers are underlain with alluvial deposits. The upper horizons are clayey in nature, followed by silt in the lower horizons and often contain thin layers of fine sand and calcareous layers resting on basalt parent rock.

Geomorphological Analysis

Geomorphological processes are generally complex and reflect inter-relationship among the variables such as climate, geology, soils and vegetation (Buol, 1973). The Deccan trap basaltic complex, which is presumed to have gone through various denudational processes causing the various physiographic entities are the remanents of the "landscape reduction process" retained after several erosional cycles (Subramanyan, 1981). In the present study, landforms have been analysed based on the satellite image characteristics and geometry of relief forms in terms of crest types, valley side/ ground slope element and shape of valley floors (Table 1). The geomorphic units distinctly separated each other by topographic change in slope segments similar to the morphological mapping techniques (King, 1962; Savigear, 1965 and Dalrymple, 1968). The delineated geomorphic units have been broadly grouped into denudational and depositional origin (Fig. 2).

Denudational Landforms

The fluvio-denudational geomorphological processes are actively involved in landscape reduction process. The physio-chemical and biological weathering and multiple slope dissections under the influence of steep slopes, high drainage density pattern and precipitation conditions lead to the development of ridge-valley land systems in the western part of the area. Mass wasting in the form of creep and debris fall are common processes of land erosion along the scarp slopes and escarpments. Dissected ridges, isolated mounds, linear ridges, escarpments and plateau spurs have been identified and mapped under denudational landforms.

G1. Dissected ridges

The unit forms a broad zone of hilly

Table 1: Image characteristics and physical properties of different geomorphic units

S.No.	*Geomorphic Unit*	*Tone/ Colour*	*Texture*	*Shape and Size*	*Pattern*	*Association*	*Slope*	*Drainage*		*Soil depth*	*Soil texture*	*Present land use*
								Pattern	*Density*			
1	Dissected Ridges	Brown to dark red	Coarse	Irregular and elongated	Elongated	Valleys	Moderately steep	Den-tritic	>3.0	Very Shallow-shallow	Gravelly Sandy Clay loam	Forest
2	Isolated mounds	Brown to light red	Coarse	Circular to elon-gated	Isolated	Dissected ridges	Moderately steep	Radial	2.5-3.0	Shallow	Gravelly Sandy Clay loam	Forest and scrubs
3	Linear ridges	Light to dark red	Coarse	Linear	Linear	Dissected ridges	Strong	Radial	2.5-3.0	Shallow	Sandy loam	Scrubs and waste lands
4	Escarpments	Brown to light red	Coarse	Irregular and elongated	Contigu-ous	Plateau spurs	Strong	Den-tritic	2.0-2.5	Shallow-Moder-ately Shal-low	Clay loam	Scrub forest
5	Plateau spurs	Light red	Coarse	Irregular	Contigu-ous	Escarpments	Moderately steep	Sub-parallel	2.0-2.5	Moder-ately Shal-low	Clay loam	Scrub forest
6	Subdued Plateau	Bright white and gray	Medium	Irregular and widespread	Scattered	Rolling plains and narrow valleys	Moderate to Gentle	Den-tritic	1.5-2.0	Moder-ately deep	Clay loam-loam	Waste lands
7	Rolling plains	Bright white *to brown*	Medium	Irregular and *widespread*	Scattered	Subdued plateau and narrow val-leys	Gentle	Sub-parallel	1.0-1.5	Deep	Clay	Crop & Current fallows
8	Pediplains	Brown to dark	Fine	Irregular and elongated	Scattered	Main valley floor	Very gentle to gentle	Sub-parallel	1.0-1 5	Very deep	Clay	Croplands
9	Narrow valleys	Brown to light red	Fine	Irregular and small	Isolated and linear	Subdued plateau	Moderate	parallel-sub-parallel	1 5-2.0	Moder-ately deep	Sandy Clay loam	Cropland & Current fallows
10	Main valley floor	Light red to dark red	Fine	Irregular and linear	Linear	Pediplains	Level	Linear	<1.5	Very deep	Clay	Croplands
11	Water bodies	Block	---	---	Isolated	---	---	---	---	---	---	---

topography in western part and represents a typical stream carved morphology comprising crested radiating eroded ridges along the down slopes. The clusters of hills with smooth and rounded hilltop are characterized by rill and gully erosion. Free faces are common on the precipitous sidewalls. The height of ridges found to decrease progressively towards east from west signifying intense linear headward stream erosion and slope retreat under high hydraulic gradient of stream. These steep to very steep slope basaltic formations are susceptible to severe to very erosion hazards. The unit occupies nearly 11.50% of the total area.

G2. Isolated mounds

These are sinuous, narrow, restricted in nature and are noticed in isolated locations on the landscape. These are mostly circular in shape and influenced by circum-denudational geomorphic processes. The surface of the crest area is generally flat, with sharp discontinuous side slopes. Crenulations facilitates the formations of alternating head and nose slopes. At the top, slope of the mounds ranges from 3 to 5 percent with low drainage density. These are highly disintegrated by mechanical and chemical weathering and are remnants of natural reduction process and stand as narrow restricted summits. Intensity of weathering under different paleo-climatic conditions in the past has detached these mounds from the main hill chain.

G3. Linear ridges

Linear ridges are mainly confined to the sandstone and partly basaltic terrain and are formed due to detachment and isolation of various fluvial processes. The radial drainage pattern is observed around the ridges in the upper part and dentritic pattern in side slopes and lower areas mainly formed due to joints/fractures. In the northern part linear ridges are capped by conglomerate beds with alternative sandstone and shale beds.

G4. Escarpments

Escarpments are associated with valley side slopes of the landscape with steep to very steep slopes and interrupted by slope-breaks in the form of benches. Broader on either side by slope discontinuities, they merge with surrounding foot slopes with sharp angles. Slope wash is the dominant geomorphic processes followed by rill and protogully formations. This narrow and elongated geomorphic unit is in association with dissected ridges confined to mainly western and eastern parts.

G5. Plateau spurs

Morphologically the dissected plateau spurs are formed by the action of differential weathering and erosion processes. These are elongated in shape and prograding headward due to upward fluvial erosional processes. Plateau spurs are characterized by strong to moderately steep slopes and high to very high drainage density.

G6. Subdued plateau

Subdued plateau possesses shallow to medium deposition of basaltic crust and shows entrenchment of stream valleys. The unit owes its origin by active physico-chemical weathering followed by sheetwash geomorphological process leading to the development of plain landforms dotted with residual mounds. The drainage pattern is mostly dentritic to sub-parallel with second and third order stream network. This subdued plateau is associated with rolling landscape and are covered with pebbles and cobbles.

Depositional landforms

The fluvio-depositional landforms are formed under the influence of corrosive and erosive dynamics and slope retreat processes. Active physico-chemical weathering accompanied by sheet wash and strip removal of debris are responsible for development of various depositional landforms. Rolling plains, pediplains, narrow valley fills and main valley floor have been identified and mapped under this landforms.

G7. Rolling plains

Below the subdued plateau and escarpment zones, the depositional rolling plain landform was formed due to various fluvial depositional processes. At places, the alluvium and colluvium deposits are dissected by incoming third and fourth order streams. Rolling plains are noticed in the northern, south-western and eastern parts of the study area with an area of about 12.5% of the total area.

G8. Pediplains

The pediplains are low in relief and consist of deposited sediment that are regularly carried out from upland catchments, subdued hill slopes and pediments. The deposited sediments are admixed with sandy loam and clay fragments. The majority of the pediplain area occupy the central and southern parts of the study area with an area of about 19.60 % of the total area.

G9. Narrow valleys

The narrow valleys have been delineated based on the image characteristics, drainage features and land use. This unit has unequal width having moderate to steep valley floors. The narrow valley floors are well entrenched in the lower elevations. There are minor valleys, generally dentritic in nature and are scooped out by the tributary streamlets and subsequently filled up by the finer sediments transported by first and second order streams.

G10. Main valley floor

A narrow strip of low lying flat zone, formed by actions of fluvial deposition on either side of river course, is delineated as flood plain. Semi-stratification of sediments in the lower part of the basin took place with cross bedding of foreign sediments transported from up lands. This elongated narrow zone occupies nearly 6.73% of the basin and consists of deep to very deep soils.

Soil Depth

The relationship between different geomorphic units and soils determine the pedological processes resulting in the present landscape. It is well known fact that different geomorphic features in conjunction with type of parent materials influence greatly on the type of soils formed in topographic sequence under specific geo-pedological environmental conditions (Kantor and Schwertmann, 1974; Beckmann *et al.*, 1974; Das and Roy, 1979; Reddy *et al.*, 1999). It is observed that, soils in dissected ridges are very shallow to shallow, excessively drained and underlain by weathered basalt. The soils in isolated mounds and linear ridges are extremely shallow to shallow under excessively drained condition (Fig.3). The escarpments with steep to very steep slopes, have shallow and excessive drained soils. The soils in the plateau spurs are extremely shallow to shallow and are somewhat excessive drained. Narrow valleys have predominantly shallow soils in upper parts and moderately shallow to moderately deep in lower parts and are well drained. The soils in the subdued plateau are shallow to moderately deep and are excessive to well drained. The soils in the rolling plains are moderately shallow to moderately deep and are well drained. The pediplains comprises deep to very deep soils and are moderately well to well drained. In the main valley floor soils are predominantly fluvial in nature and are deep to very deep and have well drained condition.

Degraded lands

Based on the slope gradient, morphometry, broad soil physical characteristics, land use/land cover and satellite image characteristics, four categories of degraded lands i.e., very severe, severe, moderate and nil to slight have been delineated (Fig. 4).

E1: *Nil to slightly degraded lands*: These lands are characterized by very gently sloping lands with less drainage density, flat surfaces with much incipient loss of surface soil, double cropped area and associated with mild sheet erosion. These lands are

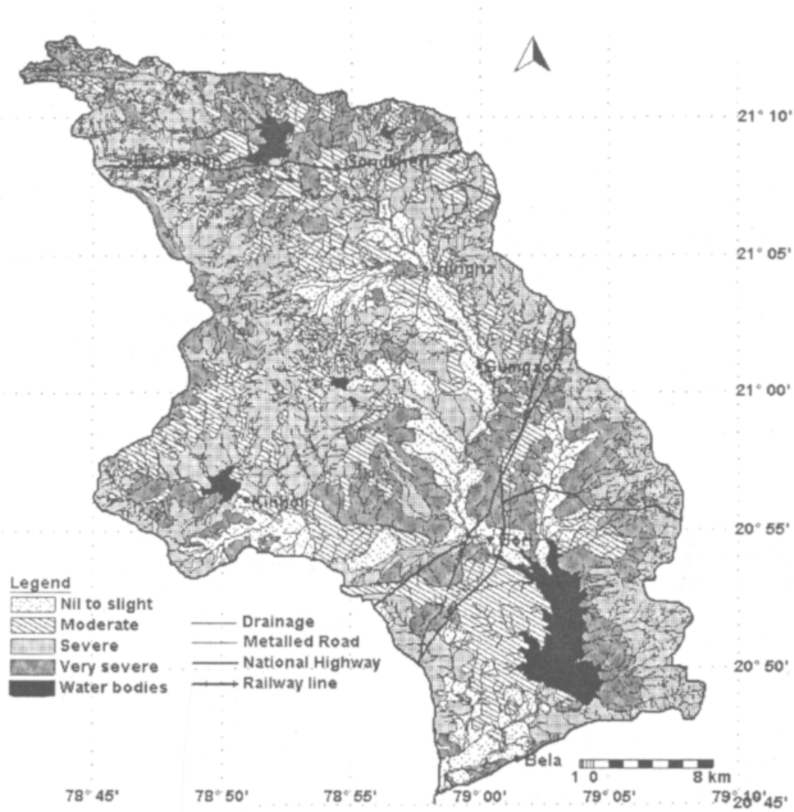

Fig. 4. Erosion status of Vena basin

mainly associated with rolling plains, pediplains, narrow valleys and main valleyfloor and occupies nearly 14.17 % of the total area.

E2: *Moderately degraded lands:* These lands are consists of very gentle to gentle slopes with moderate vegetal cover and drainage density with manifestation of rills and sheet erosion. These lands are in association with subdued plateau, Pediplains and narrow valleys with an area of about 24.10 % of the total area.

E3: *Severely degraded lands:* These land are associated with gentle to moderate slopes, high drainage density with occasional gullies and rills, exposed at place showing sub-soil horizon and weathered parent material. Severely degraded lands are noticed mainly in dissected ridges, escarpments, plateau spurs and subdued plateau with an area of about 36.05% of the total area.

E4: *Very severely degraded lands:* These lands are in association with dissected to undulating topography with steep to very steep slopes and high to very high drainage density. At places, these lands are associated with gullies and mainly covered in dissected ridges, plateau spurs, subdued plateau and rolling plains with an area of 22.22% of the total area. Wastelands with occasional rock out crops are the common feature in these lands.

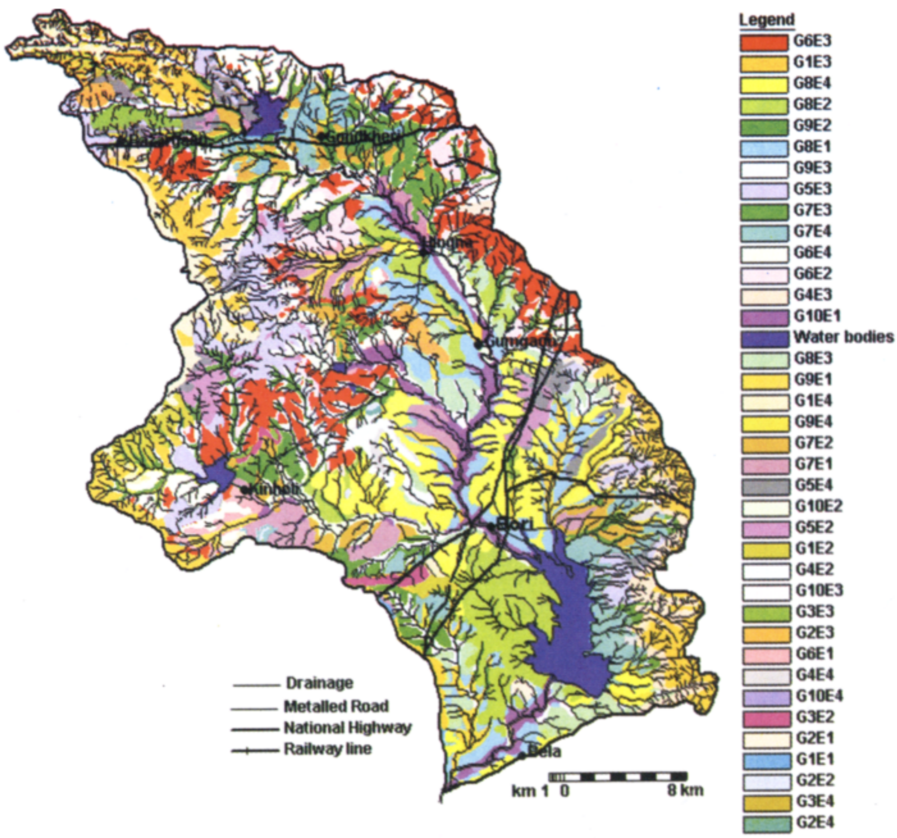

Fig. 5. Erosion status of different Geomorphic sub units in Vena basin

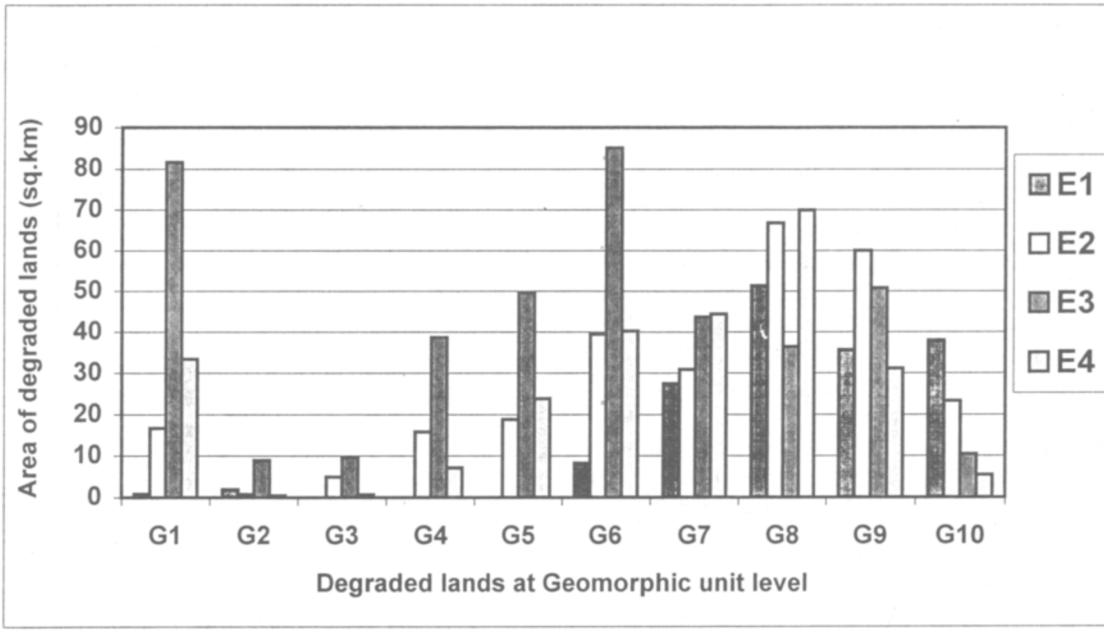

Fig. 6. Area of degraded lands at geomorphic unit in Vena basin

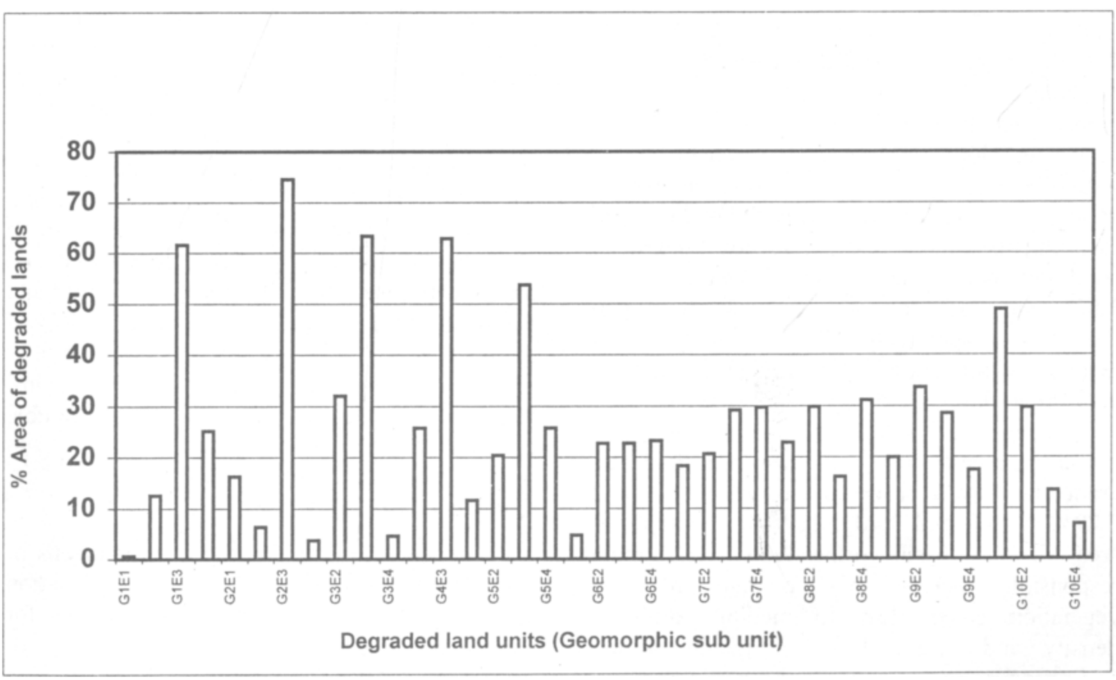

Fig. 7. Percent area of degraded lands at each geomorphic unit in Vena basin

Status of degraded lands

The spatial extent and distribution of degraded lands at each geomorphic unit were evaluated by integrating geomorphology and degraded lands layers using overlay analysis technique using union option in GIS. In the composite map 37 units (without water bodies) were identified with different erosion status at each geomorphic sub-unit level, representing the nature and magnitude of degraded lands at each geomorphic sub unit (Fig. 5). The study reveals that the pediplains, rolling plains and subdued plateau are subjected to very severe erosion with 6.05%, 3.85% and 3.47% of total geographical area of the basin respectively (Table. 2 and Fig. 6). The main attributing factors for very severe erosion are less to very less vegetation cover, medium to high drainage density and moderate to gentle slopes. The rill and sheet erosion are the prominent land degradation processes by the actions of nature and human activities. The subdued plateau and the dissected ridges with the combination of severe eroded lands were noticed with an area of 7.38 % and 7.08 % of total geographical area of the basin respectively. The main contributing factors are high to very high drainage density and steep to very steep slopes. These units are characterized with rill and gully erosion processes. The narrow valley, plateau spurs, rolling plains and escarpments are under severe degraded conditions with an area of about 4.41%, 4.31%, 3.80% and 3.35% of total geographical area of the basin respectively. The main attributing factors are moderate vegetation cover, high to very high drainage density and steep to very steep slopes. The pediplains, narrow valleys and subdued plateau with a combination of moderate eroded lands were observed with an area of about 5.79%, 5.20% and 3.40% of total geographical area of the basin respectively. The main responsible factors are moderate to good vegetation cover, low to medium drainage density and nearly level to gentle slopes. Pediplains, main valley floor and narrow valleys had very negligible degradation with an area of about 4.48%, 3.28% and 3.08% of total geographical area of the basin respectively. These areas are having nearly level to gentle slopes, low to very low drainage density, moderately deep soils with double cropped area.

The geomorphic sub units existing on subdued plateau, rolling plains and pediplains are under the influence of very severe land degradation with an area of about 23.19%, 26.69% and 31.12% of the total area of the respective geomorphic unit (Table. 3 & Fig. 7). The moderate to strong slopes, moderate drainage density and moderate to less vegetation cover are the main attributing factors for very severe land degradation. The severe degradation process is dominant in the geomorphic sub units encompassing in dissected ridges, isolated mounds, linear ridges, escarpments and plateau spurs with an area of 61.55%, 74.56%, 63.33%, 62.86% and 53.68 % of the total area of the respective geomorphic unit. The strong to steep slopes and high drainage density are associated with severely eroded lands. The moderate land degradation process is prevalent in the geomorphic sub units existing on escarpments, pediplains and narrow valleys with an area of 25.73%, 29.77% and 33.63% of the total area of the respective geomorphic unit. Moderate to gentle slopes, moderate drainage density and sparse vegetation cover are the causative factors for moderate degradation of lands. The nil to slight land degradation geomorphic sub units are prominently noticed in the main valley floor and pediplains with an area of 48.82% and 22.86% of the total area of the respective geomorphic unit. These units are under level to nearly level plains, less drainage density and single and double cropped areas.

Conclusions

The study reveals that the detail analysis of geomorphological aspects in land degradation assessment and geo-environmental planning for any terrain depends on the evaluation of landforms, their processes and properties. The application of remotely sensed data and GIS

Table 2: Erosion Status of Different Geomorphic Sub Units

Mapping unit	*Mapping unit Code*	*Geomorphic unit*	*Erosion class*	*Description*	*Area (%)*	*Area (sq km)*
3	G8E4	Pediplains	Very Severe	Moderately deep to deep soils with less vegetation, moderate drainage density and gentle to nearly level plains	6.05	69.9
10	G7E4	Rolling plains	Very Severe	Shallow to moderately deep soils with less vegetation, medium to high drainage density and nearly level to moderate slopes with sheet erosion	3.85	44.40
11	G6E4	Subdued plateau	Very Severe	Shallow to moderately deep soils with less vegetation, medium to high drainage density and gentle to steep slopes	3.47	40.20
18	G1E4	Dissected Ridges	Very Severe	Extremely shallow to shallow soils, sparse vegetation, high to very high drainage density with steep to very steep slopes	2.90	33.42
19	G9E4	Narrow Valleys	Very Severe	Moderately deep to deep soils, medium vegetation, medium to low drainage density with nearly level to gentle slopes.	2.70	31.12
22	G5E4	Plateau Spurs	Very Severe	Extremely shallow to shallow soils, moderate vegetation, high to very high drainage density with steep to very steep slopes	2.07	23.85
31	G4E4	Escarpments	Very Severe	Very shallow to shallow soils with less vegetation, very high drainage density with steep slopes	0.62	7.13
32	G10E4	Main Valleyfloor	Very Severe	Deep to very deep soils, sparse vegetation, low to very low drainage density and nearly level to very gentle slopes.	0.46	5.40
37	G3E4	Linear Ridges	Very Severe	Extremely shallow to moderately shallow soils, sparse vegetation, very high drainage density with steep to very steep slopes	0.06	0.74
38	G2E4	Isolated Mounds	Very Severe	Very shallow to shallow soils with less vegetation, very high drainage density with steep slopes	0.04	0.45
1	G6E3	Subdued plateau	Severe	Shallow to very shallow soils with high drainage density and steep slopes	7.40	85.05
2	G1E3	Dissected Ridges	Severe	Shallow to extremely shallow soils with high to very high drainage density and very steep slope	7.08	81.64
7	G9E3	Narrow Valleys	Severe	Soils varies from extreme shallow to moderately deep with sparse vegetation, medium to high drainage density with very gentle to steep slopes	4.41	50.81
8	G5E3	Plateau Spurs	Severe	Shallow soils with moderate vegetation, high drainage density and steep to very steep slopes	4.31	49.68
9	G7E3	Rolling plains	Severe	Very shallow to moderately shallow soils with less vegetation, medium to high drainage density with gentle to steep slopes	3.80	43.65
13	G4E3	Escarpments	Severe	Shallow soils, moderate vegetation cover, high drainage density and steep to very steep slopes	3 35	38.62
16	G8E3	Pediplains	Severe	Moderately shallow to moderately deep soils, moderate vegetation; medium to high drainage density with moderate to steep slopes	3.15	36.35
27	G10E3	Main Valleyfloor	Severe	Deep to very deep soils, sparse vegetation, low to very low drainage density and nearly level to very gentle slopes	0 93	10.45.
28	G3E3	Linear Ridges	Severe	Extremely shallow to moderately shallow soils, sparse vegetation, very high drainage density with steep slopes	0 84	9.70

Table 2: Contd.

Mapping unit	Mapping unit Code	Geomorphic unit	Erosion class	Description	Area (%)	Area (sq km)
29	G2E3	Isolated Mounds	Severe	Very shallow to shallow soils with less vegetation, high drainage density with gentle to steep slopes	0.78	8.97
4	G8E2	Pediplains	Moderate	Moderately deep to deep soils with sparse vegetation, moderate drainage density and very gentle to gentle slopes	5.79	66 77
5	G9E2	Narrow Valleys	Moderate	Soils varies from very shallow to deep with good vegetation, medium to high drainage density with very gentle to steep slopes	5.20	59 98
12	G6E2	Subdued plateau	Moderate	Shallow to moderately deep soils, moderate vegetation, low to medium drainage density and nearly level to gentle slopes	3.40	39.4
20	G7E2	Rolling plains	Moderate	Moderately deep to deep soils, medium vegetation, medium drainage density with very gentle to gentle slopes	2.72	30.90
23	G10E2	Main Valleyfloor	Moderate	Deep to very deep soils, double cropped area, low to very low drainage density and nearly level to very gentle slopes	2.00	23 25
24	G5E2	Plateau Spurs	Moderate	Shallow to moderately deep soils, moderate vegetation, medium drainage density and gentle to steep slopes	1.65	18.83
25	G1E2	Dissected Ridges	Moderate	Extremely shallow to shallow soils, medium to high vegetation cover, high to very high drainage density with steep to very steep slopes	1.45	16.70
26	G4E2	Escarpments	Moderate	Shallow soils, good vegetation cover, high to very high drainage density and steep to very steep slopes	1.39	15.85
33	G3E2	Linear Ridges	Moderate	Extremely shallow to moderately shallow soils, sparse vegetation, high to very high drainage density with steep to very steep slopes	0.43	4.90
36	G2E2	Isolated Mounds	Moderate	Very shallow to shallow soils with moderate vegetation, high drainage density with gentle to steep slopes	0.07	0.77
6	G8E1	Pediplains	Nil to Slight	Moderately deep to deep soils with double cropped area, less to very less drainage density with nearly level to gentle slopes	4.48	51 35
14	G10E1	Main Valleyfloor	Nil to Slight	Deep soils, very good vegetation cover, very low drainage density and level to nearly level plains	3.28	37.95
17	G9E1	Narrow Valleys	Nil to Slight	Moderately shallow to deep soils, double cropped area, low to medium drainage density with gentle to steep slopes	3.08	35.56
21	G7E1	Rolling plains	Nil to Slight	Moderately shallow to moderately deep soils, good vegetation, medium to low drainage density with very gentle to moderate slopes	2 37	27.45
30	G6E1	Subdued plateau	Nil to Slight	Shallow to moderately deep soils, good vegetation, low drainage density and very gentle to gentle slopes	0.71	8.24
34	G2E1	Isolated Mounds	Nil to Slight	Very shallow to shallow soils with moderate vegetation, medium drainage density with moderate slopes	0.17	1.96
35	G1E1	Dissected Ridges	Nil to Slight	Extremely shallow to shallow soils, high vegetation cover, high drainage density with steep to very steep slopes	0.08	0.90
15		Water Bodies	---	---	3.46	39.91
Total					**100**	**1152.91**

Table 3: Percentage area of different degraded lands in each geomorphic unit

1	2	3	4	5	6	7	8
3	G8E4	Pediplains	Very Severe	69.9	224.32	6.05	31.12
10	G7E4	Rolling plains	Very Severe	44.40	149.56	3.85	29.69
11	G6E4	Subdued plateau	Very Severe	40.20	172.74	3.47	23.19
18	G1E4	Dissected Ridges	Very Severe	33.42	132.63	2.90	25.20
19	G9E4	Narrow Valleys	Very Severe	31.12	178.36	2.70	17.45
22	G5E4	Plateau Spurs	Very Severe	23.85	92.55	2.07	25.74
31	G4E4	Escarpments	Very Severe	7.13	61.44	0.62	11.60
32	G10E4	Main Valleyfloor	Very Severe	5.40	77.51	0.46	6.86
37	G3E4	Linear Ridges	Very Severe	0.74	15.30	0.06	4.58
38	G2E4	Isolated Mounds	Very Severe	0.45	12.03	0.04	3.74
1	G6E3	Subdued plateau	Severe	85.05	172.74	7.38	22.71
2	G1E3	Dissected Ridges	Severe	81.64	132.63	7.08	61.55
7	G9E3	Narrow Valleys	Severe	50.81	178.36	4.41	28.49
8	G5E3	Plateau Spurs	Severe	49.68	92.55	4.31	53.68
9	G7E3	Rolling plains	Severe	43.65	149.56	3. 80	29.16
13	G4E3	Escarpments	Severe	38.62	61.44	3.35	62.86
16	G8E3	Pediplains	Severe	36.35	224.32	3.15	16.18
27	G10E3	Main Valleyfloor	Severe	10.45	77.51	0.91	13.48
28	G3E3	Linear Ridges	Severe	9.70	15.53	0.84	63.33
29	G2E3	Isolated Mounds	Severe	8.97	12.03	0.78	74.56
4	G8E2	Pediplains	Moderate	66.77	224.32	5.79	29.77
5	G9E2	Narrow Valleys	Moderate	59.98	178.36	5.20	33.63
12	G6E2	Subdued plateau	Moderate	39.4	172.74	3.40	22.71
20	G7E2	Rolling plains	Moderate	30.90	149.56	2.68	20.66
23	G10E2	Main Valleyfloor	Moderate	23.25	77.51	2.00	29.71
24	G5E2	Plateau Spurs	Moderate	18.83	99.55	1.63	20.35
25	G1E2	Dissected Ridge	Moderate	16.70	132.63	1.45	12.58
26	G4E2	Escarpments	Moderate	15.85	61.44	1.37	25.73
33	G3E2	Linear Ridges	Moderate	4.90	15.30	0.43	32.03
36	G2E2	Isolated Mounds	Moderate	0.77	12.03	0.07	6.40
6	G8E1	Pediplains	Nil to Slight	51.35	224.32	4.48	22.86
14	G10E1	Main Valleyfloor	Nil to Slight	37.95	77.51	3.28	48.82
17	G9E1	Narrow Valleys	Nil to Slight	35.56	178.36	3.08	19.93
21	G7E1	Rolling plains	Nil to Slight	27.45	149.56	2.37	18.31
30	G6E1	Subdued plateau	Nil to Slight	8.24	172.74	0.71	4.74
34	G2E1	Isolated Mound	Nil to Slight	1.96	12.03	0.17	16.29
35	G1E1	Dissected Ridges	Nil to Slight	0.90	132.63	0.08	0.66
15	-	Water Bodies	-	-	39.91	3.46	-

Note: 1. Mapping unit, 2. Mapping unit code, 3. Geomorphic unit, 4. Erodibility status, 5. Area of geomorphic sub unit, 6. Area of geomorphic Unit, 7. Percent area of the geomorphic sub unit in the basin and 8. Percent area of the geomorphic sub unit in the geomorphic unit integrated analysis has been found to be of immense help in terrain analysis and evaluation of basin morphometry, geomorphology and status of degraded lands. The GIS based integrated analysis of slope, morphometry, geomorphology, soil depth and degraded lands give more intrinsic characteristics to delineate the extent and magnitude of various types of degraded lands at each geomorphic sub unit. The results have been verified in the field and found in good concurrence with the image characteristics, derived parameters and degradation status of different geomorphic sub units. The integrated geomorphological and degraded lands analysis ensures better understanding of landform-degraded lands relationship and distribution to understand the status of land degradation at micro geomorphic unit for reclamation and geo-environmental planning and management. The analysis of the land degradation status in the study area reveals that the deciduous forests in the hilly catchment areas are being indiscriminately cleared for timber and cultivation, which led to rill and gully formations in up lands. The information generated at geomorphic sub unit can be useful for prioritizing areas for immediate soil and water conservation, river basins management, hazards mitigation, environmental planning and to restore fragile geo-ecological balance.

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