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RESEARCH PAPER

Estimating soil fertility status in physically degraded land using GIS and remote sensing techniques in Chamarajanagar district, Karnataka, India

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KEYWORDS

Bulk density;
Physical degradation;
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Soil erosion

Abstract Soil physical degradation is a major environmental problem throughout the world due to its negative impact on biomass and economic production. This study presented new ways of combining rapid soil analysis using GIS and remote sensing imagery to provide a precision mapping of soil physical condition indicators in the study area and producing fertility status using Geostatistical approach. Study has been carried out to map the areas with physical degradation using remotely sensed data from Indian Remote Sensing LISS III sensor. It was observed that the data enabled better delineation of small units of eroded areas. Satellite data have been used for qualitative assessment of areas, being subject to soil erosion. Soil erosion was found to be none or slight to very sever using visual interpretation of IRS data along with field survey method where soil erosion was found to be moderate to high using the RUSLE method. The eroded areas of degraded lands will be used as an input for planning reclamation and conservation programs in Chamarajanagar district of Karnataka.

Soil compaction is a form of physical degradation resulting in densification and distortion of the soil where biological activity, porosity and permeability are reduced, strength is increased and soil structure partly destroyed. Compaction can reduce water infiltration capacity and increase erosion risk by accelerating run-off. The compaction process can be initiated by wheels, tracks, rollers or by the passage of animals. Some soils are naturally compacted, strongly cemented or have a thin

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topsoil layer on rock subsoil. Soils can vary from being sufficiently strong to resist all likely applied loads to being so weak that they are compacted by even light loads.

1. Introduction

Land is the most valuable resource for the production of food, fiber, fuel and many other essential goods required to meet human and animal needs. However, it is facing serious threats of deterioration due to unrelenting human pressure and utilization incompatible with its capacity. Land degradation in general, implies temporary or permanent recession from a higher to a lower status of productivity through deterioration of physical, chemical and biological aspects. It is a complex ensemble of surface processes (e.g. wind erosion, water erosion, soil compaction, salinization, and soil water-logging). These can ultimately lead to "Desertification". As the increasing world population places more demands on land for food production etc., many marginal arid and semiarid lands will be at risk of degradation. Though conventional soil surveys provide information on land degradation; they are slow, time consuming and expensive. Among the new technologies emerging for studying natural resources, remote sensing and GIS are effective technologies for detecting, assessing, mapping, and monitoring the land degradation. The systematic efforts in the application of remote sensing technology in the study of natural resources has resulted in the development of well-established methodologies for mapping and monitoring of various degraded land in the investigated area. The application of remotely sensed data in mapping degraded lands enabled to map and monitor degraded lands more efficiently. Many studies were carried out on mapping eroded lands (Venkataratnam and Rao, 1977; Rao et al. 1980), ravines (NRSA, 1981; Karale et al., 1988). GIS proved to be an effective tool in handling spatial data available at different scales, voluminous point data such as soil information, rainfall, temperature etc. and socioeconomic data and to perform integrated analysis of data on various resources of any region and to arrive at optimum solutions for various problems. Throughout the world the concern for the environment is increasing day by day due to physical, chemical and biological degradation of the natural resources that have led to the ecological imbalances. The over-exploitation and mismanagement of land resources have resulted in the degradation of land, a major environmental issue in the contemporary times. Nearly 175 million hectares of land in India is subject to one or other kind of degradation process (Das, 1985). Soil degradation is a severe problem while the information of the degraded land is scanty, and needs to be collected. Hence, the study was carried out with the objective being delineation of degradation area by using satellite data and GIS software and producing the nutrient status and physical degradation maps (increase in bulk density and water erosion) using Geostatistical approach. The specific objectives of this study were to identify degradation degree of soil erosion based on satellite images and physical degradation status, and to identify spatial patterns of physical and chemical soil properties and spatial distribution of soil fertility.

2. Material and methods

Chamarajanagar district with an area about 5101 Km^2 (Fig. 1) is located in the southern tip of Karnataka state; North latitude 11° 40′58″ to 12° 06′32″ and East longitude 76° 24′14″ to 77° 46′55″. It falls in the southern dry zone. Topography is undulating and mountainous with north south trending hill ranges of Eastern Ghats. It is bounded by Salem and Coimbatore districts of Tamil Nadu in the east, Mandya and Bangalore districts in the north, parts of Mysore district in the west and Nilgiris district of Tamil Nadu in the south.

IRS-P6 LISS-III (FCC) images of February 2006, 13 February 2012 and LISS-IV January, March and November 2012 were used for Visual interpretation of erosion along with soil survey carried out in the field as shown in Table 1.

The data therefore represent *spring* (*Rabi*), *autumn* (*Kharif*) and *summer* seasons. The standard false color composite (FCC) images of the study area were prepared using bands 4 (NIR), 3 (Red), and 2 (Green) and discrimination of features was made by visual interpretation (on screen) using these images. The interpretation key was based on the relationships established between ground features and image elements, like, texture, tone, shape, location and pattern. IRS-LISS-III and IRS-LISS-IV Satellite data were used for qualitative

Table 1 IRS sensors used in this study.

Sensor	Resolution (m)	Swath width (km)	Sensor channels	Spectral bands (μm)
Linear Imaging Self-Scanning System III (LISS-III)	23	142	LISS-III-2	0.52–0.59 (green)
			LISS-III-3	0.62–0.68 (red)
	50	148	LISS-III-4	0.77–0.86 (near IR)
			LISS-III-5	1.55–1.70 (mid-IR)
	6	70	PAN	0.5–0.75
High Resolution Linear Imaging Self-Scanning System IV (LISS-IV)	5.8	24–70	LISS-IV-2	0.52–0.59 (green)
			LISS-IV-3	0.62–0.68 (red)
			LISS-IV-4	0.77–0.86 (near IR)

According to Indian Remote Sensing Satellites website (http://uregina.ca/piwowarj/Satellites/IRS.html).

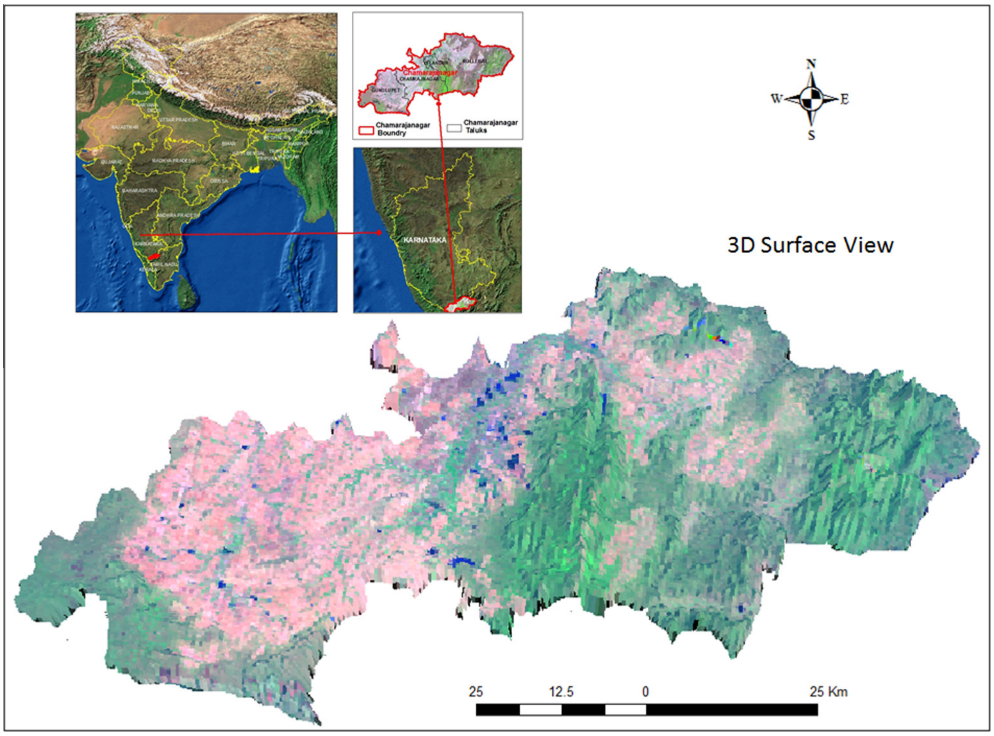

Figure 1 Location map of study area and 3D surface view.

assessment of areas, being subject to soil erosion. Based on length and degree of slope from SRTM, ASTER and topographic sheets (1:50,000 and 1:250,000), representative sample sites were selected for ground truth data collection. During field visits, features of topography and soil profiles were studied; site characteristics and soil samples were also collected for laboratory analysis. The preliminary interpreted maps were modified based on the field data and analytical data and final maps were prepared with appropriate legend.

Land use/land cover was produced supervised classification (maximum likelihood method using ENVI 5.1 software) and visual interpretation done for enhancing the accuracy of the classification along with ground truth points through field trips with overall accuracy 96.7%.

In Chamarajanagar district, the problem of soil degradation is caused mainly by soil erosion. The assessment of soil physical degradation entailed prediction of the risk of soil loss. The RUSLE (Revised Universal Soil Loss Equation) model equation (Renard et al., 1997) is a multiplicative function of five factors controlling the erosion:

$$A = R * K * LS * C * P$$

where:

A is the mean annual soil loss expressed in ton\ha * yr.

R is rainfall and runoff erosivity index (in MJ * mm\ha * yr).

K is soil erodibility factor (in ton * ha * h/ha * MJ * mm).

LS is slope and length factor (dimensionless).

C is the cover factor (dimensionless).

P is the conservation practice factor (dimensionless).

where A is the computed soil loss per unit area, expressed in the units selected for K and for the period selected for R (in common practice these are usually selected such that they compute A, soil loss in US tons per acre per year); R, the rainfall and runoff factor, is the number of rainfall erosion index units, plus a factor for runoff from snowmelt or applied water where such runoff is significant; K, the soil erodibility factor, is the soil loss rate per rainfall erosion index unit for the specified soil under Unit Plot conditions; L and S are the slope length and steepness factors in relation to the conditions on a unit plot; C, the cover and management factor, is the ratio of soil loss from an area with specified cover and management to that from an identical area under the tilled continuous fallow Unit Plot conditions (C thus ranges from a value of zero for completely non-erodible conditions, to a value of 1.0 for the worst-case Unit Plot conditions); and P, the support practice factor, is the ratio of soil loss with a support practice like contouring, strip-cropping, or terracing to that with straight-row farming up and down slope.

3. Results and discussion

3.1. Land use/land cover

The knowledge of land use and land cover is important for many planning and management activities as it is considered as an essential element for modeling and understanding the earth feature system. Land use is defined as to the human activity or economy related function associated with a specific piece of land, while the term land cover relates to the type of feature present on the surface of the earth (Lillesand and Kiefer, 2000). The remote sensing technology has found its acceptance worldwide for rapid resource assessment and monitoring, particularly in the developing world.

The synoptic view of the area allows better monitoring capability, especially when the coverage is repetitive, interval is short, and resolution of the image is high. Remote sensing provides data in several discrete bands, enabling creation of false color composites (FCC) and the interpretation accuracy is thereby increased visually and digitally. It provides real time and unbiased base line information (Gupta, 2001). On the basis of the information obtained by the identification of the physical characteristics from the RS data and their verification in the field, the major land use categories as shown in Fig. 2 were identified and mapped. Large part of the study is mainly covered by Agriculture. Forest is defined as all land bearing vegetative association dominated by trees of any size, capable of producing wood or other forest products and exerting an influence on climate or water regimes or providing shelter for wild life and livestock. Wastelands those lands which are currently unutilized or underutilized and can be brought under vegetation cover/cultivation with reasonable efforts were derived from the imagery.

From the estimation of GIS calculation it is found that forest areas are occupying 47.54%, Agricultural land 42.61%, Wastelands 4.58%, Built-up land 1.03%, Water Bodies 1.92%, Grassland/Grazing land 0.28%, and other land use/land cover areas occupying 2.04 of the total areas derived from IRS 2013.

3.2. Slope of study area

In this study, SRTM resolution (90 m) and ASTER resolution (30 m) data can be freely downloaded from internet websites and topographic sheets scaled (1:50,000 and 1:250,000) were used. The major part of the area is having 0–3 slope per cent. However, variations in the slope (0–100%) was made to group the entire area into six slope classes i.e., 0–3,3–5,5–15,15–30, 30–50 and > 50%. The areas having slope 0–3 and 3–5% were assigned moderate in erosion and the areas, which were having slope > 5% were considered as severe in view of the erosion. Soil loss increases as slope increases but after 50% slope, soil erosion tends to decrease due to the presence of dense vegetation. With the increase in vegetation cover, average soil loss dramatically decreases.

3.3. Assessment of soil erosion

FCCs obtained from LISS III and IV sensors (with 23.9 m and 5.8 m spatial resolution) were evaluated for delineation of eroded areas. It was observed that the data enabled better delineation of small units of eroded areas. Based on soil, slope, and land use/land cover, current soil erosion status was mapped. Visual interpretation involves identification and delineation of degraded lands that are manifested on False Color Composite (FCC). The False Color Composites are analyzed initially with the help of topographical maps, published reports and other available ancillary data; broad categories of degraded lands were delineated. Soil erosion categories were delineated through visual interpretation of IRS data and found to be none or slight, moderate, severe and very severe as shown in the Fig. 3. Land degradation has numerous environmental, economic, social and ecological consequences. Every ecosystem on the earth is affected by some or the other form of land degradation. When land is degraded, the ecology is damaged. There can be rather serious effects in terms of soil erosion, loss

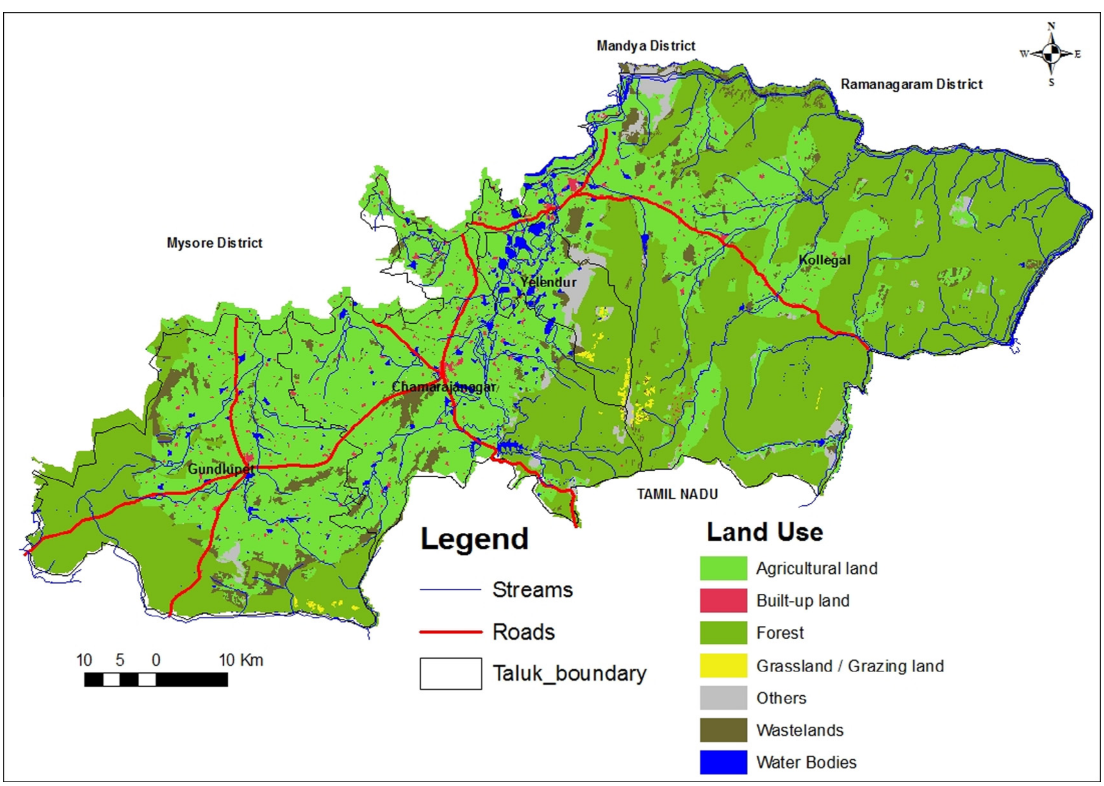

Figure 2 Land use/land cover of study area.

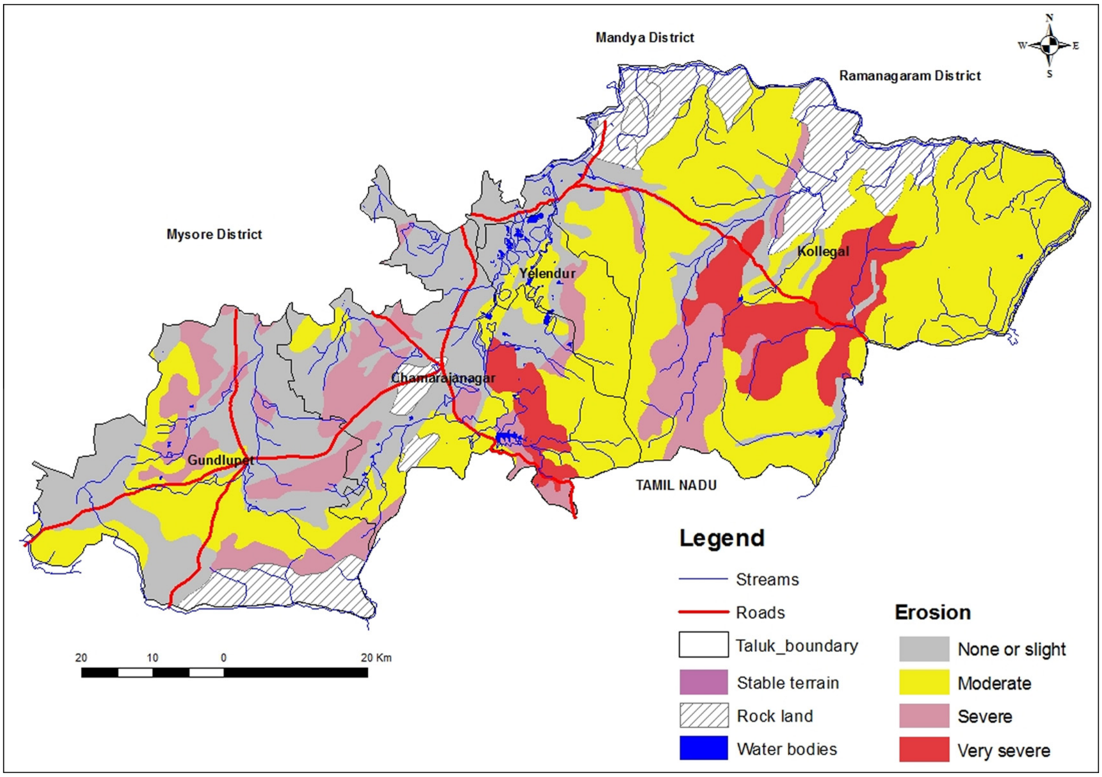

Figure 3 Erosion based on satellite images.

of soil fertility and thus reduced plant growth or crop productivity, clogging up of rivers and drainage systems, extensive floods and water shortages. Accelerated erosion adversely affects the quality of soil on site (Norton et al., 1998; Lowery et al., 1998; Lal et al., 1998) and its agronomic productivity (Olson et al., 1998; Lal, 1998). The eroded areas were identified distinctly on the FCC as a result of erosion of soil by running water. They are more common on sloping surface. Fig. 3 shows the soil erosion map of the site on 1:50,000 scale.

The RUSLE calculation considered all the variables which affect the soil erosion. These parameters affecting soil degradation like (natural vegetation factor, climatic factor, land use factor, soil factor, management factor, topographic factor) have been generated from fieldwork data and have been classified according to the RUSLE in integer values to obtain the ranges for the assessment of the risk of Water Erosion (Fig. 4) and assessment of present Water Erosion (Fig. 5) and those two map were generated using Geostatistical approach for predicting the spatial distributions of maps in Figs. 4 and 5.

Integrating different types of the factors affecting land erosion, the results show that the majority of the study area fall under the moderate land erosion classes. High land degradation class has been found in areas affected by high soil loss; this is the major reason for Biological Degradation by removing plow layer of the top soil. It is a well-known fact that soil organic matter is the main biological wealth of soils. Erosion removes the SOM (Soil Organic Matter) along with other mineral components of the soil resulting in soil biological degradation.

GIS spatial modeling tools manifested great efficiency in land degradation assessment process, whose results hopefully may help decision makers to take the necessary actions to protect the most degraded spots. These outputs have been analyzed and weighted in terms of degradation classes. Moderate and high classes depend on the magnitude of annual soil loss (RUSLE).

It is almost impossible to avoid topsoil compaction. On the other hand, tillage and natural processes can re-loosen the topsoil. Subsoil compaction is much more persistent and difficult to remove. Artificial loosening of the subsoil has proven to be disappointing. The loosened subsoil is recompacted very easily and many physical properties are strongly reduced.

Subsoil compaction should be prevented instead of being repaired or compensated. Even on weak soils, relatively high wheel loads are possible by using large tyres with low inflation pressures or well-designed tracks. Subsoil compaction during plowing can be prevented by using improved steering systems and adapted plows allowing the tractor to drive with all wheels on the untilled land. It is also possible to concentrate wheel loads on permanent traffic lanes and limit the compaction to these sacrificed wheel ways. By using gantries, the sacrificed area can be limited. However, these solutions are rarely used because of short-term economical constraints, lack of awareness, and negligence because the damage to the subsoil is not readily visible. Also the limited knowledge and data on soil strength under dynamic loading makes prevention of subsoil compaction difficult.

Provisional map of Bulk density and Physical degradation risk initial levels of soil in investigated area to compaction, based on soil properties alone. Further input data are required on climate and land use before vulnerability to compaction of subsoil in the investigated area can be inferred from the map shown in Figs. 6 and 7.

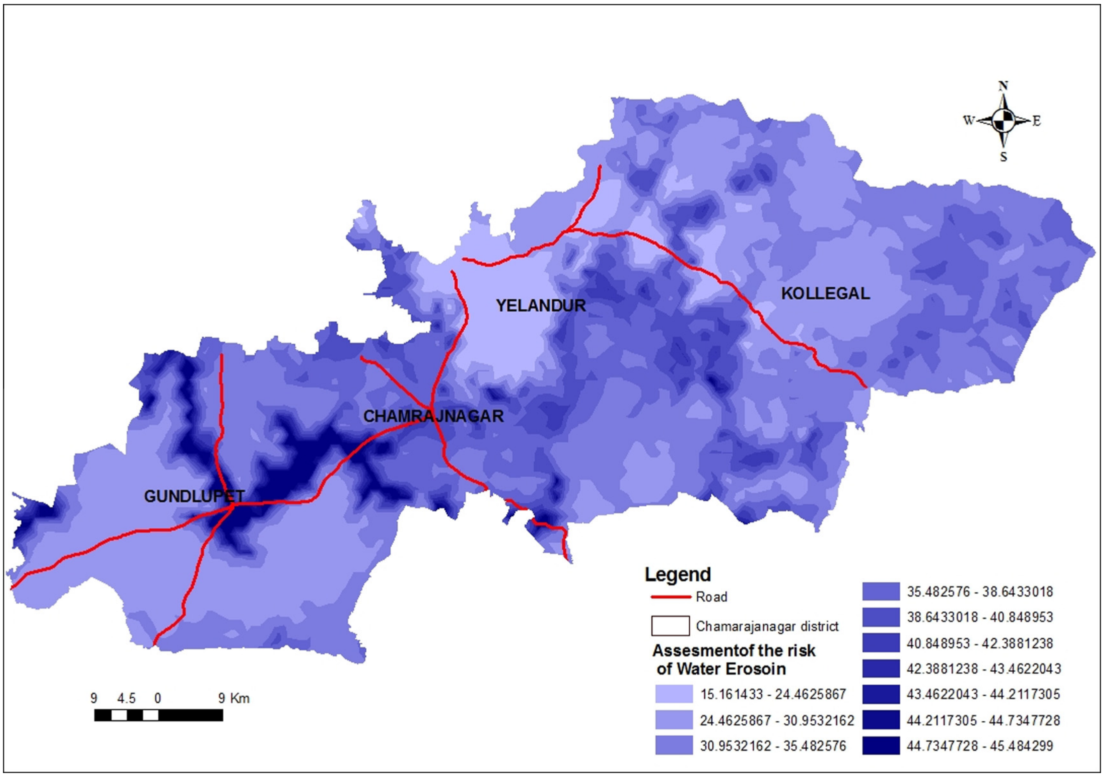

Figure 4 Assessment of the risk of water erosion (t/ha/year) based on RUSLE.

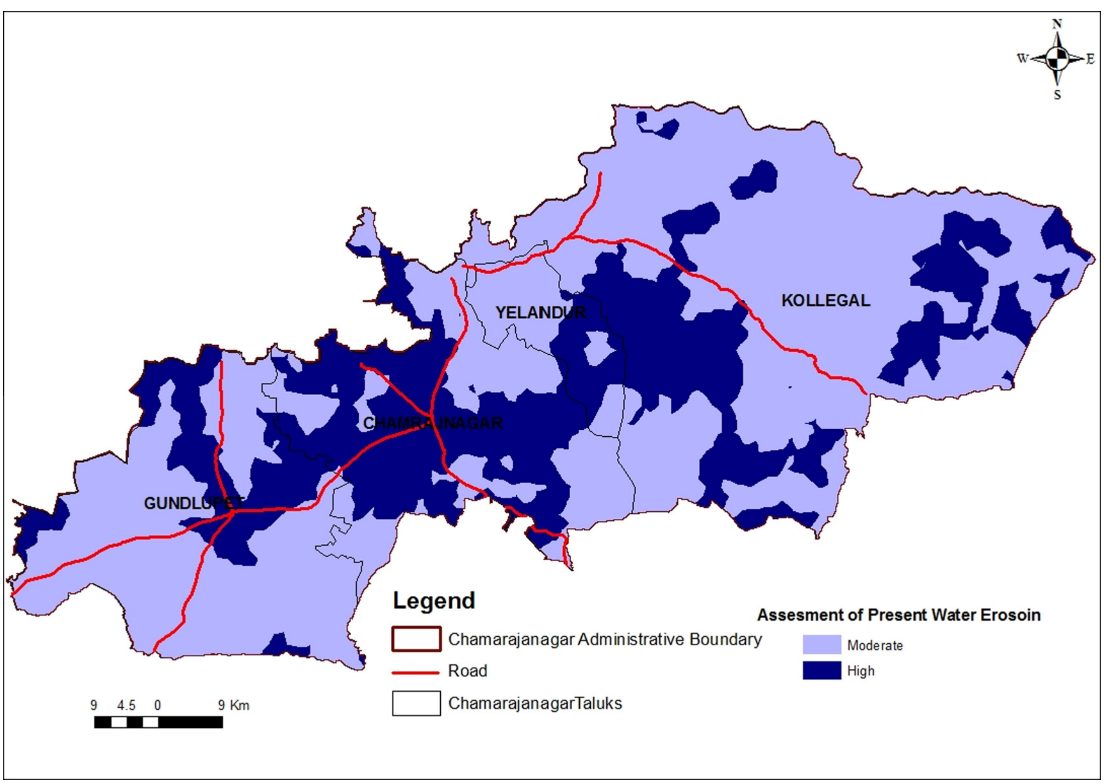

Figure 5 Assessment of present water erosion based on RUSLE.

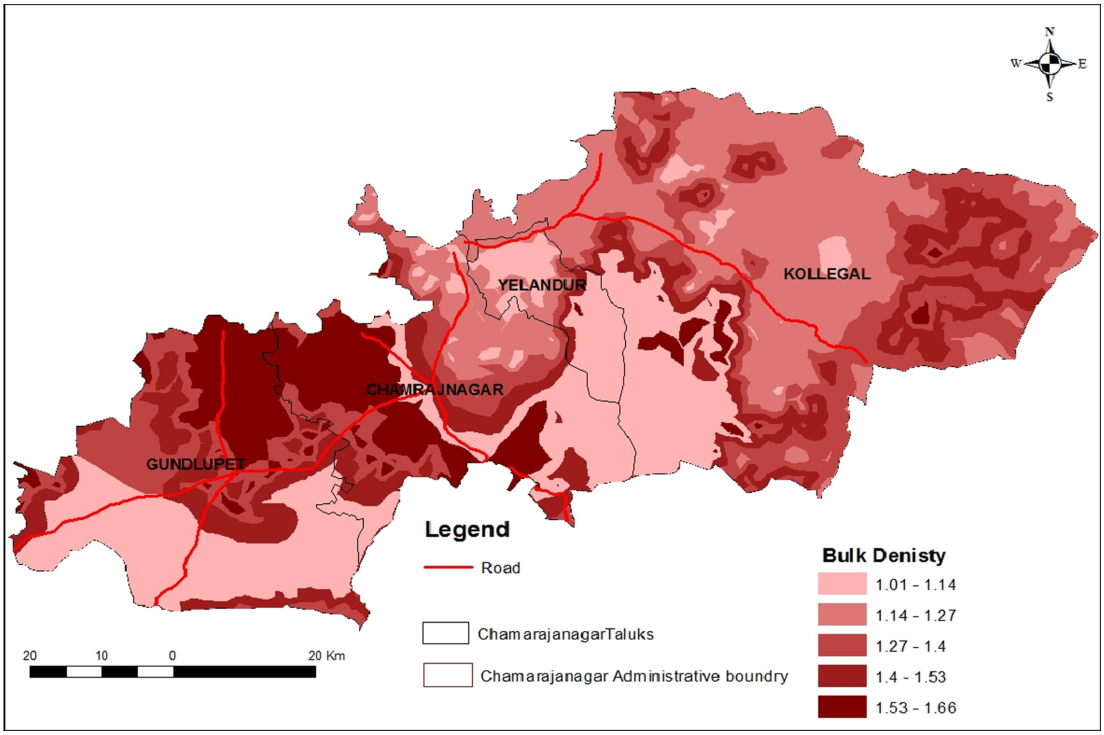

Figure 6 Assessment of bulk density.

3.4. Creation of digital data base of degraded lands

Though voluminous information on degraded lands in the form of maps and attributes (physical and chemical properties, geographic location, current land use, etc.) is available with various organizations, there is no organized digital data base available at the district or state level to the concerned users. Thus, a centralized digital database in a Geographic Information System (GIS) domain on degraded lands was developed which has related terrain parameters covering the location of the soil observation, using Global Positioning System (GPS) with adequate accuracy. It would enable studying the variations in properties of degraded lands in space and time.

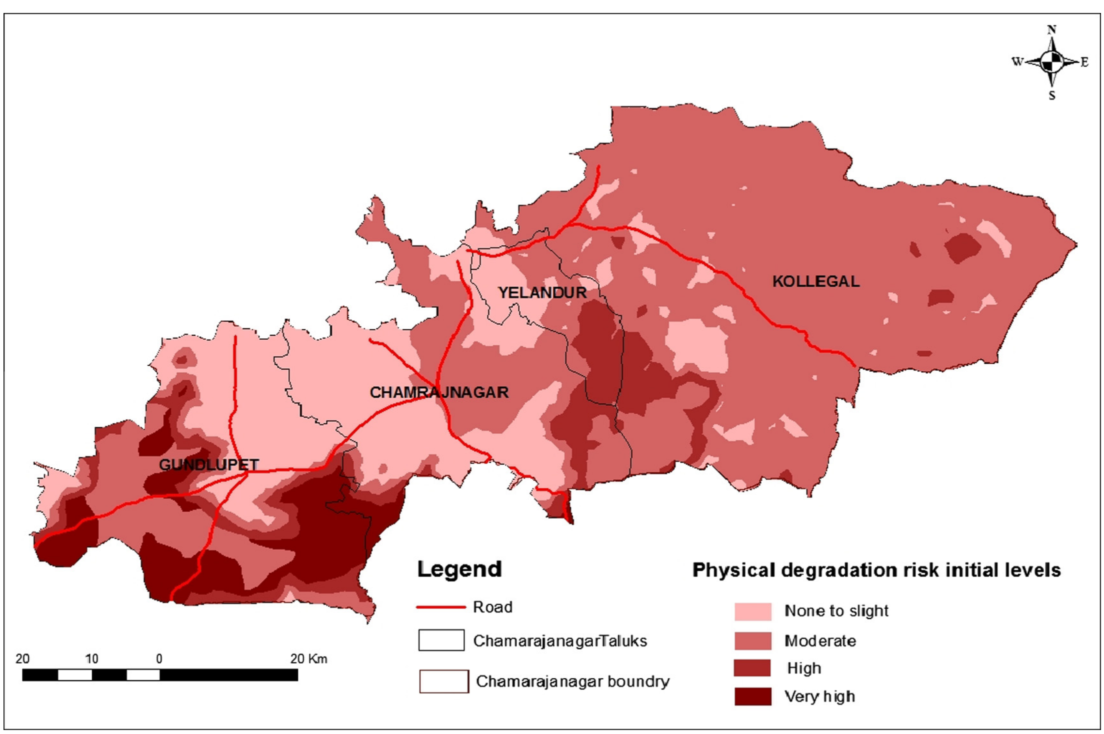

Figure 7 Assessment of physical degradation risk initial levels.

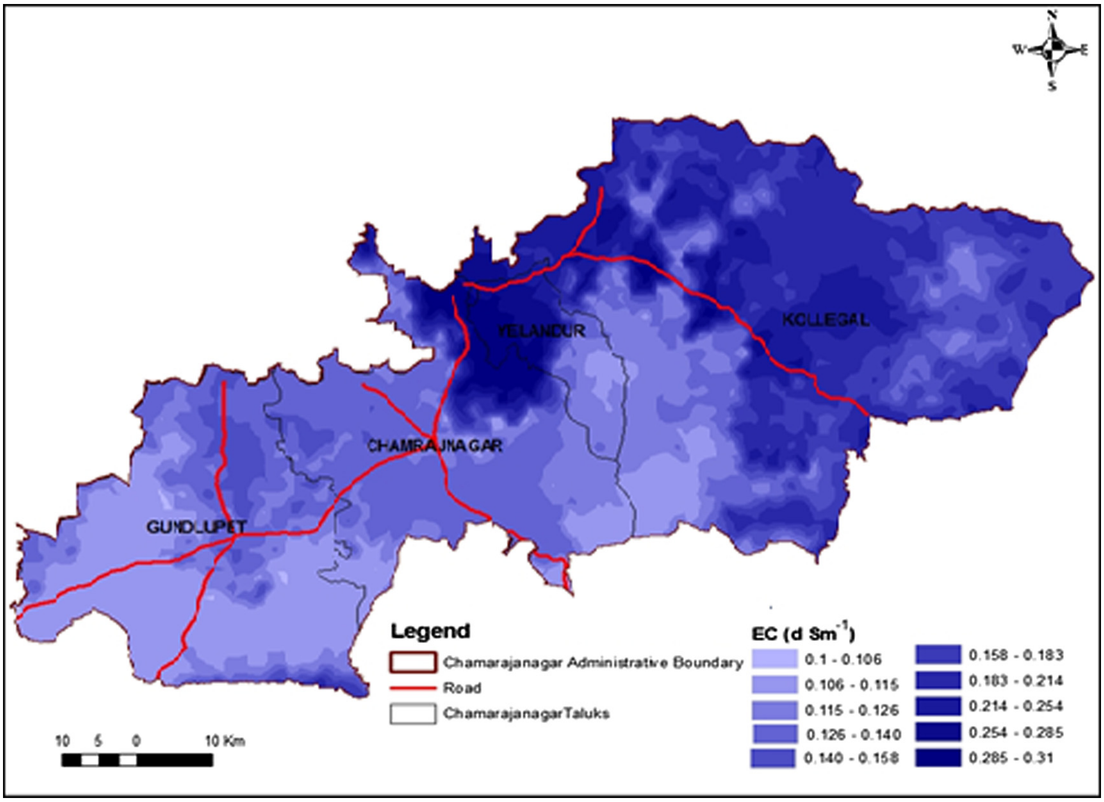

Figure 8 Electrical conductivity of Chamarajanagar district soil in (d Sm^{-1}).

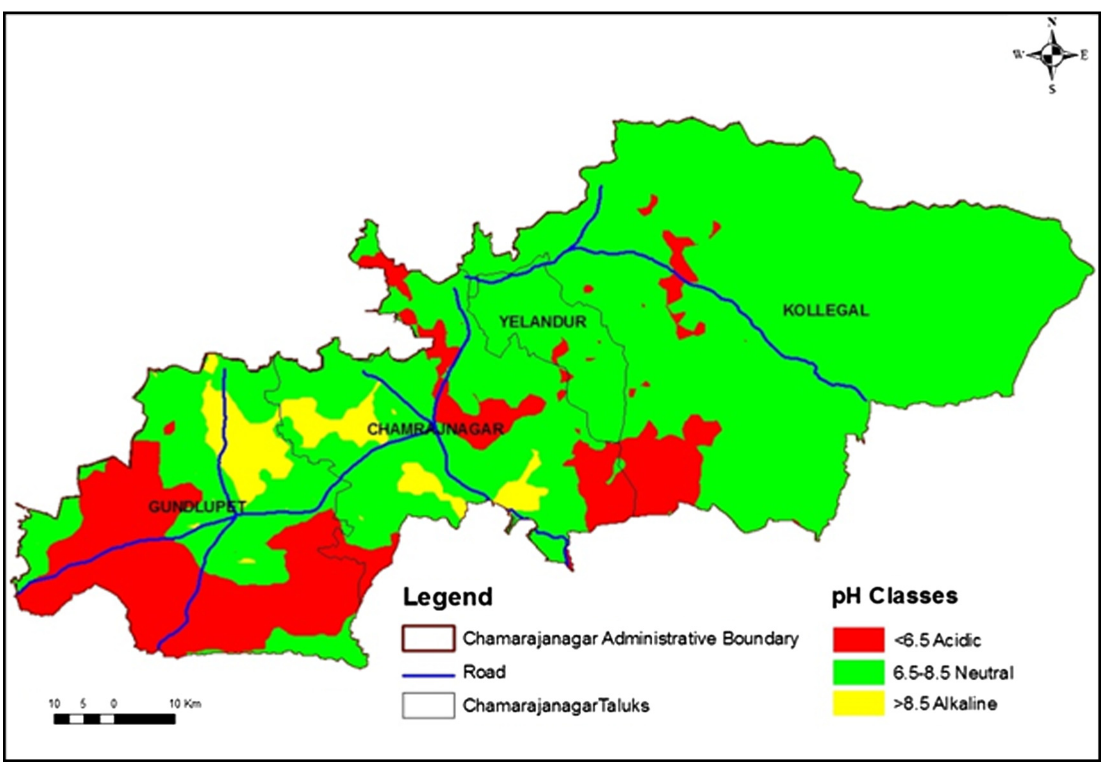

Figure 9 Soil pH classes of Chamarajanagar district.

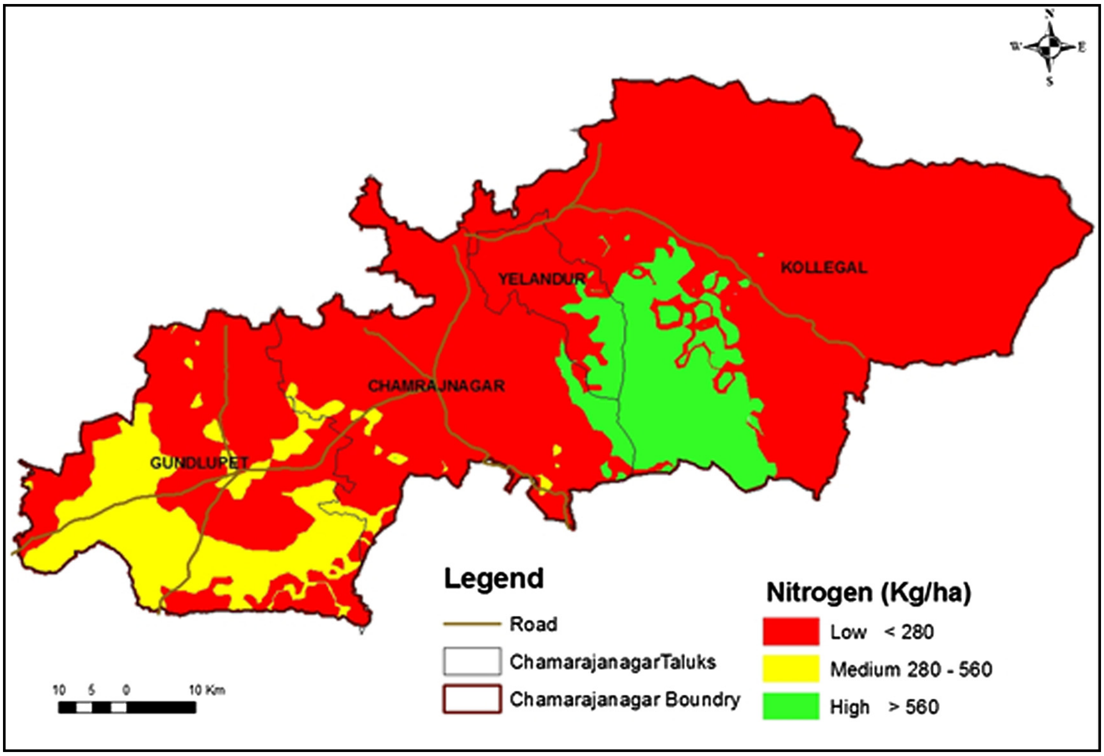

Figure 10 Nitrogen content (kg/ha) in soil of Chamarajanagar district.

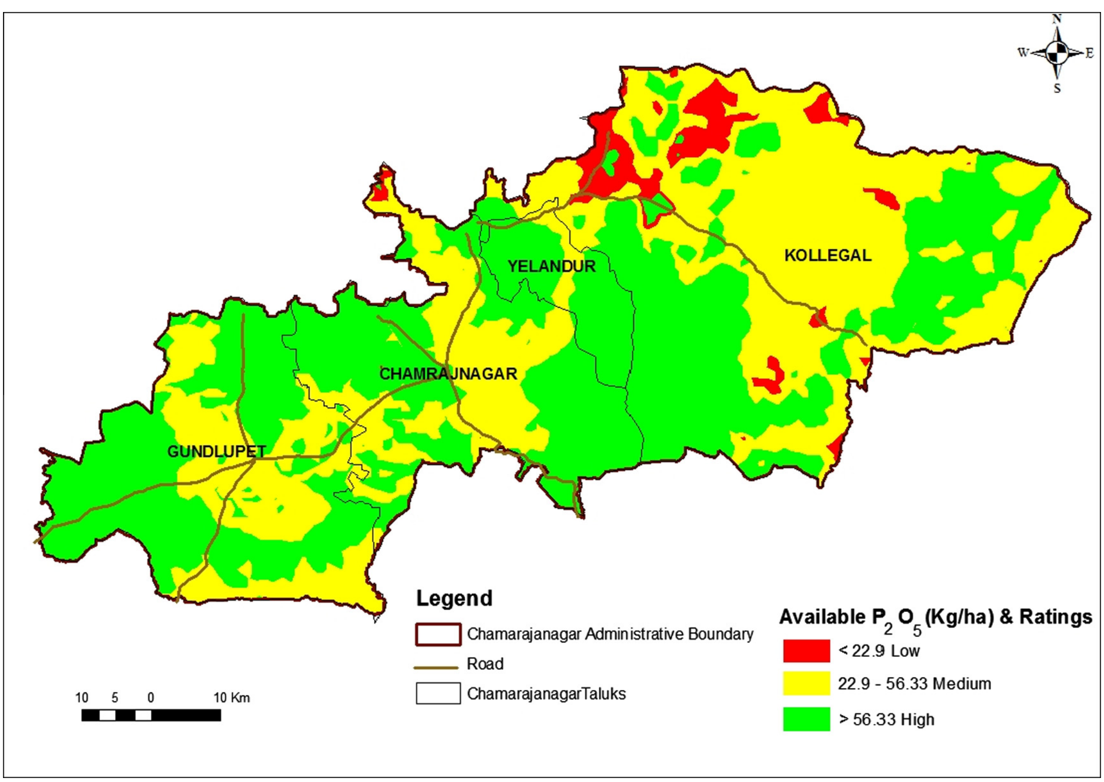

Figure 11 Available phosphorous content (kg/ha) in soil of Chamarajanagar district.

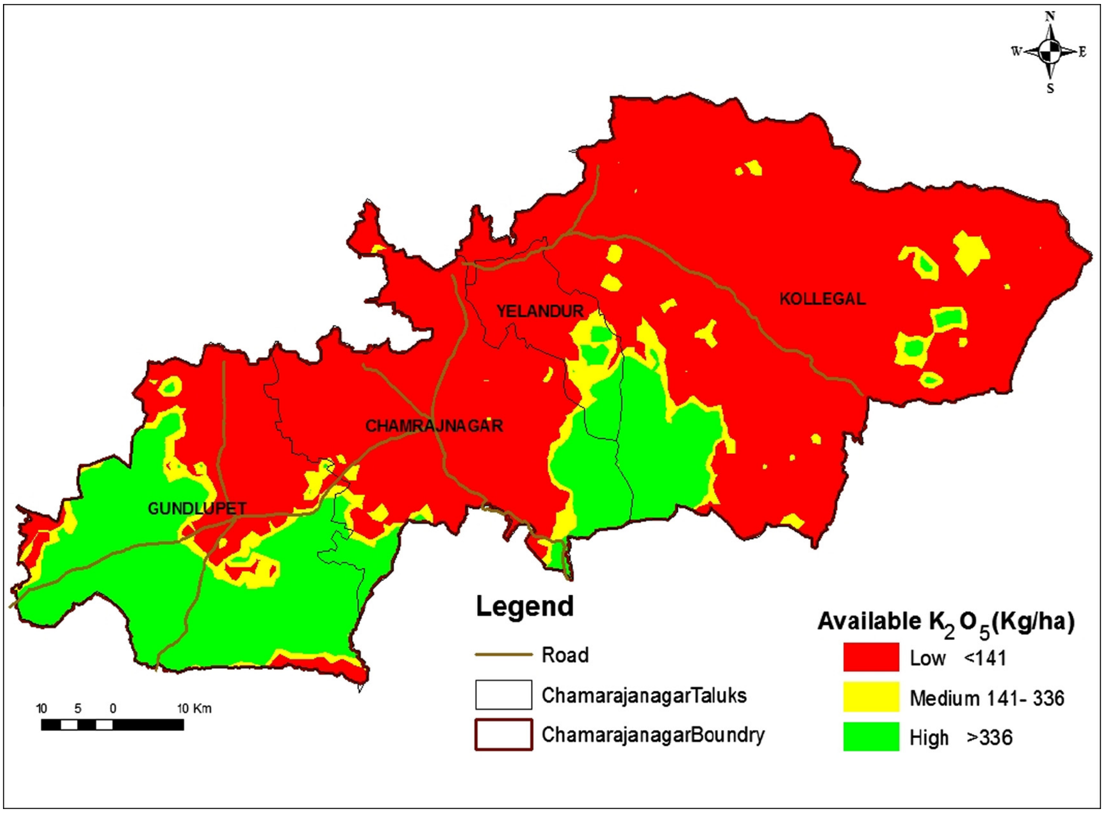

Figure 12 Available Potassium (kg/ha) in soil of Chamarajanagar district.

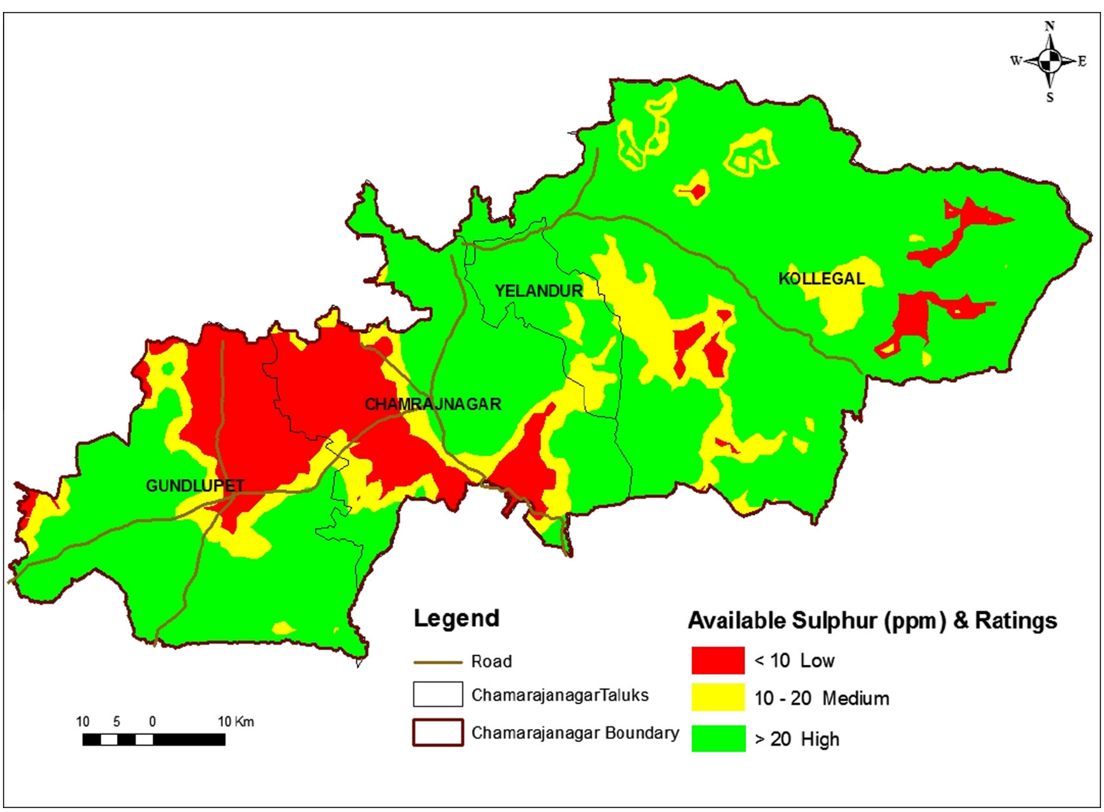

Figure 13 Available sulfur (ppm) in soil of Chamarajanagar district.

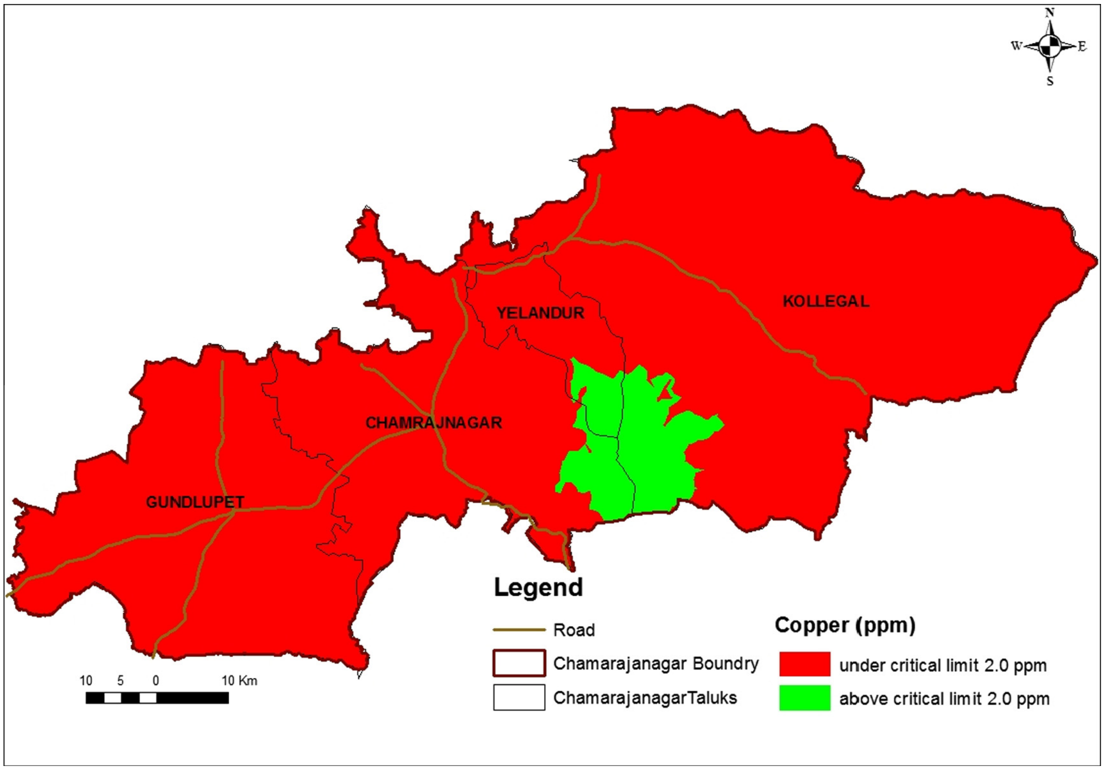

Figure 14 Copper content (ppm) in soil of Chamarajanagar district.

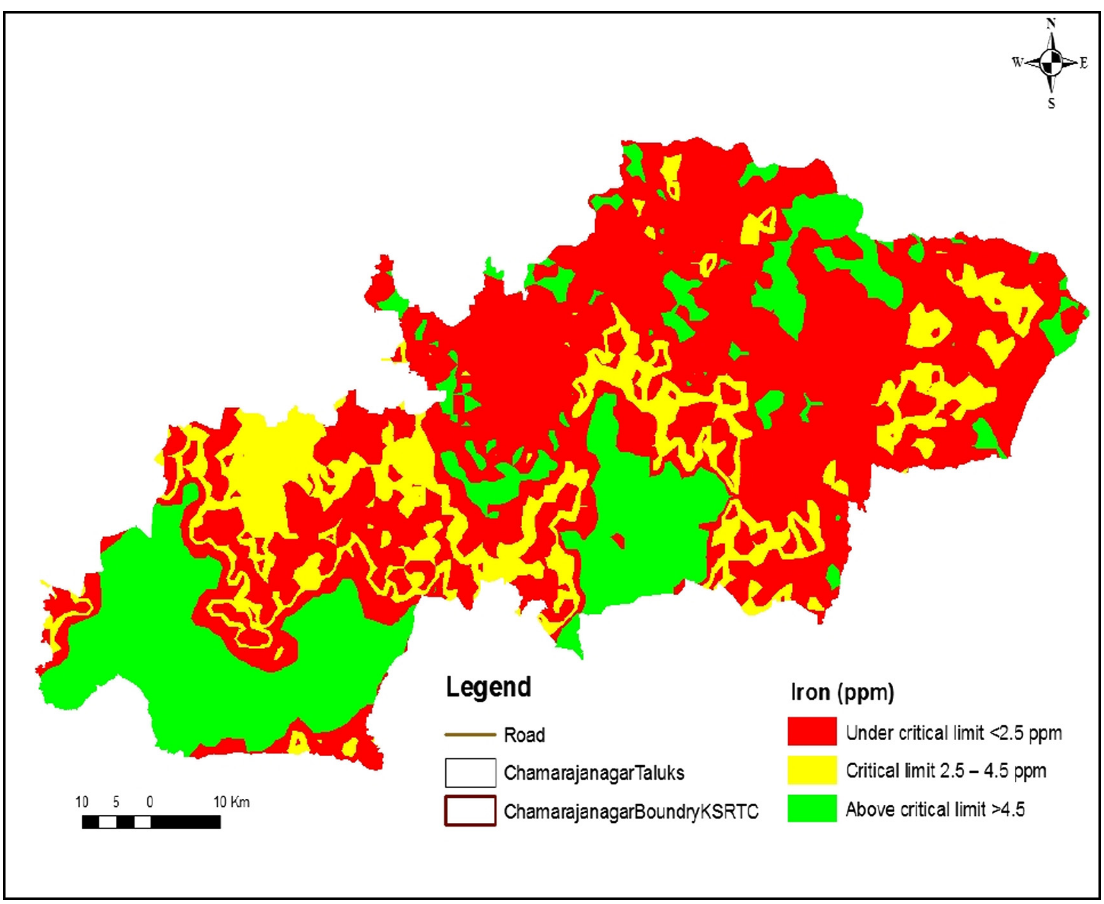

Figure 15 Iron content (ppm) in soil of Chamarajanagar district.

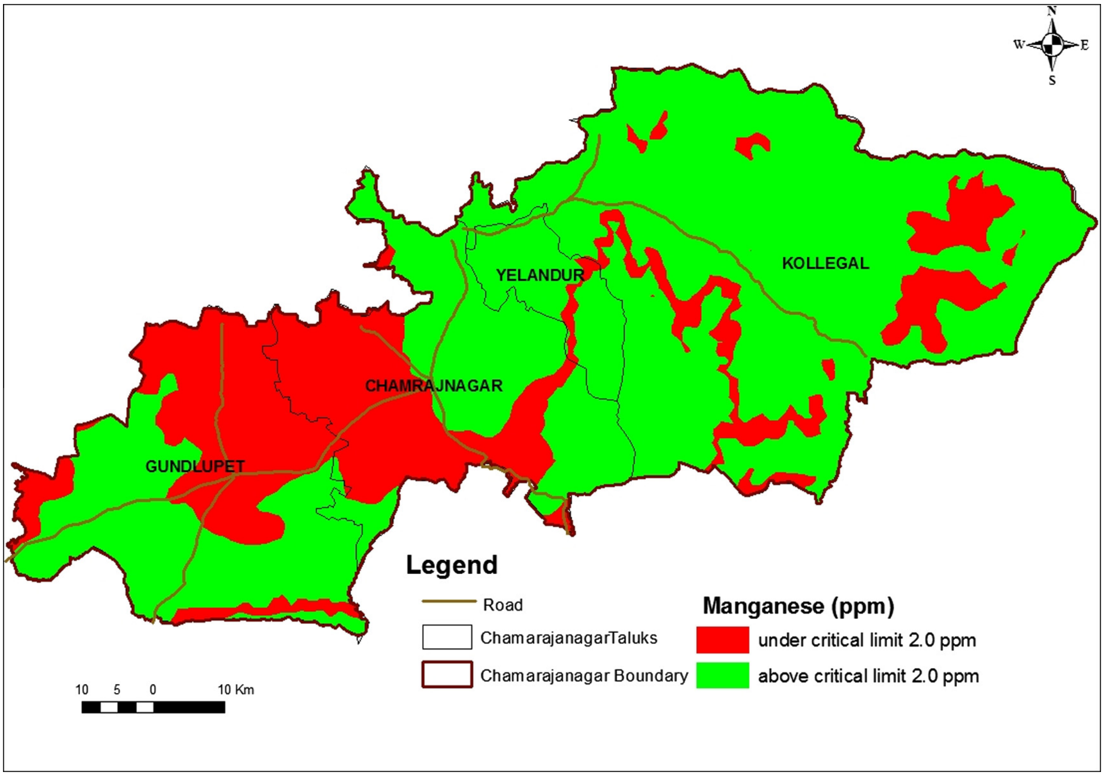

Figure 16 Manganese content (ppm) in soil of Chamarajanagar district.

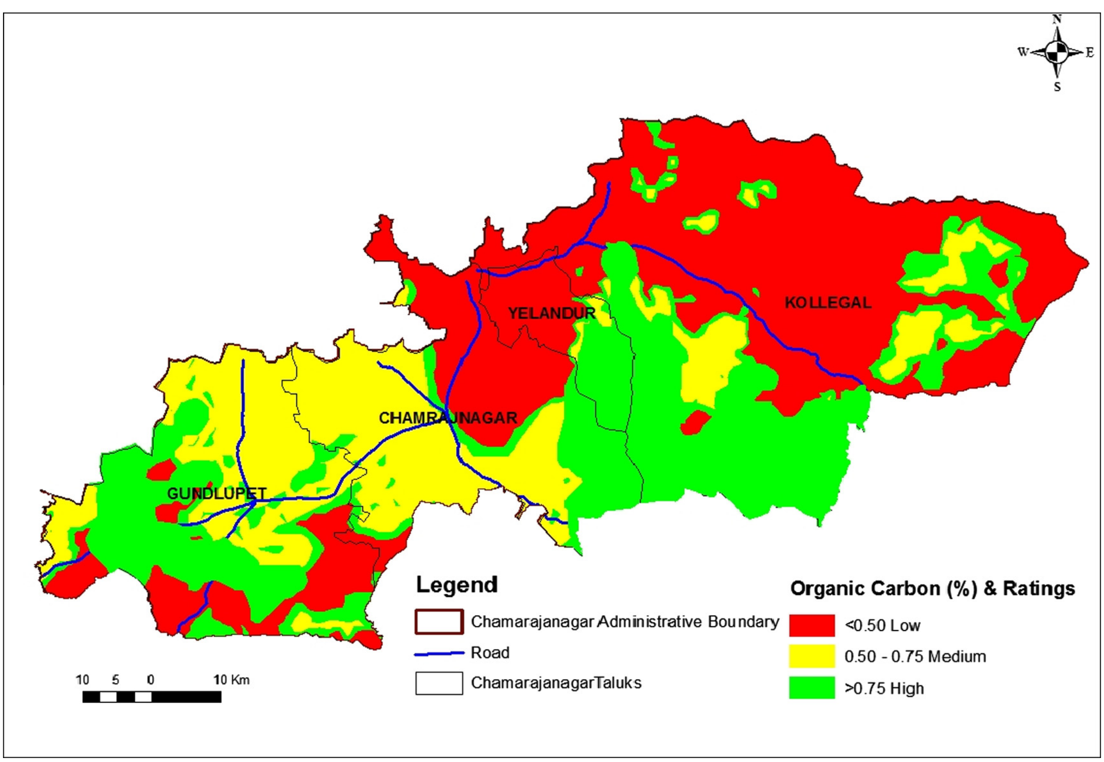

Figure 17 Organic carbon ratings of Chamarajanagar district.

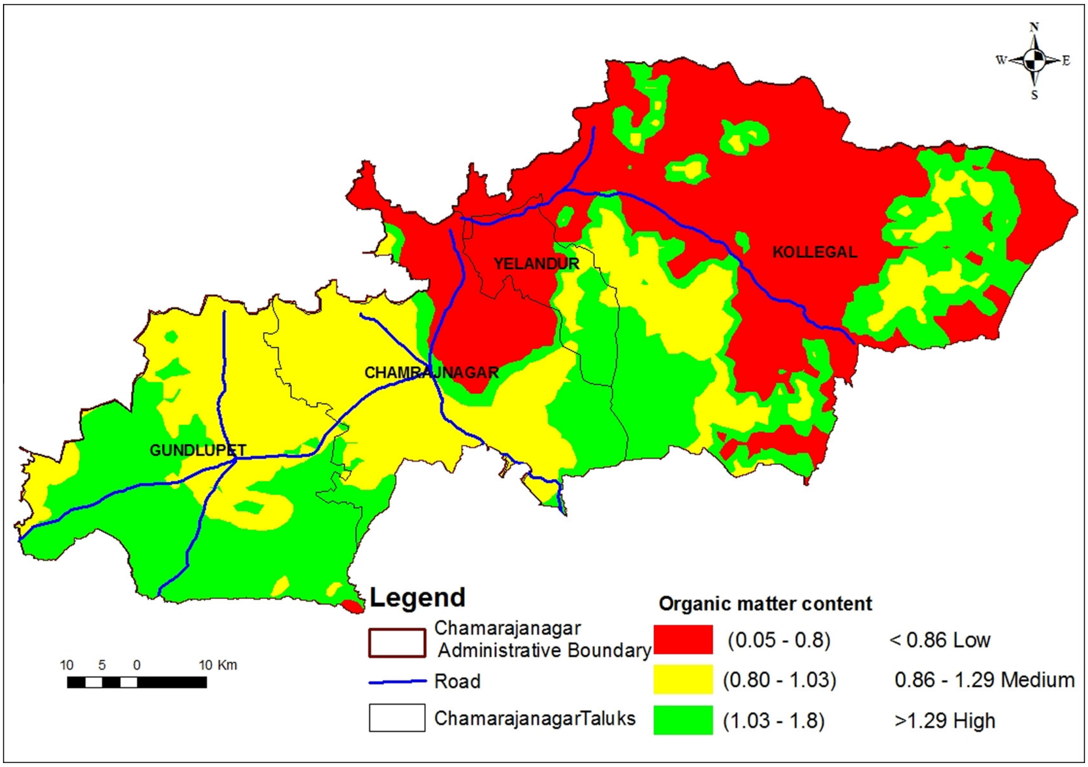

Figure 18 Organic matter of Chamarajanagar district.

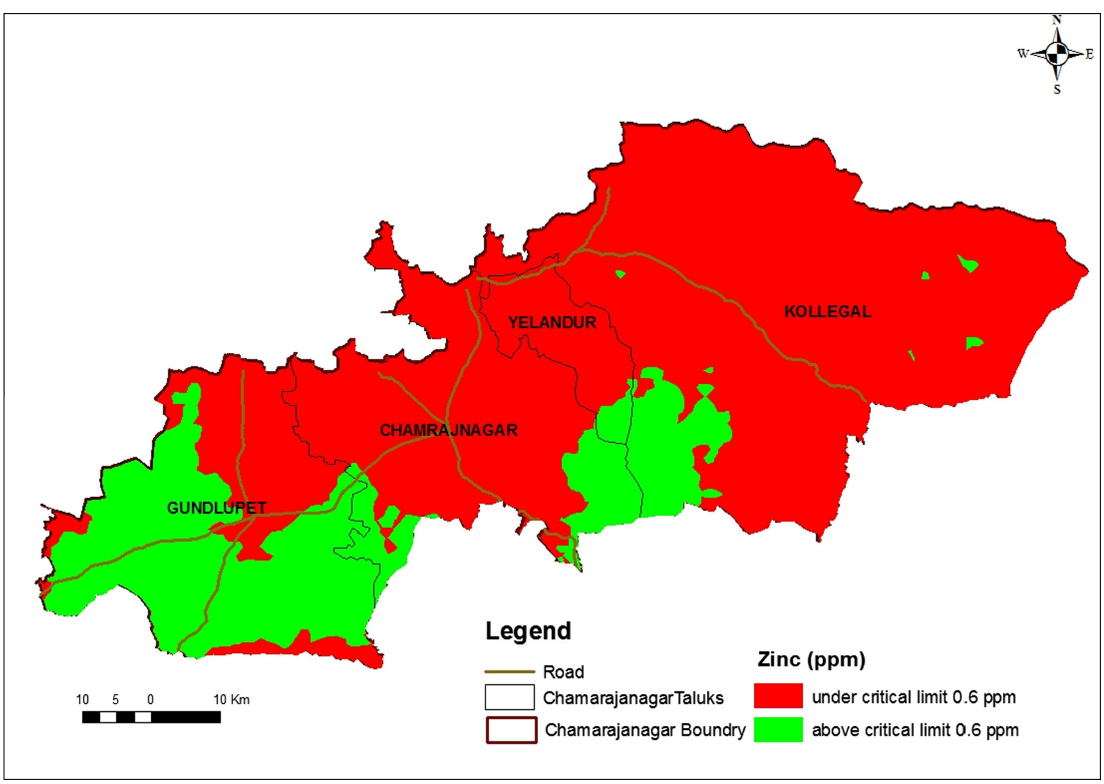

Figure 19 Zinc content (ppm) and its ratings in soil of Chamarajanagar district.

3.5. Nutrient status under actual land degradation

The chemical properties of the study area as in (Figs. 8–19) shows that EC is ranged from 0.1 to 0.31 d Sm-1 in salinity class low and the nature of the soil is normal. pH shows that the soil difference between acidic, neutral, and alkaline soil and this clear in the area as it is suffer from moderate water erosion. Acidic classes found in high land, neutral soil found in mid portions of low land and alkaline soil found in low land as a result of water erosion. Organic carbon (%) shows that soil is different between low, medium and high. Low classes of organic carbon found in high land, medium organic carbon content in soil found in mid portions of low land and high content in soil found in low land and the highest amount found in forest area. Low content of Organic matter refers to the high rate of organic decomposition because of high temperature of the climate and less application of organic residue. Nitrogen shows that the study area has low nitrogen content as result of low organic matter in soil. Available phosphorous shows that the study area has the three ratings low, medium and high phosphorous content in soil. Small area has low content and remains area between high and medium content of phosphorous. Micronutrients show that most the study area has Iron content under critical level (2.5–4.5 ppm) and very less occupied area with iron within the critical level (2.5–4.5 ppm). Eastern part of the agriculture area of Chamarajanagar district has manganese content above the critical limits 2.0 ppm but western part is under the critical limits. Copper is higher than the critical level 2.0 ppm in most of the area and small part of the district is under the critical level. Zinc is lower the critical level 0.6 ppm in most of the area and small part of the district is above the critical level 0.6 ppm.

4. Conclusions

Based on the length and degree of slope from SRTM, land use/cover and soil characteristics as revealed by IRS-LISS-III and IV data and other related ancillary data from field survey, assessment of soil erosion was found to be none or slight to very sever while using RUSLE the present water erosion was found to be moderate to high in Chamrajanajar district of Karnataka. The extent and geographical distribution of degraded lands areas can be used as an input for future planning reclamation conservation program. IRS LISS-III & IV remotely sensed satellite digital data have been used to classify the different land use/land covers, and Shuttle Radar Topographic Mission (SRTM) digital elevation model (DEM) data were used to draw the classified slope maps. Satellite data have become valuable tools in studying the spatial extent of degraded lands and for monitoring the changes that have taken place over a period of time due to reclamation/conservation measures. The methodologies can be used to extract precise and timely information on different aspects of degraded lands in a cost effective manner on operational basis. The methodology developed can be used for regular monitoring of degraded lands.

Land degradation map is generated from the combination of many parameters (soil degradation factors) which interact with each other in a complex way generating the final quantitative degradation classes. The data showed that the immediate result of biological degradation is the loss of organic matter, the main consequences of which are physical degradation, loss of nutrients and increase of runoff and erosion. Loss of organic matter can also result from erosion. The present study confirms that Remote Sensing and GIS spatial modeling are useful tools in generating spatial and quantitative information on land degradation status of any area and for risk assessment mapping. Future work should focus on the suitable soil and water conservation practices to overcome the land degradation.

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References

Das, D.C., 1985. Problem of soil erosion and land degradation in India. Proc. Nat. Sem. Soil Conserv. Watershed Mgmt., New Delhi.

Gupta, H.S., 2001. Remote sensing techniques for evaluating landuse/land cover: a case study. Indian Forester 127, 755–761.

Karale, R.L., Saini, K.M., Narula, K.K., 1988. Mapping and monitoring ravines using remotely sensed data. J. Soil Water Conserv. 32 (1,2), 75.

Lal, R., 1998. Soil erosion impact on agronomic productivity and environment quality. Crit. Rev. Plant Sci. 17, 319–464.

Lal, R., Mokma, D., Lowery, B., 1998. Relation between soil quality and erosion. In: Lal, R. (Ed.), "Soil Quality and Soil Erosion". CRC Press, Boca Raton, FL, pp. 237–257.

Lillesand, T.M., Kiefer, R.W., 2000. Remote Sensing and Image Interpretation, IV Edition. John Wiley & Sons Inc, USA.

Lowery, B., Hart, G.L., Bradford, J.M., Kung, K.-J.S., Huang, C., 1998. Erosion impact on soil quality and properties and model estimates. In: Lal, R. (Ed.), Soil Quality and Soil Erosion. CRC Press, Boca Raton, FL, pp. 75–93.

Norton, D., Shainberg, I., Cihacek, L., Edwards, J.H., 1998. Erosion and soil chemical properties. In: Lal, R. (Ed.), Soil Quality and Soil Erosion. CRC Press, Boca Raton, FL, pp. 39–55.

NRSA. 1981. Satellite remote sensing survey for soil and land use in part of Uttar Pradesh. Project Report National Remote Sensing Agency, Hyderabad.

Olson, K.R., Mokma, D.L., Lal, R., Schumacher, T.E., Lindstrom, M. J., 1998. Erosion impacts on crop yield for selected soils of the North Central United States. In: Lal, R. (Ed.), Soil Quality and Soil Erosion. CRC Press, Boca Raton, FL, pp. 259–283.

Rao, K.V.S., Bali Y.P., Karale R.L. 1980. Remote Sensing for soil conservation and watershed management. Proc. Sem. Application of Photointerpretation and Remote Sensing Techniques for Natural Resources Survey and Environmental Analysis, Dehradun.

Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool, D.C. Yoder (coordinators). "Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE)". USDA Agr. Handb. No 703, 1997.

Venkataratnam L., Rao K.R. 1977. Computer aided classification and mapping soils and soil limitations using Landsat multispectral data. Proc. Symp. Remote Sensing for Hydrology, Agriculture and Mineral Resources. Space Applications Centre. Ahmedabad.