CHARACTERIZATION AND MAPPING OF DEGRADED LANDS IN NAGPUR DISTRICT OF MAHARASHTRA USING REMOTE SENSING AND GIS TECHNIQUES

THESIS

Submitted to

Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola
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for the Degree of

DOCTOR OF PHILOSOPHY
IN
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(SOIL SCIENCE AND AGRICULTURAL CHEMISTRY)
(Land Resource Management)

BY

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DECLARATION OF STUDENT

I hereby declare that the experimental work and its interpretation of the thesis entitled **"Characterization and mapping of degraded lands in Nagpur district of Maharashtra using remote sensing and GIS techniques''** or part thereof has not been submitted for any other degree or diploma of any University, nor the data have been derived from any thesis / publication at any University or scientific organization. The sources of materials used and all assistance received during the course of investigation have been duly acknowledged.

Place : Nagpur **(Thelkar Sonal Ishwardas)**

Date : **Enrolment No. KK - 2581**

CERTIFICATE

This is to certify that the thesis entitled "**Characterization and mapping of degraded lands in Nagpur district of Maharashtra using remote sensing and GIS techniques**" submitted in partial fulfillment of the requirements for the degree of "**Doctor of Philosophy in Agriculture (Soil Science and Agricultural Chemistry with specialization in Land Resource Management)**" of the Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola is a record of bonafide research work carried out by **Miss. Thelkar Sonal Ishwardas** under my guidance and supervision.

The subject of the thesis has been approved by the student's Advisory Committee.

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AEZ	Agro Ecological zone
AWC	Available Water Content
B.D.	Bulk density
BS	Base Saturation
CV	Coefficient of variation
CEC	Cation Exchange Capacity
cmol (p+) kg^{-1}	Centimole protons per kilogram
ESP	Exchangable Sodium Percentage
et al.	Et alia (and others)
EVI	Enhanced Vegetation Index
FC	Field Capacity
GIS	Geographical Information System
Ha	Hectare
Kpa	Kilo pascal
LGP	Length of Growing Period
ML	Marginal Land
MPL	Moderate Prime Land
Mgm^{-3}	Mega gram per cubic meter
Mm	Milli meter
MSL	Mean Sea Level
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
NMI	Normalized Moisture Index
NRSC	Natural Resources Conservation Services

OC	Organic carbon
PET	Potential evapotranspiration
Ppm	Parts per million
SAVI	Soil Adjusted Vegetation Index
SEZ	Special economic zone
SEM	Standard Error Mean
SOI	Survey of India
TGA	Total Geographical Area
USDA	United State Department of Agriculture
VCI	Vegetation Condition Index
WP	Wilting Point

(D) THESIS ABSTRACT

a)	Title of the thesis	:	**CHARACTERIZATION AND MAPPING OF DEGRADED LANDS IN NAGPUR DISTRICT OF MAHARASHTRA USING REMOTE SENSING AND GIS TECHNIQUES**
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ABSTRACT

The present investigation was undertaken to characterize and map soil erosion and degraded lands in Nagpur district of Maharashtra using remote sensing and GIS techniquesto prioritize and suggest suitable soil and water conservation measures for management of degraded lands of Nagpur district. Landsat 5, 7 TM+ temporal data, Cartosat-1, Digital Elevation Model (DEM) with 30 m resolution, land use/land cover, soil, climatic data, Survey of India (SoI) toposheets have been collected and processed using image processing software (TNT MIPS) to compute widely used RUSLE factors and integrated to compute soil loss. For Land degradation assessment, various important land degradation indicators have been identified and generated data sets using Landsat 5, 7 TM+ data and used in the development of land degradation index and generation of land degradation status map using Arc GIS software. The prime agriculture lands are delineated using established soil criteria and a multi-criteria analysis is carried out using soil, vegetation and water stress parameters to delineate prioritized conservation units.

Ten land use/land cover classes namely agricultural land (crop, fallow and plantation), forest (deciduous, plantation and degraded), barren scrub land/ wasteland, waterbody, habitation and mining have been delineated.Five slope classes *viz*. very gently sloping, gently sloping, moderately sloping, moderately steep sloping and steep sloping lands have been identified. Seven major physiographic units were delineated, namely, plateau top, hills and ridges, escarpments, subdued plateau, pediments, alluvial plain and valley. Based on the soil-physiography relationship, 23 soil series are tentatively identified in different physiographic units.

The study indicates that rainfall erosivity, soil erodibility, topographic, crop management and conservation factors range from

359.3 to 512.9 MJ. mm.ha^{-1}.hr^{-1}.yr^{-1}, 0.02 to 0.26 ton.ha.hr.ha^{-1}.MJ^{-1}.mm^{-1}, 0 to 50, 0.0 to 0.99 and 0.10 to 1, respectively. The classified soil erosion map indicates that 27.4 per cent area has severe to extremely severe erosion (25-50 to >50 ton.ha^{-1}.yr^{-1}), 4.3 per cent area has moderate erosion (15-25 ton.ha^{-1}.yr^{-1}) and 47.9 per cent and 12.4 per cent area has minimal to slight (<5 to 5-15 ton.ha^{-1}.yr^{-1}) erosion. The total soil loss of the study area is found to be 211 $\times$ 10^5ton.yr^{-1}. The average annual soil loss is estimated to be 21.4 t.ha^{-1}.yr^{-1}.

Quantitatively estimated soil loss, vegetation indices and soil wetness indices are used as land degradation indicators for land degradation assessment.Principal Component Analysis (PCA) was run on both vegetation indices and water stress indices separately to reduce the data redundancy and generate best Principal Component. This has been done using Eigen values, per cent Eigen values, factor loading/Eigen vectors. Principal Component which explained highest per cent variability for each vegetation and water stress are considered as input layer for land degradation assessment. Thus, Soil erosion in terms quantitative soil loss and Principal Component-1 (PC1) of Vegetation Index and Principal Component-1 (PC1) of Water Stress Index have been considered for more realistic land degradation estimates and included in the development of Land Degradation Index (LDI).The LDI computed was reclassified into four classes *viz*. non-degraded, slightly degraded, moderately degraded and severely degraded lands The spatial extent of land degradation indicates that 44.8 per cent of the TGA is under non-degraded lands, 25.2 per cent of TGA is under slightly degraded lands, 5.2 per cent of TGA is under moderately degraded lands, whereas, 17.0 per cent of TGA is under highly degraded lands.

Site characteristics recorded during ground truth and soil physical and chemical properties were used to validate soil erosion. Significant and negative correlation between organic carbon and soil erosion (r=-0.86**) and clay and soil erosion (r=-0.79**) is observed, whereas, significant and positive correlation is observed between slope and soil erosion (r=0.82**).

The Prime agricultural lands have been delineated using the criteria developed by NRCS of USDA. The area identified under prime lands was 470418 ha accounting 47.6 per cent of TGA. The area under moderate prime land is 85096 ha (8.6 % of TGA), whereas, area under marginal lands is 74700 ha (7.6 % of TGA).

Five prioritized soil conservation units have been delineated using a weighted multi-criteria analysis in Arc GIS taking into account the soil, vegetation and moisture stress and other soil-site parameters to delineate prioritized soil conservation units. Appropriate soil and water conservation measures have been suggested for management of degraded lands.

Chapter I

INTRODUCTION

1.1 Background Information

Land is the most valuable resource for production of food, fiber, fuel and many other essential goods required to meet human and animal needs. Land is continuously under threat of erosion and degradation due to various reasons (Bhaskar *et al.*, 2017). It is facing serious threats of deterioration due to unrelenting human pressure and utilization incompatible with its capacity (Tagore *et al*., 2012). The decline in land quality caused by human activities has been a major global issue since the 20th century and will remain high on the international agenda in the 21st century (Eswaran *et al*., 2001).

As per FAO definition, land degradation generally signifies the temporary or permanent decline in the "productive capacity" or "biological potential" of the land (Lacaze, 2004). Land degradation is a complex process in which several facts may be contributing to the loss of productivity. The kind and degree of land degradation depend on soil site characteristics, land use and management (Sehgal *et al.,* 1990). It is estimated that about one sixth of the world's population and one quarter of global terrestrial land is threatened by land degradation (UNCED, 1994).

On account of various forms of degradation, it has been estimated that the loss of 5,334 million tones of top soil occurs annually, which is equivalent to 5.37 to 8.4 million tones of plant nutrients (Dhruvanarayana and Rambabu, 1983). The Global Assessment of Human-induced Soil Degradation (GLASOD) used the GIMMS radiometer (AVHRR) data (8 km^2 resolution) and distinguished degrees and kinds of degradation globally, e.g. soil erosion by water or by wind. Out of total geographic area (TGA), India has occupied 1.75 per cent area subjected to land degradation (Bai *et al.*, 2008). In India, out of the total geographical area of 328.73 million hectares, 120.4 million ha of land, representing 37 per cent of the total geographical area, is subjected to soil erosion and land degradation (ICAR-NBSS&LUP, 2010) due to the pressure of growing population, increased demand for food, fodder and fuel wood and intensive industrial activity. Out of total degraded land (about 120.4 million ha) land, Maharashtra has occupied 9.70 million ha area out of which 8.8 million ha was affected by water and wind erosion followed by alkali soils (0.42 million ha) and remaining are acid soils, saline soils, water logged soils and industrial use (0.48 million ha) *etc*. (ICAR-NBSS & LUP, 2010).

Land degradation is an environmental issue (UNCED, 1992; UNEP, 2008) and increasing in severity and extent in many parts of the world, with more than 20 per cent of all cultivated areas, 30 per cent of forests and 10 per cent of grasslands undergoing degradation (Bai *et al*., 2008). Land degradation has affected around 5 to 10 million ha of agricultural land singly (Gao and Liu, 2008). It is estimated that 2.6 billion people are affected by land degradation and desertification in more than a hundred countries, influencing over 33 per cent of the earth´s land surface (Adams and Eswaran, 2000). Land degradation has mainly been studied at a local scale and from the perspective of the farmer and pastoralist, but it also has effects at the country, continental and global scales (Prince, 2002).

Land degradation can’t be simply defined and assessed by any single measure (Warren, 2002). Owing to its complex nature, use of indicators and identification of monitorables through remote sensing are inevitable; e.g. decline in crop yield may be an indicator that soil quality has changed, which in turn may indicate that soil and land degradation are also occurring.

The most common methods used to assess land degradation are: expert opinions, land users opinions, field monitoring, observations and measurement, modelling, estimates of productivity changes and remote sensing. Solely conventional ground based methods of land degradation suffer from limitations such as inadequate data of standard format and high subjectivity. In such a situation, a comprehensive approach that involves an optimum blend of modern survey techniques in conjunction with ground truth will be of immense value in taking timely and appropriate decisions. Remote sensing techniques are gaining increasing attention in this process (Narayan, 1989) and have long been suggested as a time and cost-efficient method for monitoring land degradation over a range of spatio-temporal scales (Bastin *et al*., 1993; Hill & Peter, 1996; Jafari *et al*., 2008; Kim, 2013).

Soil degradation can be characterized in terms of (1) accelerated soil erosion, and (2) a change in soil quality. The GLASOD survey provides basic data on the world distribution and intensity of erosional, chemical and physical types of degradation (Bridges and Oldeman, 1999). However, the study didn't include any remote sensing or field measurements; making it subjective and difficult to compare regions (Jones *et al*., 2003). Surrogate measures of soil erosion and quality can be derived from remote sensing imagery (Ostir *et al*., 2003). It can provide calibrated, quantitative, repeatable and cost effective information for large areas and can be related to the field data (Jafari *et al*., 2008).

Several erosion prediction models are available to predict the average annual soil loss and to assess the soil erosion risk (Renschler and Harbor, 2002). The Universal Soil Loss Equation (USLE), an empirical model (Wischmeier and Smith, 1978) or Revised USLE (RUSLE) model (Renard *et al.,* 1997; Dela Rossa *et al*., 1999; Lu *et al*., 2004; Fu *et al*., 2006; Schiettecatte *et al*., 2008) are widely used to predict potential soil water erosion. RUSLE uses the same empirical principles as USLE, but includes numerous improvements in computation of various factors. It predicts longtime average annual soil loss as a product of rainfall erosivity (R), soil erodibility (K), slope length (L), terrain steepness (S), cover and management (C) and conservation practices (P) factors. Among these factors, topographic factor is most sensitive in prediction of the soil loss (Risse *et al.,* 1993). Other physically-based models such as WEPP (Flanagan *et al.*, 2007), LISEM (De Roo *et al.,* 1996), and SWAT (Gassman *et al*., 2007) have certain disadvantages: (a) extensive data requirement and calibration parameters; (b) complex laboratory analyses and expensive field data collection mostly unfeasible to use in many developing countries; and (c) lack of optimization method. The use of remote sensing and GIS techniques makes soil erosion estimation and its spatial distribution feasible with reasonable costs and better accuracy in larger areas as compared to the traditional methods (Boggs *et al.,* 2001; Cerri *et al.,* 2001; Bartsch *et al.,* 2002; Wang *et al.,* 2003).

In recent years, the availability of high resolution satellite data has facilitated in large scale inventory of land use / land cover, erodibility, erosivity, *etc* (Millward and Mersey, 1999; Reusing *et al.,* 2000; Ma *et al.,* 2003), while, GIS tools were used for derivation of the topographic factor from Digital Elevation Model (DEM) for calculation of soil erosion loss (Bartsch *et al.* 2002; Wang *et al.* 2003). Soil erosion assessment of Nagpur district of Maharashtra using remote sensing and GIS techniques employing USLE method had been documented (Srinivas *et al*., 2002). The RUSLE / RUSLE- 3D model has been widely used for spatial prediction of soil loss and erosion risk potential (Shi *et al.*, 2004; Terranova *et al.,* 2009; Park *et al*., 2011). The present study aims to assess the spatial pattern of soil erosion risk of degraded lands in Nagpur district of Maharashtra using RUSLE model.

Land degradation necessarily involves not only the soil degradation and its impact on vegetation component; but also the interrelations of other land components as climate, soil, water and vegetation which might be characterized through water stress or drought related indicators of remote sensing. Majority of the previous studies regarding land degradation had ignored the interrelationships of other components. Characterizing and monitoring of water stress in semi-arid regions of Nagpur district, Maharashtra is of immense importance as the district had a historical background of recurring water stress situations (MNCFC/NCFC, 2012).

Traditional water stress assessment and monitoring methods rely on rainfall data, which are limited in the region, often inaccurate and most importantly, difficult to obtain in near-real time. In contrast, the increased availability of satellite data have the potential to capture the magnitude of water stress based on monitoring of vegetation condition as well as water content vis-à-vis drought related indicators using long term temporal satellite data. Several researchers have already tried to use satellite images to detect water stress through indices (Anderson *et al*., 2010; Mu *et al*., 2013). In the last three decades, several water stress related indices have been proposed based on normalized different vegetation index (NDVI, Rouse *et al.,* 1974) to monitor water stress severity such as Normalized Différence Water Index (NDWI) (Ceccato *et al.,* 2001), Normalized Moisture Index (NMI) (Jang, 2004), Vegetation Condition Index (VCI) (Kogan 1995), Temperature Condition Index (TCI) and Vegetation Health Index (VHI) (Kogan *et al*., 2004) *etc*.

Despite the importance of Land degradation Index (LDI) in describing land degradation status, there is no universally accepted selection, scoring, weighted and Land Degradation Indexing method for regional scale. The most widely reported MDS (Minimum Data Sets) methods of Land Degradation indicators are expert opinion and statistical tools (e.g. Principal Component Analysis, PCA). A number of data reduction techniques are based on finding Eigen functions for the second-order statistics of the data (Therrien, 1989). The most prominent of these approaches is called principal component analysis also referred to as the Karhunen–Loeve transform in the signal processing literature.

Selection of appropriate land degradation indicators on the basis of their functions and other decision rules such as relation to degradation, their role in determining degradation status as well as other specific factors is very important. The three indicators *viz*. soil erosion, vegetation and water stress usually appears together in areas, so it should be more useful to study them in conjunction. A system requires a comprehensive and multilayer platform to integrate the simulation of the three land degradation indicators through a relatively complex modeling approach like PCA in Arc GIS software. These indicators are used for selecting a minimum dataset, combining indicators into a final index approach, reducing the number of indicators. The method was recommended by several authors (Karlen and Stott, 1994; Chen, 1999; Hussain *et al.,* 1999; Murage *et al.,* 2000; Brejda and Moorman, 2001; Wander *et al.,* 2002; Andrews *et al.*, 2002, 2004, 2005; Govaerts *et al.,* 2006). The main applications of the factorial techniques are reducing the number of variables and detecting the relations between them. It is the transformation to a new set of variables, the principal components (PCs), which are uncorrelated and ordered so that the first PC retains most of the variation present in all of the original variables (Dunteman, 1989; Jolliffe, 2005). Thus, the integration of expert based system with PCA in GIS to study degradation risks is on the rise (Le Bissonais *et al*., 2002; Ni *et al*., 2008).

1.2 Importance and need of study

Land degradation is one of the most serious ecological problems in the world. It entails two interrelated, complex systems: the natural ecosystem and the human social system (Fadil, 2009). Causes of land degradation are not only biophysical but also socio-economic (marketing, income, human health, institutional support, poverty), undermining food production and political stability (UNCCD, 2004; WMO, 2006)**.** The immediate causes of land degradation are inappropriate land use that leads to degradation of soil, water and vegetative cover and loss of both soil and vegetative biological diversity, affecting ecosystem structure and functions (Snel and Bot, 2003). Degraded lands are more susceptible to the adverse effects of climatic change such as increased temperature and more severe droughts.

Although numerous works had been directed towards soil erosion, degradation and drought monitoring using remote sensing approach, very few works have been reported from the semi arid black soil regions (BSR) of India, despite of the fact that these soils are more prone to erosion, water stress and degradation.

While, soil survey database of Nagpur district (NBSS&LUP, Nagpur, 1990) revealed a considerable proportion of survey sites to be under different levels of soil erosion and degradation, the semi arid nature of the climate makes it inherently susceptible to water stress situation. Black Soil Region (BSR) being one of the most productive zones of the country, it is very essential to understand the degradation processes and estimate their extent and distribution to prioritize areas for soil and water conservation measures and alternative land use options for better management of degraded lands.

1.3 Objectives of study

The present study aims to characterize and map degraded lands in Nagpur district of Maharashtra using remote sensing and GIS techniques with the following objectives:

1. To characterize and assess the land degradation status of Nagpur district combining ground study and satellite based monitorable indicators.

2. To estimate the potential soil loss of Nagpur district based on satellite data and ancillary soil-climate informations.

3. To prioritize and suggest suitable conservation measures for management of degraded lands of Nagpur district.

1.4 Hypothesis

Geo-information technology (Remote Sensing, Geographic Information Systems, GIS and Global Positioning System, GPS) and their integration help in assessing and monitoring the land degradation environment and its components. Areas affected by degradation can be identified and mapped using satellite images by computing different vegetation and water stress indices in integration with soil erosion studies. Information on soil erosion, vegetation indices and water stress indices can be derived from remotely sensed data for spatial distribution of land degradation and monitoring.

1.5 Scope and limitations

The conventional ground based methods of land degradation suffers from limitations such as inadequate data of standard format and high subjectivity. Hence, a comprehensive approach can provide calibrated, quantitative, repeatable and cost effective information for larger areas. Hence, different methods *viz*., an expert knowledge, Multi Criteria Analysis (MCA) and Principal Component Analysis (PCA) algorithms are effectively used for the land degradation assessment. The detailed characterisation and mapping of degradation helps in estimating degradation risks of the areas using remote sensing and GIS techniques. Assessment of soil erosion with remotely sensed data and integrating with other land degradation indicators *viz.* vegetation and water stress indices is found to be a time and cost-efficient methods for realistic assessment and monitoring of land degradation over a range of spatio-temporal scales. It helps in identification of soil and climatic related constraints for prime agricultural land delineation, prioritize soil and water conservation measures and suggest alternative land use for better management of degraded lands.

Chapter- II

REVIEW OF LITERATURE

A brief review of literature related to the study has been grouped under following heads and sub-heads.

2.1 CHARACTERIZATION AND MAPPING OF LAND RESOURCES

2.1.1 Land Use/Land Cover Mapping

2.1.2 Physiography-soil Mapping

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2.1 CHARACTERIZATION AND MAPPING OF LAND RESOURCES

2.1.1 Land use/ land cover

Saxena *et al*. (2000) prepared the land use/land cover map of Gondkhairi watershed near Nagpur, Maharashtra using geocoded false colour composites (FCCs) of IRS-1B LISS-II and IRS-IC LISS-III at 1:50000 scale. The land use/land cover study indicated that the major land utilization types are single crop (28.8%), double crop (14.3%); scrub land (43.1%); degraded notified open forest (7.2%), rock outcrop (3.8%) and water bodies (2.8%).

Lingade (2001) prepared the land use/land cover map of Mangli village, Nagpur district of Maharashtra using IRS-1C LISS-III PAN merged data. The land use/land cover classes identified are agricultural land (single crop and double crop land, orchard, fallow land), scrubland and wasteland, habitation, streams/nala and roads.

Mahajan *et al*. (2001) carried out the topographic analysis of Ashwani Khad watershed in Himachal Pradesh using IRS-ID satellite data of 1999. They reported that out of the total geographical area (85.30 km^2) of watershed, 54.5 per cent is under wasteland, 33.6 per cent under agriculture and the remaining 11.9 per cent under forest lands.

Patel *et al*. (2001) prepared the land use/land cover map of part of Solani watershed of Haridwar and Saharanpur districts in Uttaranchal and Uttar Pradesh using IRS-1C and LISS-III (October, 1997 for *kharif* and March, 1998 for *rabi* season). They identified five categories of land use/land cover *viz*. agricultural land (*Kharif*, *rabi*, *kharif*+*rabi*, plantation, fallow) forest land (Dense forest, moderately dense forest, open forest, forest plantation), waste land/scrub land, habitation and water bodies.

Srivastava *et al*. (2001) visually interpreted IRS-1C PAN merged LISS-III data to derive information on land use/land cover of Junewani village of Nagpur district in Maharashtra for village level agricultural resource planning. They have reported that nearly 68 per cent area of the village is under agriculture, 13 per cent under forest, 14 per cent under wasteland and the remaining 5 per cent under miscellaneous category (habitation, road and streams).

Bodhankar *et al*. (2002) studied the land use/land cover of Devadkasha watershed of Nagpur district, Maharashtra based on data of two seasons (*kharif* and *rabi*) of IRS-1C LISS-III (1:50,000 scale) and reported that agriculture land occupied nearly 33 per cent area of watershed, whereas, forest, scrub/wastelands occupied 43 and 22 per cent, respectively and the remaining 2 per cent under water body and habitation.

Gawande *et al*. (2002) prepared land use/land cover map of Kamthi area, Nagpur district, Maharashtra using IRS LISS-III FCC of bands 2, 3 and 4 (1:250,000 scale) and reported that major part of the area was covered by agricultural land followed by built up and waste land.

Sreedevi *et al*. (2002) prepared the land use/land cover map of Pageru river basin on 1:50,000 scale by visual interpretation of IRS-1B LISS-II FCC in conjunction with SOI toposheets. Agricultural land occupied 72.9 per cent. The double cropped area was very limited occupying 3.2 per cent. Degraded/open forest, wastelands, water bodies and grassland/grazing land constituted 4.0, 14.4, 1.97 and 2.0 per cent, respectively. The built-up land in the basin area was only 1.0 per cent.

Potdar *et al*. (2003) prepared the land use/land cover map of two seasons of Nanda-Khairi watershed of Nagpur district, Maharashtra. They identified agricultural lands, notified forests, wastelands, habitation and streams/nala.

Durbude and Venkatesh (2004) prepared land use/land cover map on 1:50,000 scale for Hire watershed in Koppal district of Karnataka using IRS-1C LISS-III in conjunction with SOI toposheet. They categorized land use/land cover in five classes *viz*. agriculture, built-up land, scrub land, waste land and water body.

Shamsudheen *et al*. (2005) used IRS-1D LISS-III data to prepare land use/land cover map of Kumtataluka of Uttar Kannada district of

Karnataka. Their study indicated that majority of the land was under agriculture (groundnut, paddy, pulses, sugarcane and plantation crop), wasteland, forest plantation, forest, degraded forest and water bodies.

Solanke *et al*. (2005) characterized the land resources of Ganeshpur micro-watershed near Nagpur, Maharashtra using IRS-1C PAN merged LISS-III data of March 2002 and December 2002 in conjunction with Survey of India toposheet. They classified land use/land cover in eight classes *viz*. agricultural land (Single and double crop), notified forest (Moderately dense and degraded forest), wastelands (with scrub and without scrub), habitation and water body.

Sharma and Chaudhary (2007) prepared the land use/land cover map of Mandhala watershed in Shiwalik foot hills of Himachal Pradesh. Watershed was characterized by six major land use/land cover classes *viz*. mixed dense forest, sparse/open forest, agriculture, scrub-land, grassland and agricultural plantation.

Bandyopadhyay *et al*. (2009) prepared land use/land cover map using IRS-1D LISS-III data of Feb. 2004 at 1:50,000 scale in conjunction with SOI toposheet of Hisarghatta watershed, Karnataka. They classified land use/ land cover as double crop (Kharif crops, rabi crops with fallow land), plantation crops, forest, grasslands, scrubs, rocky area, settlement and water body.

Kashiwar *et al*. (2009) characterized the land resources of Salai watershed near Nagpur, Maharashtra using IRS-1D LISS-III and PAN sharpened LISS-III data. They delineated and mapped land use/land cover classes as single crop, double crop, scrubland and moderately dense forest.

Shukla *et al*. (2009) studied the land resources of Dhamni micro-watershed in Chandrapur district of Maharashtra and reported that 84.2 per cent of watershed was under cultivation. Forest comprises 4.5 per cent (mainly degraded) and wasteland with scrub covering 9.4 per cent area of the watershed.

Singh *et al*. (2009) used IRS-1C/P6 satellite imagery for preparation of land use/land cover map of Soankhad watershed, Punjab. They identified six different classes of land use (i) agriculture (ii) dense forest (iii) open forest (iv) shrub forest (v) barren land and (vi) river bed/choe.

Ardak *et al*. (2010) prepared land use/land cover map of Khapri village of Nagpur district of Maharashtra on 1:12,500 scale based on IRS-P6 LISS-IV and IRS-1D PAN merged LISS-III data. They identified and mapped land use/land cover classes as agriculture (Single crop and double crop), degraded forest and wasteland with scrub.

Girish-Patil *et al*. (2010) prepared the land use/land cover map of Lendi Watershed, Chandrapur district of Maharashtra using IRS-1D LISS-III. The major land use/land cover classes identified in the watershed were cultivated land (62.8%), wasteland with scrub (18.9%), forest (14.9%), rockout crop (quarry) (0.7%) and water body (2.0%). The cultivated area was further delineated into single (43.3%) and double cropped (19.5%) areas.

Shilpa-Patil *et al*. (2010) prepared land use/land cover map of Longadga watershed of Chandrapur district of Maharashtra using IRS-1D LISS-III and Landsat-7 TM data. They classified land use/land cover into cultivated land, wasteland with scrub, water body and habitation.

Bante *et al*. (2012) visually interpreted IRS-1D LISS-III and LISS-IV data of Taroda watershed of Vidarbha region of Maharashtra for land use/land cover which indicated that 54.8 per cent of TGA was under cultivation, 22.7 per cent under wasteland with scrub and 21.1 per cent was under degraded forest.

Deshmukh *et al*. (2012) studied the land use/land cover of Tandulwani watershed of Nagpur district, Maharashtra using Geocoded FCC of IRS-P6 LISS-IV imagery and SOI toposheet (1:50,000) and found nearly 42.8 per cent of the area is crop land, 37.5 per cent notified forest, 19.4 per cent wasteland and the remaining 0.3 per cent habitation.

Das *et al*. (2013) studied nine villages of Doomdoma sub division of Tinsukia district of Assam using IRS-P6 LISS-IV, Cartosat-1and LISS-IV + Cartosat-1merged and LISS-III images and classified land use and land cover as agriculture (Field crops and tea garden), wastelands (Scrubland), built up forest plantations and water body where in 81 per cent of thestudy area was under agriculture use that includes *kharif* crop (Mostly winter rice called Sali rice in Assam), double crop (i.e. *kharif* and *rabi*) and tea gardens. Area under tea gardens was the highest and occupies 1173.3ha area which is 50 per cent of the total study area and 62 pe cent of agricultural land.

Nasre *et al.*(2013) prepared land use/land cover map of Karanji watershed of Yavatmal district of Maharashtra using IRS-P6 LISS-III and LISS-IV data and identified single crop, double crop, dense forest, moderately dense forest and waste land with scrub.

Raju *et al*. (2013) used remote sensing and Geographic Information System to classify land use/land cover of Vizianagaram district of Andhra Pradesh and identified agriculture land, built-up land, forest land and wasteland and water bodies. About 68 per cent of the total geographical area of the district is covered by agricultural land followed by forest land (15% of TGA) and waste land (10% of TGA), while built up land area covered 1 per cent of total geographical area.

Bhandari *et al*. (2014) studied watershed of Tons river in Dehradun using LISS-III remote sensing data. They identified the five LULC classes out of which, forest had the maximum cover of 60%, followed by agriculture (28.9%), waterbed (4.7%), flood plains (4.4 %) and scrub (1.0%) using a combination of two approaches, namely, visual image interpretation and digital image classification of FCC (Geocorrected at 1:50,000 Scale).

Das *et al*. (2014) characterized and evaluated land resources of Mawryngkneng block using IRS-P6 LISS-III and LISS-IV data. Visual interpretation of satellite data indicated that 32.2 per cent of the total geographical area (TGA) is under dense forest followed by wastelands

(28.8%), open forest (16.1%), cultivated area (13.6%), built up area (8.2%) and water body (0.9%).

Nagaraju *et al*. (2014) delineated five land use/land cover classes, namely, single crop, double crop, wasteland with and without scrub and degraded forest using Cartosat-1 merged IRS-P6 LISS-IV data in Savli village of Wardha district.

Nisha-Sahu *et al*. (2014) delineated six land use/land cover classes namely single crop, double crop, orchard, land with and without scrub and degraded forestusing IRS-P6 LISS-IV data in Miniwada Panchayat, Nagpur district.

Nagaraju and Gajbhiye (2014) prepared land use/ land cover map of Kukadi Command of Ahmednagar district of Maharashtra and classified land use/ land cover classes in to cultivated land (single and double crop),degraded and moderately dense forest and wasteland with scrub.

Rane and Joshi (2014) visually interpreted IRS-P6 LISS-III data to derive information on land use and land cover of Jalgaon district in Maharashtra. They have reported that agriculture remains the major land use class comprising about 65.8 per cent of the total geographical area followed by barren land (21.1 %), forest cover (8.4%), water body (2.8 %), built-up area (1.5%) and agriculture within the forest (0.6%).

Sarkar *et al*. (2014) identified eight land use land cover classes, namely, upper terrace, single crop, double crop, forest, degraded forest, rivers and water bodies, sandy area and settlements of Cooch Behar District, West Bengal by integrating Geographical Information System (GIS) approach with Hybrid classification using District Planning Map and multispectral Indian Remote Sensing-P6LISS-III data for 2008 and 2009 based on an emerging digital classification technique.

Nagaraju *et al*. (2015) prepared land use/land cover map in Saraswati watershed, Buldhana district, Maharashtra based on FCC of IRS-P6 LISS-III data. They identified and mapped land use/land cover classes as single crop, double crop, wasteland, water body and habitation.

2.1.2 Physiography-soil mapping

Saxena *et al*. (2000) used IRS-1C LISS-III (1:50,000 Scale) for characterization and management of Gondkhairi watershed in Kalmeshwar taluka of Nagpur district. Six physiographic units *viz*. tableland top, subdued plateau, escarpment, pediment, upper and lower valley were identified and mapped.

Bodhankar *et al*. (2002) utilized geo-coded false colour composite of IRS-1C LISS-III to prepare physiography map of Dewadkasha watershed in Nagpur district, Maharashtra. They identified and mapped the physiographic units *viz*., hills and ridges, plateau top, escarpment, pediment and buried pediment, which were further sub-divided based on slope and image characteristics.

Potdar *et al*. (2003) used FCC of IRS-1C LISS-III data visually interpreted in conjunction with SOI toposheet (1:50000 scale) of Nanda-Khairi watershed of Nagpur district, Maharashtra. Based on visual interpretation of satellite data and ground truth survey, six major physiographic units *viz*. plateau/summits, escarpment, upper foot slope, lower foot slope, upper alluvial plain and lower alluvial plain were identified and mapped.

Obi-Reddy and Maji (2003) characterized different geomorphic units of Tundiya river catchment in a part of lower Maharashtra, north eastern part of Nagpur district using IRS-ID LISS-III satellite data (bands 2, 3 and 4). Based on the satellite data analysis, the distinct geomorphological units *viz*. table top summits, structural hills, subdued plateau, linear ridges, shallow, moderate and deeply buried foot slopes, shallow valley fills and deep valley fills have been delineated.

Srivastava and Saxena (2004) prepared the soil map of Junewani village on 1:12,500 scale using IRS-1C PAN merged LISS-III data. They visually interpreted the remote sensing data of two seasons *viz*. kharif and rabi in conjunction with SOI toposheet (1:50,000 scale) and available ground truth to prepare the physiography–land use (PLU) map. The PLU delineation explained three-tier approach comprising landform, slope and land use characteristics of a given parcel of land.

Maji *et al*. (2005) used IRS-1C LISS-III data and identified summit crest, escarpment, isolated mounds, denuded plateau, foot slopes, upper piedmont, lower piedmont and narrow valley floor as dominant landforms in basaltic terrain in sub-humid tropics of Central India.

Solanke *et al*. (2005) delineated and characterized physiographic units of Ganeshpur micro-watershed, Nagpur district, Maharashtra using IRS-1C PAN merged LISS-III data of March 2002 and December 2002 in conjunction with SOI toposheet. The watershed has 4 major physiographic units *viz*. plateau top, escarpment, pediment and valley.

Sarkar *et al*. (2006) used IRS-1D LISS-III data merged with PAN to prepare the physiographic map of Patloinala micro-watershed of Puruliya district of West Bengal and delineated three physiography units *viz*., Upland (Tanr), Midland (Badi) and Lowland (Bahal and Kanali).

Martin and Saha (2007) used remote sensing and GIS techniques for the preparation of physiography map of Ason river watershed using LANDSAT TM data in conjunction with SOI toposheet (1:50,000 scale) and delineated physiographic units as hills, piedmont, valley, side slope and alluvial plain.

Martin *et al*. (2007) analysed landforms of Almora district, Uttarakhand in Kumaon region of lesser Himalayas. They visually interpreted IRS-1D LISS-III FCC (bands 2, 3 and 4) of April 30, 2000 on 1:50,000 scale. Major physiographic units identified in the area are summits /ridge tops, side/reposed slopes and fluvial valleys.

Kashiwar *et al*. (2009) visually interpreted FCC of IRS-1D LISS-III and PAN sharpened LISS-III in conjunction with SOI toposheet in Salai watershed of Nagpur district, Maharashtra. Physiographically, the area has been characterized into subdued hills,pediments and upper valley and 8 soil series were tentatively identified and mapped.

Shukla *et al.* (2009) carried out soil resource characterization of Dhamni micro-watershed of Chandrapur district, Maharashtra using IRS-

ID LISS-III satellite data and demarcated the watershed into three broad landscape units, *viz*., upland, midland and lowland.

Velmurugan and Guillen (2009) used IRS-P6 LISS-III (April and October 2006) and Landsat TM data for physiographic analysis and delineated alluvial plain, piedmont, Siwalik hill, residual hill and river in Solani watershed in Haridwar district, Uttarakhand and Saharanpur district, Uttar Pradesh. They reported that majority of mapping units are Typic Haplustepts with Entisols and Inceptisols being the major soil orders.

Ardak *et al.* (2010) used IRS-P6 LISS-lV and IRS-1D PAN sharpened LISS-lll (1:12,500 scale) data and GIS coupled with field survey for characterization and evaluation of land resources in Khapri village of Nagpur district of Maharashtra. Six major landforms *viz*. isolated hillocks, plateau top, escarpments, pediment, upland, and valley plain were identified and classified.

Nasre *et al.* (2013) interpreted IRS-P6 LISS-IV and LISS-III (1:50,000 scale) satellite data of two seasons to prepare physiography and soil map of Karanji watershed of Yavatmal district, Maharashtra. They identified seven major physiographic units *viz*. plateau top, escarpment, isolated hillocks, foot slope, undulating land, alluvial plain and valley. The soils of very gently sloping plateau top were very shallow, clayey and classified as Typic/Lithic Ustorthents, whereas, soils occurring on undulating land, foot slope, alluvial plain and valley having very gentle slopes, were moderately deep to very deep, clayey in texture and were classified as Typic/Vertic Haplustepts and Sodic Haplusterts. The soils of escarpments and isolated hillocks on moderately to moderately steeply sloping lands were very shallow, loamy and classified as Typic/Lithic Ustorthents.

Bhandari *et al.* (2014) characterized the physiography of Tons watershed, Dehradun. They divided study area into three major landforms (hilly, piedmont plains and flood plains) and further divided into 10 physiographic-soil units. Most part of the study was covered by Himalayan Mountains and piedmont plains.

Nagaraju *et al.* (2014) used a high-resolution Cartosat-1 DEM with a posting of 10 m generated from a Cartosat-1 stereo pair to derive terrain attributes. Based on erosional and depositional processes, five major landforms, namely, plateau top, escarpment, pediment (erosional), alluvial plain, and narrow valley (depositional), have been delineated using 3D perspective viewing of the landscape. Nine soil series were identified and a detailed soil map has been developed from the PLU map using soil series information and augur observations through the PLU–soil relationship.

Nisha-sahu *et al*. (2014) interpreted IRS-P6 LISS-IV with Digital Elevation Model (DEM) derived from Cartosat-1 stereo data of two seasons in Miniwada Panchayat, Nagpur district on basaltic terrain of central India. They identified seven major landforms *viz*.plateau top, scarp slopes, plateau spurs, pediments, undulating plains, valley and floodplain.

Singh (2014) interpreted IRS-1C LISS-III data of Mohan Rao watershed which exists between two states Haridwar district of Uttarakhand and Saharanpur district of Uttar Pradesh at the scale of 1:50,000. They delineated different physiographic units *viz*. Siwalik hills, Piedmont plain, Alluvial plain and Residual hills.

Nagaraju *et al*. (2015) studied the soils of Saraswati watershed in Buldhana district of Maharashtra and identified four physiographic units *viz*. plateau, pediments, broad and narrow valley. Soils of plateau are shallow to moderately shallow (Lithic Ustorthents/Typic Haplustepts/Vertic Haplustepts); soils of pediments are very shallow to shallow (Lithic Ustorthents/Vertic Haplustepts) and soils of broad and narrow valley are deep (Vertic Haplustepts/ Typic Haplustepts).

2.2 SOIL EROSION ESTIMATION

Several erosion prediction models have been used over the years to estimate soil erosion and topographic factors conventionally for large areasto predict the average annual soil loss and to assess the soil erosion risk. The Universal Soil Loss Equation (USLE), an empirical model (Wischmeier and Smith 1978) or Revised USLE (RUSLE) model (Renard *et al*., 1991; Renard *et al*., 1994; Renard *et al.,* 1997) are widely used to predict potential soil water erosion. Although, the RUSLE uses the same parameters as the USLE, it provides a more accurate estimation of soil loss. This is because the RUSLE has much expanded the existing data base of the USLE as well as made use of data previously not included in the same (Sinha and Joshi, 2012). The use of remote sensing and geographical information system (GIS) techniques makes soil erosion estimation and its spatial distribution feasible with reasonable costs and better accuracy in larger areas as compared to the traditional methods (Millward and Mersey 1999; Wang *et al*., 2003).

Batta *et al.* (1988) studied the soils of Saongi watershed and reported that the maximum runoff was observed from Lithic Ustorthents (300 mm) followed by Typic Chromusterts (230 mm) and Typic Ustochrepts (200 mm), whereas, the maximum soil loss was from Typic Ustochrepts (12.5 t ha^{-1} yr^{-1}) followed by Lithic Ustorthents (8.5 t ha^{-1} yr^{-1}) and Typic Chromusterts (7.9 t ha^{-1} yr^{-1}).

Pratap-Narain *et al.* (1993) prepared the soil erosion of map of West Bengal using Universal Soil Loss Equation(USLE). The soil erosion rates in West Bengal ranged from less than 5 t/ha/yr in deltaic and dense forest regions to more than 40 t/ha/yr in western parts of Chhotanagpur plateau and hilly regions. About 10 per cent of the area of state is under severe erosion (>20 t/ha/yr) needing immediate attention. The area under moderately severe (15-20 t/ha/yr) and moderate erosion classes (10-15 t/ha/yr) is about 6 and 13 per cent, respectively. About 70 per cent of the area of West Bengal lies under slight to moderate erosion class with a soil loss of <10 t/ha/yr.

Saxena *et al.* (1994) followed the integrated approach of remote sensing for land degradation assessment of Kangra district, Himachal Pradesh. They prepared physiography, altitude, slope, land use, soil map and demarcated landscape ecological units and suggested priority area for soil and water conservation.

Jana *et al.* (1995) utilized remote sensing data to identify the eroded areas and formulated different conservation measures in the Darjeeling Himalayas in India. They proposed biological and mechanical soil conservation measures. Biological measures included improving the soil organic matter content and appropriate tillage and cropping practices. Mechanical methods included gully diversions, channel protection and terracing. Contour ploughing is practiced to control soil erosion.

Adinarayana (1996) utilized multi source data for evaluation of watershed environmental resources and soil erosion in Western Ghats. Maps of different themes were prepared from different sources, which included remotely sensed data, topographical sheets and some ground data.

Bhattacharya (1997) carried out the erosion assessment of the Rakti river basin in the Darjeeling Himalaya to formulate the suitable conservation measures for various zones of soil erosion. Four important factors based on the Universal Soil Loss Equation of USDA as well as the procedure of FAO have been taken into account for such quantitative assessment. They were (i) climatic rainfall erosivity (R); (ii) soil erodibility (K); (iii) topographic erosivity (LS) and (iv) biological erosivity (CP). Both the potential and predicted or actual soil erosion has been estimated using the equations RKLS and RKLSCP, respectively.

Roslan *et al.* (1997) studied the land use management factor *i.e*. cover and management factor (C) and support practices (P) of the universal soil loss equation (USLE) from remote sensing imagery as this parameter affects the land cover in the study area and its effects on soil erosion.

Srivastava *et al.* (2000) adopted an integrated approach of remote sensing and GIS in assessing soil erosion hazards in Jhilpi watershed of Nagpur district, Maharashtra using USLE model. Soil erodibility (K) and crop management and conservation factors (CP) were derived from the soil and land use/land cover maps prepared using IRS-1C LISS-III data. The soil erosion map prepared by the integration of USLE factors resulted in six soil erosion classes. Major area (38.3 %) of the watershed is under slight erosion with soil loss of <5 t/ha/yr. The moderately slight erosion (5-10 t/ha/yr) and moderate erosion (10-15 t/ha/yr) covered 26.4 and 22.3 per cent area of the watershed. The area under moderately severe (15-20 t/ha/yr), severe (20-40 t/ha/yr) and very severely erosion (>40 t/ha/yr) classes cover nearly 4.5, 2.1 and 6.4 per cent, respectively.

Kurothe *et al.* (2001) prepared soil erosion map of Maharashtra state. For this, Universal Soil Loss Equation (USLE) was used to estimate soil loss from 2735 points on 10x10 km grid distributed over entire Maharashtra. Various parameters of USLE were worked out by using information on rainfall, soil parameter, topography and land use collected from various sources. The computed values of soil loss were grouped into seven classes. The results showed that soil loss in Maharashtra varied from very slight (<5 t/ha/yr) in 45.54 per cent area to extremely severe (>80 t/ha/yr) in 5.61 per cent area. The severity of erosion normally increased with rainfall and steepness of slope. High intensity rainfall received on hilly areas of Konkan coast and Western Ghats region produced relatively higher amount of soil loss.

Sharma *et al.* (2002) determined the priority of sub-watersheds of Song River based on estimates of soil loss using Universal Soil Loss Equation and suggested suitable soil conservation measures. Land use/land cover and physiography cum-soil maps were prepared from IRS-ICLISS-III data, terrain slope information obtained from topographic maps and climatic data were used to provide inputs to USLE model. Average soil loss for each sub-watershed was computed and priority categories were determined.

Srinivas *et al.* (2002) predicted the soil loss in Nagpur district of Maharashtra employing USLE method integrated with GIS analysis to delineate suitable conservation units by remote sensing techniques leading to a reduction in potential soil loss. The average soil loss was estimated to be 23.1 and 15.5 tons/ha/yr under potential and actual conditions, respectively.

Potdar *et al.* (2003) studied soil erosion in Nanda-Khairi watershed of Nagpur district, Maharashtra using geocoded false colour composite (FCC), IRS-ICLISS-III data. Nearly, 62 per cent area of the watershed was under slight erosion with a soil loss of <5 t ha^{-1} yr^{-1}. The moderately slight erosion (5-10 t ha^{-1} yr^{-1}) and moderate erosion (10-15 t ha^{-1} yr^{-1}) covered 28.1 and 0.4 per cent area of the watershed, respectively. The area under moderately severe (15-20 t ha^{-1} yr^{-1}) and very severe erosion (>20 t ha^{-1} yr^{-1}) classes covered 6.5 and 1.0 per cent area, respectively.

Essa (2004) used RUSLE to assess the impacts of changing land cover on soil. For this, a GIS-based erosion model has been developed to predict annual soil loss by water in northern Jordan. Spatially distributed static (topographic and soil) parameters for this model are extracted from a regional GIS and the dynamic (vegetation cover) parameter is estimated from the land cover maps, derived by digital processing of multi-resolution, multi temporal Landsat MSS Landsat TM data.

Gonzalez (2008) used USLE equation to compute soil erosion in Puerto Rico, basically in Río Grande de Arecibo basin by using Remote Sensing (RS) and GIS. Cover factor (C) and Conservation practice factor (P) were derived from remotely sensed data, while, the topographic factor (LS) map was generated from DEM. The K factor map was prepared from soil map of Soil Survey of United States and Virgin Islands (1998). These parameters (R, K, LS, C and P) were integrated to generate a composite map of potential erosion intensity based on advanced GIS functionality.

Svoray and Ben-Said (2009) used of remotely sensed data, terrain analysis and a multi-criteria mechanism for evaluating risks of soil loss, sediment deposition in an agricultural Mediterranean catchment under 80 years of intensive cultivation. They reported that increase in rainfall intensity and land-use transformation from orchard to fieldcrops has led to a significant increase in soil loss and sediment yield.

Adediji *et al*. (2010) has demonstrated the significance of satellite remote sensing and GIS technologies in modelling soil erosion by RUSLE in Katsina State of Nigeria. Data on parameters such as slope factor, crop cover and management practice support (P) factor were obtained from Digital Elevation Model (DEM) and Landsat ETM+ of

2002. They estimated potential mean annual soil loss of 17.4 ton/ac/yr based on the refined RUSLE.

Benzer (2010) used geographical information system and USLE for spatial assessment of soil erosion mapping in Goynuk, southeastern part of Bolu, Turkey. In this study, USLE factors including rainfall erosivity (R-factor), soil erodibility (K-factor), slope and slope length (LS-factor) factors were derived using DEM and Landsat TM imagery was used to extract vegetative cover to determine the spatial C factor and P factor and integrated to compute soil loss in tons/ha/year in Arc GIS software. The erosion classes were ranked into three classes as low, moderate, and high. The study indicated that highly eroded areas were observed on bare lands with steep slopes whereas, less eroded areas are associated with lower slope classes.

Hazra *et al.* (2011) studied the interrelationship of water resources available with that of soil class and its properties including soil drainage and erosional characteristics in Jharkhand and found that 62.7 per cent of soils is classified as well to excessively drained soils, whereas, only 18.1 per cent of soil is imperfectly to poorly drained. It was also found that only 12.3and 28.4 per cent of total soil showed slight erosion and severe erosion characteristics, respectively, whereas, remaining is moderately eroded.

Nagaraju *et al*. (2011)derived spatial information related to existing geology, land use/ land cover, physiography, slope and soils through remote sensing and reclassified to USLE factors and computed soil loss in Warora Tehsil of Chandrapur district of Maharashtra. The study indicate that 45.4 thousand ha. (13.7% of TGA) is under moderate, moderately severe, severe and very severe soil erosion categories.

Tagore *et al.* (2012) derived length and degree of slope from SRTM, land use /cover and soil characteristics from IRS-1C LISS-III data and other related ancillary data, integrated and identified three soil erosion categories namely sheet erosion, gullied, and stony waste in Rajgarh district of Madhya Pradesh. The eroded areas were infested distinctly on the FCC. The sheet erosion occupied 58365 ha followed by gullied 1519 ha. The stony waste is encountered in 923 ha area.

Farhan *et al*. (2013) estimated annual soil loss using the Revised Universal Soil Loss Equation (RUSLE), remote sensing (RS) and geographic information system (GIS) in WadiKufranja catchment (126.3 km^2), northern Jordan. RUSLE factors (R, K, LS, C and P) were integrated in ArcGIS to predict soil erosion rates and to generate soil erosion risk categories and severity maps. The potential average annual soil loss is 10 $ton \cdot ha^{-1} \cdot yr^{-1}$ for the catchment and the potential erosion rates ranged from 0.0 to 1850 $ton \cdot ha^{-1} \cdot yr^{-1}$. About 42.1 per cent (5317.23 ha) area was predicted as moderate risk of erosion (5-25 $ton \cdot ha^{-1} \cdot yr^{-1}$), whereas, severe to extremely severe was over 31.2 per cent (3940.56 ha) area (25-50 and >50 $ton \cdot ha-1 \cdot yr^{-1}$).

Kamaludin *et al.* (2013) studied the potential soil loss of the sub-catchments of Pahang River Basin using the RUSLE model and the sediment yieldGeographical Information Systems (GIS) environment by utilizing information on rainfall erosivity (R) using interpolation of rainfall data, soil erodibility (K) using field measurements and soil map, vegetation cover (C) using satellite images, topography (LS) using DEM and conservation practices (P) using satellite image. The results indicated that the rate of potential soil loss in these sub-catchments ranged from very low to low (99% of TGA) to extremely high (1% of TGA).

Kumar and Kushwaha (2013) used RUSLE-3D model and GIS for predicting the soil loss and the spatial patterns of soil erosion risk for soil conservation planning. High resolution remote sensing data (IKONOS and IRS-P6 LISS-IV) were used to prepare land use / land cover and soil maps to derive vegetation cover and soil erodibility factor, whereas, DEM was used to generate spatial topographic factor. The study predicted that 15 per cent area has moderate tomoderately high and 26 per cent area has high to very high risk of soil erosion in the sub-watershed.

Amsalu and Mengaw (2014) integrated Geographic Information System (GIS), Remote Sensing (RS) and Multi-Criteria Evaluation (MCE) techniques to quantify and map erosion vulnerable areas using RUSLE model. Slope gradient, slope length, soil type, soil conservations techniques, cover management and rainfall variables were used as input model parameters/variables. The data had been collected and analyzed from different land sat imageries, SRTM data, topomaps and point interpolations of primary data. Finally, the aggregated effects of all parameters had been analyzed and soil loss from Jabi Tehinan Woreda area was calculated using RUSEL model. They identified lands on steeper slopes with soils of Lithosols, Eutric Nitosols, Orthic Luvisols, croplands, bare lands and river banks as the most erosion vulnerable to soil erosion. Quantitatively, an estimated annual soil loss in Jabi Tehinan Woreda ranges from nearly 0 in south and central parts of the area to 504.6 t/ha/yr in steeply sloping mountainous areas of the north and north-eastern parts of the catchment.

Bagyaraj *et al.* (2014) used Resourcesat (IRS-P6 LISS-IV) data, survey of India (SOI) toposheets (1:50000), Geographical Information System (GIS)integrated with the weighted index overlay (WIO) methods for theidentification and delineation of soilerosion susceptibility zones in the Kodai Hills. The eroded area is divided into three zones representing low (38.1%), moderate (50%) and high (11.9%).

Rasool*et al.* (2014) calculated average annual soil loss by multiplying five factors: R, K, LS,C and P using Satellite Remote Sensing (RS) and GIS in Sallar Wullarhama Watershed State of Jammu and Kashmir. The mean average soil loss using USLE was estimated to be 5.0 kg/m^2/yr. The study area was classified into five erosion classes ranging from <2 to >8 kg/m^2/yr. However, 27.2 per cent of the area is within slight erosion class (Less than 2 kg/m^2/yr). The moderate class ranges 2-4 kg/m^2/yr was estimated 5.0 per cent.The high class ranges between 4-6 kg/m^2/yr was estimated 19.9 per cent. The very high class ranges between 6-8 kg/m^2/yr was estimated 25.6 per cent. Severe rate of soil loss >8 kg/m^2/yr was estimated approximately 22.2 per cent of the total soil loss estimation at Sallar Wullarhama Watershed.

2.3 VEGETATION/WATER STRESS INDICES AS LAND DEGRADATION INDICATORS

Land degradation necessarily involves not only the soil degradation and its impact on vegetation component; but also the interrelations of other land components as climate, soil, water and vegetation which might be characterized through water stress or drought related indicators of remote sensing. Majority of the previous studies regarding land degradation had ignored the interrelationships of other components like recurring water stress situations.

The advancement in remote sensing comes up with high-resolution hyperspectral data that provide a significant enhancement of spectral measurement capabilities for investigating the most powerful contiguous and narrow wavelengths (less than 10 nm) throughout the ultraviolet, visible and infrared portions of the electromagnetic spectrum (Kumar *et al.,* 2001; Thenkabail *et al.*, 2004). These narrow spectral wavelengths allow the identification of characteristic spectral attributes for the mapping and monitoring of vegetation at species levels in different ecosystems (Thenkabail *et al.,* 2004; Zwiggelaar, 1998). Multispectral remote sensing with different properties (spatial and spectral resolution) and a variety of sensors (Landsat TM, Landsat ETM+ and SPOT) have been used to discriminate vegetation cover in degraded areas (Liu *et al.,* 2004; Sun *et al.,* 2007; Wu*et al.,* 2008).

The most widely used vegetation indices are the normalised difference vegetation index (NDVI) (Rouse *et al;* 1974), simple ratio (SR) (Gitelson and Merzlyak, 1996), and transformed vegetation index (TVI) (Deering *et al.,* 1975), all of which respond to the variation in the red and near-infrared portions. Other vegetation indices were developed in order to minimise the effects of soil background, atmospheric conditions, canopy geometry and sun view angles. These vegetation indices include the transformed chlorophyll absorption in reflectance index (TCARI)

(Haboudane *et al*., 2002), visible atmospherically resistant index (VARI) (Gitelson *et al*., 2002), modified normalised difference (MND) (Sims and Gamon, 2002) and soil-adjusted vegetation index (SAVI) (Huete, 1988). Four vegetation indices (NDVI, SAVI, PVI and RVI) have been used to assess rangeland degradation in semi-arid part of the Qazvin province, Iran (Ajorlo and Abdullah, 2007).

Lacaze (2004) stated that land degradation monitoring systems must take into account several indicators like vegetation cover, rain-use efficiency, surface run-off and soil erosion. Some of these indicators may be derived from remote-sensing data. Estimation of vegetation cover from satellite-data relies mainly on conventional or improved vegetation indices, although evidences of better results in arid zones have been obtained from the use of spectral unmixing techniques. Estimation of vegetation condition is generally achieved through drought-related indices, obtained from a combination of NIR and SWIR data (canopy water content) or from a combination of NDVI and thermal data (health condition, dryness). NOAA-AVHRR archived data remain the reference data source for identifying temporal trends, but, recently available satellite data (EOS-MODIS, MSG-SEVIRI) should give significantly improved monitoring results due to better spectral, spatial or temporal resolutions.

Normalized difference vegetation index (NDVI) derived from LANDSAT-enhanced Thematic Mapper plus (ETM+) data, advanced space-borne thermal emission and refection radiometer, slope from digital elevation model were derived and used in modelling land degradation in Budgam district of Kashmir Himalayan region of India. The results reveal that about 13.2 per cent of the study area has undergone moderate to high degradation, whereas about 44.1per cent of the area has undergone slight degradation (Rashid *et al.,* 2011).

2.4 LAND DEGRADATION ASSESSMENT

Oldeman *et al.* (1991) developed a classification method named GLASOD (Global Assessment of Human-induced Soil Degradation) based on types of soil degradation, degree of degradation and causative factors in soil degradation and reported that about 15per cent of global land is degraded. Bridges and Oldeman, (1999) states that the GLASOD survey provides basic data on the world distribution and intensity of erosional, chemical and physical types of degradation. The maps identify areas with a subjectively similar severity of erosion risk, irrespective of the conditions that would produce such erosion (Oldeman *et al.,* 1990). Asia is reported to be the second highest (18%) among the Continents. According to this well established expert-based (GLASOD) types, soil erosion is the most extensive (83%) followed by salinity, nutrient depletion and soil physical problems *etc*. The immediate causes of land degradation are inappropriate land use that leads to degradation of soil, water and vegetative cover and loss of both soil and vegetative biological diversity, affecting ecosystem structure and functions (Snel and Bot, 2003). However, the GLSOD study didn't include any remote sensing or field measurements.

Different satellite data products, particularly Landsat data have been successfully employed in land use/land cover, soil degradation and small scale soil resource mapping by several researchers using visual interpretation techniques (Karale *et al.,* 1978; Venkatratnam, 1980; Karale *et al.,* 1986; Gastellu *et al.,* 1990).

Saxena *et al.* (1991) identified the soil degradation problems such as drought affected soils, flooding hazards, salinity and alkalinity in Etah district using multi-date LandsatTM spectral bands and FCC.

Ghatol and Karale (2000) generated district-wise land degradation maps on 1:250000 scale through visual interpretation of IRS-1A data supported by limited ground survey and identified 2.1 M ha under degraded lands.

Symeonakis *et al.* (2006) established the relationship between land use/land cover (LULC) and land degradation in two Mediterranean sites using remotely sensed and ancillary data in the Xaló river catchment in the north of the Alicante province in southeast Spain and the Aegean island of Lesbos, Greece. In the soil erosion model, parameters *viz*. soil erodibility, slope, vegetation cover and overland flow were integrated in

GIS in order to study the susceptibility of the areas to overland flow and rainsplash erosion. The results indicated that increased susceptibility to runoff and erosion in areas affected by forest fires, urbanization, and/or overgrazing.

Lu *et al.* (2007) effectively used remotely sensed data for identification, mapping and monitoring of land degradation risks in a Western Brazilian Amazon rural settlement area by using a surface cover index (SCI) and identified major causes like deforestation and associated soil erosion leading to land degradation.

Gao *and Liu* (2008) compared the role of spectral and spatial resolutions in mapping land degradation in the form of salinization and water logging in Tongyu County, western Jilin Province of northeast China using Landsat ETM+ and ASTER data using supervised classification techniques together with other land covers. They reported a map accuracy of 56.8 per cent and higher for moderately degraded (e.g. salinized) farmland and over 80 per cent for severely degraded land (e.g. barren) from both ASTER and ETM+ data.

Fadhil (2009) used Landsat TM and ETM+ imageries to assess the extent of land degradation in Iraq during the period from 1990 to 2000. The indices used in this research are: Normalized Difference Vegetation Index "NDVI", Normalized Differential Water Index "NDWI", Tasseled Cap Transformation Wetness "TCW", and a new proposed index Normalized Differential Sand Dune Index "NDSDI". They reported that a clear deterioration in vegetative cover, an increase of sand dune accumulations, and a decrease in soil/vegetation wetness with a concomitant increase in land degradation risk (111%) in the study area.

Krishan *et al*. (2009) interpreted the land degradation in the upper catchment of river Tons, a tributary of Yamuna river in Uttarkashi district of the Uttarakhand by using on-screen visual interpretation of IRS LISS-III + PAN merged data. Vegetation cover, slope and erosion status were considered in land degradation assessment and categorized land degradation into non-degraded (58.8%), moderately degraded (32.8%), degraded (6.6%) and severely degraded (2.9 %). The depletion of vegetation cover and subsequent cultivation without proper protection measures is the reason for severe soil erosion and land degradation.

Mustafa *et al*. (2009) used IRS-P6 LISS-III satellite data of three dates *viz*., February, May and October, 2009 and derived indices such as Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI) and Soil Brightness Index (SBI) for identifying vegetation, waterlogged area and salt affected land respectively in Kheragarah tehsil of Agra, Uttar Pradesh. They applied Decision Tree Classifier (DTC) on these derived indices for delineating and mapping different types of degradation. Results revealed that about 41.2per cent of area is non agricultural land in which four categories of degradation could be identified i.e. degraded hill (4.1 %), degraded forest (3.5 %), wetland (6.3 %) and ravenous land (3.3 %). The remaining (58.8 %) is agricultural land out of which 75.1 % is normal land and (24.9%) suffers from two types of degradation *viz*., chemical (salinity) and physical deterioration (waterlogged).

Amara *et al*. (2014) visually interpreted IRS-P6 LISS-IV data and identified severely degraded lands on moderate to steep slopes in undulating midlands and uplands, whereas, moderately degraded lands in all land uses but prominently in agriculture lands on moderate slopes in Singhanhalli-Bogur Micro-watershed in Northern Transition Zone of Karnataka.

El-Baroudy and Moghanm (2014) used Landsat ETM+ image (2003) and Digital Elevation Model (DEM)to quantify soil degradation risk in some soils of the Northern Nile Delta of Ezypt and reported that 48.1 per cent and 51.9 per cent area has undergone very high risk and low risk of chemical degradation respectively. About 20.1 per cent of the total area was characterized by high risk of physical degradation. Salinity, alkalinity and water logging are identified as the main common degradation hazards.

2.5 SOILS CHARACTERIZATION

2.5.1 Morphological characteristics

The Black Soils of India (Regur) are characterized by dark colour, low chroma and low organic matter. They are rich in smectitic clay and have shrink-swell potential that can develop deep and wide cracks on drying. The shrink-swell soils (Vertisols) can be differentiated easily from other soil orders by the characteristic signatures reflecting dynamic morphological, physical, chemical and mineralogical properties. Dudal (1965) reported that drainage, duration and severity of dry season, composition of the parent material and type of soil development might be the possible causes of dark colour of Vertisols whereas according to Gawande and Biswas (1967) the nature of clay, organic matter, presence of bases, free calcium carbonate and moisture, influenced colour of black soils. These soils tend to crack in the upper parts and have distinctive structural elements in the major body of the soil. These elements as elaborated by (Eswaran *et al*.,1988) are either in the form of blocky structures with smoothened surfaces or slickensides (Blokhuis, 1982), which are shear induced surfaces or gradations between the two. Vertisols are also characterized by the cyclic A1 horizon of varying thickness with micro-knolls and micro-depressions resulting in a typical micro-relief pattern which grade to a wedge-shaped structure horizons (NBSS Staff, 1988). The associated soils of Vertic subgroups generally show A-(B)-C profiles (Landey *et al*., 1982; Murthy *et al*., 1982).

Challa *et al*. (2000) studied four representative Vertisols occurring on upper and lower Maharashtra (Deccan) plateau and found that soils have very dark greyish brown (10 YR 3/2) to dark yellowish brown (10 YR 4/4) colour and the structure ranges from moderate medium sub angular blocky to coarse, strong sub angular to angular blocky through depth in all the profiles.

Maji *et al*. (2005) studied the soils developed over basaltic terrain in Ringnabodi watershed of Nagpur district and reported that with changing topographic position, the depth of soil increased from 33 to 140 cm and the coarse fragments decreased from 61 to 2 per cent. Soils developed on topographically higher elevation have 7.5YR hue and those developed on lower elevation have 10YR hue colour. Soils at higher elevation have clay loam texture, whereas low-lying areas have clayey textural class. Soils were classified as Lithic Ustorthents on summit crest and escarpment; Lithic Haplustepts on isolated mounds;

Typic Ustorthents on denuded plateau and foot slopes; Typic Haplusterts on upper and lower piedmonts and Vertic Haplustepts on narrow valley floor.

Pal *et al*. (2006) studied pedogenic processes in a shrink-swell soil of Central India and found that the soils are deep (>100 cm), very dark greyish brown (10YR 3/2) in colour and fine textured throughout the depth.The structure is sub angular blocky in the Ahorizon and angular blocky in the B horizon where the soil is very sticky and plastic. Roots are distributed to a depth of 75 cm. Morphological examination did not indicate any sign of stratification in the parent material. Clay skins were absent, cracks >5 mm wide at the surface do not extend beyond the A horizon.

Lingade *et al*. (2008) reported the occurrence of Sodic Vertisols (first time) in Nagpur district of Maharashtra. The pedon was deep and characterized by very dark greyish brown colour (10YR 3/2), clay in texture and has angular blocky structure of different grade and size except in Ap horizon. Wet consistency indicates that soils are very sticky and very plastic. The number and size of calcretes and effervescence increased with depth particularly in the slickenside zone.

Meresht (2013) reported that soil structure was weak, granular in all surface horizons and single grain in the sub-surface horizons of the coastal plain, whereas, soil structure was sub-angular blocky and angular blocky in the sub-surface horizons of other units in the Guilan Province, Northern Iran.

Jena *et al.* (2016) characterized the soils of Jirang Block in Meghalaya plateau and reported that the surface soils varied from dark greyish brown (10YR 4/2) to yellowish red (5YR 4/6), whereas, the sub-surface layers are generally reddish in colour. The structure was predominantly sub angular blocky in all pedons and texture of the surface layer varied from loam to clay. The sub-surface horizon supported by enriched clay distribution indicated the presence of cambic horizon (Bw).

2.5.2 Physical characteristics

Black soils are usually dominated by clay which commonly ranges between 40 to 60 percent but, it may be as high as 80 per cent (Bhattacharyya *et al*., 2003). In general, surface soils show low amount of clay and increases with depth (Butler and Hubble, 1977). Clay content of black soils is uniformly high to a depth of 50 cm (Dudal, 1965).

Anantwar *et al*. (2000) studied the soils in basaltic plateau of Wardha district, Maharashtra and reported that sand content varied from 40 to 53 per cent in Typic Ustorthents, 13 to 21 per cent in Vertic Ustochrepts and 24 to 28 per cent in Typic Haplusterts. The silt to clay ratio in soils varies from 0.33 in Typic Haplusterts to 0.84 in Chromic Haplusterts indicating uniformity in distribution of silt and clay with a variation of 26.7 per cent.

Mohekar and Challa (2000) studied five representative pedons of Nagpur district, Maharashtra and reported that clay content in soils ranged from 49.8 to 79.4 per cent. High clay content was noticed in the soils of narrow flood plain.

Chinchmalatpure *et al*. (2001) studied the soils developed in different landforms on basaltic and sandstone parent materials in a micro-watershed situated in Nagpur district and reported that texture of soils on basaltic transects ranges from clay through clay loam to loam and that of sandstone transect from sandy clay to sandy clay loam.

Mandal *et al*. (2003) studied the physical characteristics of soils in Sawangi micro-watershed in Nagpur district, Maharashtra and reported that sand content in soil varied from 14.0 to 40.8per cent, silt from 4.0 to 36.9per cent, clay from 32.8 to 66.0 per cent and coarse fragment from 24 to 44 per cent.

Marathe *et al*. (2003) reported that in Nagpur soils, clay content ranged from 24.5 to 84.2 per cent having smectite as the dominant mineral. Silt content varied from 14.3 to 42.4 per cent and sand from 1.5 to 43.4 per cent.

Maji *et al.* (2005) studied the soils of basaltic terrain in sub-humid tropics and reported that soils at higher elevation had clay loam texture, whereas, low lying areas had clayey textural class.

Balpande *et al.* (2007) studied the grape growing soils of basaltic origin in Nashik district of Maharashtra and indicated that clay had significant positive influence on moisture retention.

Dhale and Jagdish-Prasad (2009) reported wide variations in soil physical properties in sweet orange-growing soils of Jalna district, Maharashtra. The sand, silt and clay content ranged from 14.4 to 46.9, 8.1 to 27.3 and 38.1 to 66.3 per cent in different horizons.

Chetna and Jagdish-Prasad (2011) characterized and classified orange growing soils developed from different parent materials and reported that, in general, sand, silt and clay ranged from 0.6 to 46.1, 19.3 to 40.0, 24.1 to 68.2 per cent in different horizons, respectively.

Chandran *et al. (*2013) reported alkaline, sodic and smectitic ferruginous Alfisols from semi-arid part of southern India on micro-low (ML) position in a catena which are spatially associated with non-sodic soil at micro-high (MH) positions. The soils of the MH are well drained, sandy clay loam to sandy clay in texture. The saturated hydraulic conductivity (sHC) of the ML soils is almost nil in the sub-surface horizons due to high ESP resulting in dispersion of clay and clogging of soil pores as compared to the MH where, the saturated hydraulic conductivity (sHC) ranged from 0.16 to 0.66 cm.hr^{-1}.

Yogita-Gore *et al.* (2014) characterized the soils of basaltic terrain in Savli watershed of Wardha district, Maharashtra and reported that mean value for sand, silt and clay content are 35.2, 32.6 and 32.1 per cent with a range of 3.8 to 67.1, 19.8 to 75.1 and 7.8 to 67.6, respectively. Clay had the largest variation (CV = 0.45) followed by sand (CV = 0.43) and silt (CV = 0.24).

Dongare *et al.* (2016) studied the physical and chemical properties of the Tirora tehsil of Gondia District, Maharashtra and the particle size distribution showed that the majority of the soils have high amount of clay. Soils developed on shallow weathered pediment, moderately weathered pediments, deeply weathered pediments and aggraded valley fills have higher clay content (49.2 to 64.2%).

Jena *et al.* (2016) characterized the soils of Jirang Block in Meghalaya plateau and reported that the sand, silt, and clay content varied from 11 to 53.2, 18.3 to 45.9, and 25.5 to 47.5 per cent respectively, for surface layers, whereas, the sand, silt, and clay content varied from 4.5 to 88.5, 1.0 to 48.0 and 10.5 to 61.0 per cent, respectively, for sub-surface layers.

Naitam *et al.* (2016) reported that the sand, silt and clay content ranged from 9.6 to 78.7, 4.3 to 50.3, and 9.2 to 49.7 per cent, respectively in eastern plains, Bhilwara district, Rajasthan.

Vasu *et al.* (2016) characterized the rainfed soils of semiarid Deccan plateau and reported that the mean value for sand, silt, and clay content are 64.6, 8.8, and 26.6 per cent with a range of 48.8 to 78.5, 1.1 to 14.4, and 16.8 to 41.2, respectively for surface soil (0-20 cm depth), whereas, the mean value for sand, silt, and clay content are 62.8, 9.3, and 27.9 per cent with a range of 45.4 to 78.8, 2.7 to 13.3, and 9.5 to 43.7, respectively for sub-surface soil (20-50 cm depth).

2.5.3 Chemical characteristics

Mohekar and Challa (2000) reported variation in calcium carbonate from 4.4 to 26.0 per cent, soil pH from 8.1 to 8.4 and the CEC from 30.7 and 67.0 cmol(p^+)kg^{-1} in soils of Nagpur district. However, soils of Wardha district, Maharashtra were slightly alkaline with pH varied from 7.6 to 8.1, organic carbon from 0.8 $g.kg^{-1}$ in Typic Ustorthents to 10 $g.Kg^{-1}$ in Chromic Haplusterts

Chinchmalatpure *et al*. (2001) reported relatively higher organic carbon content (0.27 to 0.56 %) in basaltic soils as compared to those on sandstone soils (0.24 to 0.48 %) in Nagpur district.

Jagdish-Prasad *et al*. (2001) studied four typical shrink-swell orange-supporting soils of Nagpur district and reported that pH of the soils ranged from 7.5 to 8.3 and it gradually increases with depth. The organic carbon content varies from 2.1 to 9.9 $g.kg^{-1}$ through depth being higher in surface layer of pedons than the subsurface horizons.

Raghvendra Reddy *et al*. (2004) studied the soils of Mohgaon and Degma villages of Nagpur district, Maharashtra and reported that soil pH ranged from 6.6 to 7.9 on higher elevation *viz*. plateau summits, isolated mounds, linear ridges, escarpments, plateau, spurs, subdued plateaus and rolling plains. The low-lying areas *viz*. pediments, narrow valleys and main valley floor soils had pH values between 8.2 and 9.2. The organic carbon varied from 0.08 to 1.08 per cent in different horizons.

Srivastava *et al*. (2004) studied the physical and chemical characteristics of surface and sub-surface horizon of shrink-swell soils occurring in Nagpur, Akola, Wardha and Bhandara district of Maharashtra, Indore (M.P.) and Raipur (Chattisgarh) and reported that soils are clay in texture and the clay content varied from 24.0 to 76.6 per cent. The pH of soil ranged from 5.7 to 9.4, calcium carbonate content from 0-17.3 per cent, organic carbon from 0.1 and 2.0 per cent, CEC from 19.3 to 68.1 $cmol(p^+)kg^{-1}$.

Venugopalan *et al*. (2004) reported that shallow shrink-swell soils (clayey, smectitic, Typic Haplustepts) of ICAR-CICR farm, Nagpur are moderately alkaline (pH 7.9-8.0) and have more than 55 per cent clay in all the horizons. Organic carbon varies from 2.2 to 6.0 g kg^{-1} in the surface horizons.

Maji *et al*. (2005) reported slightly acidic (6.0 to 6.5) soils on summit crest, escarpment and isolated mounds but slightly alkaline (7.7-8.3) on denuded plateau to narrow valley floor. Clay increased with decreasing elevation and slope in soils of Ringnabodi watershed of Nagpur district.

Solanke *et al*. (2005) studied the soils of Ganeshpur micro-watershed of Nagpur district and reported that soils were slightly acidic (pH 6.2) to strongly alkaline (pH 8.5) and their organic carbon content ranged from 1.2 to 8.1 g kg^{-1}.

Dhale and Jagdish-Prasad (2009) reported wide variations in soil physical properties in sweet orange-growing soils of Jalna district, Maharashtra. The soils were alkaline to strongly alkaline in reaction and relatively higher organic content in surface and sub-surface layers than the underlying ones.

Chetna and Jagdish-Prasad (2011) characterized and classified orange growing soils developed from different parent materials and reported that the pH had positive and significant correlation with clay.

Chandran *et al. (*2013) reported alkaline, sodic and smectitic ferruginous Alfisols from semi-arid part of southern India on micro-low (ML) position in a catena which are spatially associated with non-sodic soil at micro-high (MH) positions. The organic carbon was lower in pedons having higher pH.The soils of the MH are acidic to slightly alkaline. However, soils on ML is clayey, alkaline pH (9.1 – 9.4).

Yogita-Gore *et al.* (2014) studied the soils of basaltic terrain in Savli watershed of Wardha district and reported that the pH of the soils varied from 6.1 to 8.6 and organic carbon varied from 0.18 to 2.86 per cent with a mean value of 0.91.

Dongare *et al*. (2016) studied the physical and chemical properties of the Tirora tehsil of Gondia District, Maharashtra and reported that the pH of the soils ranged from 4.7 (Moderately acidic) to 7.7 (Slightly alkaline). The organic carbon content in the soils ranged from 0.3 to 1.8 percent.

Jena *et al.* (2016) studied the soils of Jirang Block in Meghalaya plateau and reported that the pH and organic content of the pedons varied from 4.2 to 5.9 and 0.4 to 19.8 g kg^{-1}**,** respectively.

Naitam *et al.* (2016) reported that the pH values ranged from 7.5 to 9.5, EC ranged from 0.05 to 2.92 dSm^{-1} and the organic carbon content was higher in the surface soils and decreased with depth in eastern plains, Bhilwara district, Rajasthan.

Vasu *et al.* (2016) characterized the rainfed soils of semiarid Deccan plateau and reported that pH ranged from 6.1 to 9.4 with a mean value 7.7 for 0-20 cm depth soil, whereas, pH ranged from 6.1 to 9.4 with a mean value of 8.1 for 20-50 cm depth soil. The soil organic carbon content for 0-20 cm and 20-50cm depth soil ranged from 4.3 to 16.6 $g.kg^{-1}$ and 3.3 to 9.3 $g.kg^{-1}$,respectively.

2.6 PRIME AGRICULTURAL LAND

USDA-NRCS (2007) has developed criteria for identification of prime agricultural lands criteria and included soil properties *viz*., pH, EC, ESP, gravelliness, permeability, flooding, $CaCO_3$ content, slope, salinity, drainage, water table, soil temperature and soil moisture regime.

Naidu *et al*. (2014) delineated prime, moderate prime and marginal lands of Andhra Pradesh based on important soil and climatic parameters *viz*., soil depth, presence of gravel, slope and length of growing period. The extent of total prime lands in Andhra Pradesh is 51.5 lakh ha (31.9%) and marginal lands is 43.7 lakh ha (27.0% of TGA).

Rammurthy *et al*. (2015) delineated prime and marginal lands of Mysore District, Karnataka by spatial integration of externalland features, soils, agro-ecological regions, present land use and farming systems. On the basis of the criteria, Mysore district has 26.9 per cent of TGA under irrigated prime land, 43.5 per cent of TGA under rainfed prime lands and 4.5 per cent of TGA under marginal lands. They opined that prime rainfed agricultural land is more prone to urbanization and thereby affecting the food security of the district.

Chapter - III

MATERIALS AND METHODS

The materials used and methods followed during the course of the investigation are described in this chapter under the following heads and sub-heads:

3.1 GENERAL DESCRIPTION OF THE STUDY AREA

3.1.1 Location

3.1.2 Climate

3.1.3 Natural vegetation and agricultural land use

3.1.4 Physiography

3.2DATASETS USED

3.3CHARACTERIZATION AND MAPPING OF LAND RESOURCES

3.3.1 Land Use/Land Cover Mapping

3.3.2 Drainage Morphometry

3.3.3 Slope Mapping

3.3.4 Physiography Mapping

3.3.5 Soil mapping

3.4COMPUTATION OF RUSLE FACTORS FOR SOIL EROSION ASSESSMENT

3.4.1 Rainfall erosivity factor (R-factor)

3.4.2 Soil erodibility factor (K-factor)

3.4.3 Topographic factor (LS-factor)

3.4.4 Crop management factor (C-factor)

3.4.5 Conservation practice factor (P-factor)

3.5.LAND DEGRADATION ASSESSMENT

3.5.1 Land Degradation Indicators

3.5.1.1 Soil Erosion

3.5.1.2 Estimation of Vegetation Cover indices

Normalised Difference Vegetation Index (NDVI)

Soil Adjusted Vegetation Index (SAVI)

Enhanced Vegetation Index (EVI)

3.5.1.3 Estimation of Water Stress Indices

Normalised Difference Water Index (NDWI)

Normalised Moisture Index (NMI)

Vegetation Condition Index (VCI)

3.5.2 Principal component Analysis

3.5.2.1 Land Degradation Indicators

3.5.2.2 Land Degradation Index (LDI)

3.5.3 Normalization of Maps

3.5.4 Development of land Degradation Index

3.5.5 Classification of Land Degradation

3.6. SOIL CHARACTERIZATION FOR VALIDATION OF SOIL EROSION

3.6.1 Ground truth collection

3.6.2 Physical properties

3.6.3 Chemical properties

3.6.4 Statistical correlation and regression analysis

3.7 DELINEATION OF PRIME AGRICULTURAL LAND

3.8 MULTICRITERIA ANALYSIS FOR PRIORITIZATION OF CONSERVATION MEASUERS IN DEGRADED LANDS

3.1 GENERAL DESCRIPTION OF THE STUDY AREA

3.1.1 Location

The study area is Nagpur district of Vidarbha region of Maharashtra and lies between 20°30′ to 21°45′ N latitudes and 78°15′ to 79°40′ E longitudes with a total geographical area (TGA) of 9892.30 km^2 (Fig.1).

3.1.2 Climate

The climate of Nagpur district is sub-tropical dry sub-humid with a mean annual temperature of 26.8°C and mean total rainfall of about 1127 mm. The soil temperature and moisture regimes are *hyperthermic* and *ustic*, respectively. The climatic data of the study area is presented in Table 1.

3.1.3 Natural vegetation and agricultural land use

The natural vegetation consists of trees, shrubs and grasses. The dominant tree species of the area of babul (*Acacia arabica*), ber (*Zizyphus jujuba*), palas (*Butea frondosa*), neem (*Azadirachta indica*), teak (*Tectona grandis*), *etc*.

The dominant *kharif* crops are cotton (*Gossypium spp.)*, soybean (*Glycine max*), paddy (*Oryza sativa*), pigeonpea (*Cajanus cajan*), sorghum (*Sorghum bicolor*), cowpea (*Vigna sinensis*), while wheat (*Triticum spp*.) and gram (*Cicer arietinum*) are *rabi* crops. Mandarin *(Citrus reticulate* Blanco*)* is an important horticultural crop of the study area.

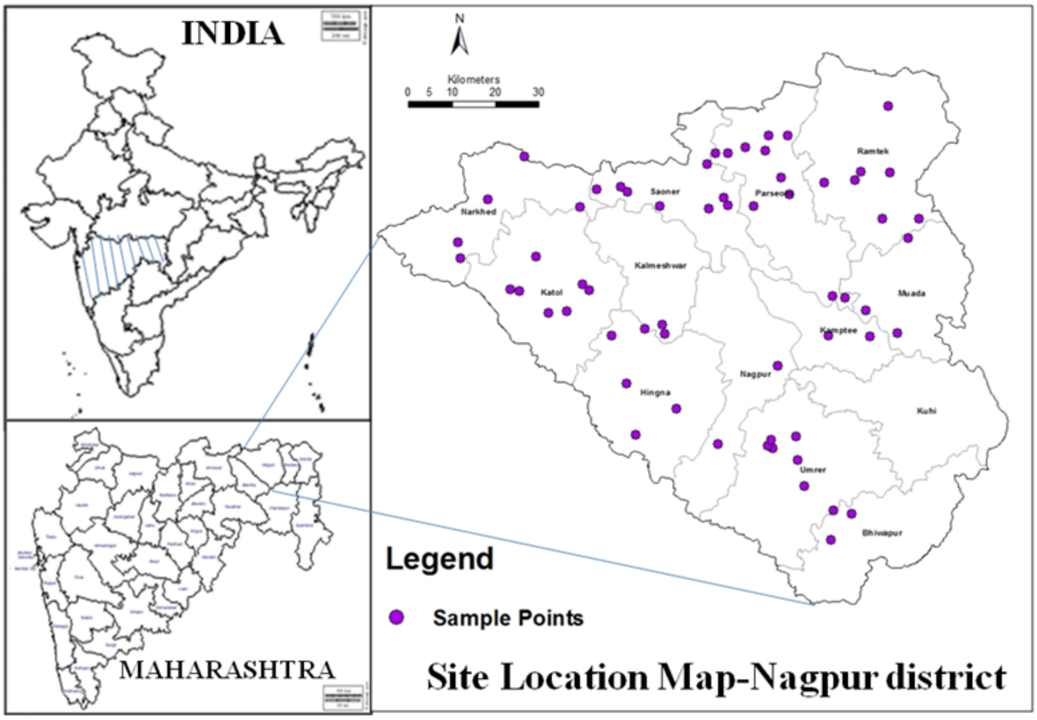

Fig.1. Location map of the study area

3.1.4 Physiography

The major geological formations are Deccan Traps in west and south and granite-gneisses in the eastern part of the district. The general elevation of the district ranges between 150 and 600 m above MSL. Much of the topography of the area is typically that of Deccan Trap having flat topped hills and isolated knolls. The eastern and south eastern part exhibit a comparatively plain terrain with some isolated hillocks. The elevation of the terrain progressively declines from north to south.

Wainganga and its tributaries *viz*. Kanhan, Kolar, Pench, Sur, Amb and Nag drain about 2/3rd of the north-eastern and east-central parts. The tributaries while flowing from hill to plain, have carved rocky valleys in the northern part but give an appearance of severe bank-cutting when they reach the plain in the east-central part. The western and south-western parts are drained by Wardha river and its tributaries like Jam, Nandkar and Wunna rivers. Physiographically, Nagpur district covers very gently to gently sloping plateau, hills and ridges, escarpments with steep slopes, subdued plateau, nearly level to very gently sloping alluvial plain and valley.

Table No. 1. Climatic data of study area (Nagpur district) (1969-2010)

Month	Rainfall (mm)	PET (mm)	Temperature (ºC)			Relative Humidity (%)		
			Max.	Min.	Mean	Morning	Evening	Mean
January	15.3	196	28.9	6.4	13.1	60.2	48.6	54.4
February	20.8	227	31.8	7.4	15.6	49.8	37.5	43.6
March	18.1	260	36.5	10.1	19.7	30.6	28.7	29.7
April	8.6	289	40.7	16.2	24.2	27.8	23.2	25.5
May	18.2	299	42.7	20.4	27.8	29.7	26.2	27.9
June	163.4	254	37.8	21.0	26.4	61.2	49.3	55.3
July	304.0	195	31.7	19.5	24.2	83.8	70.9	77.4
August	275.0	173	30.6	19.8	23.7	85.6	73.9	79.7
September	170.1	192	32.2	16.6	23.1	79.5	69.9	74.7
October	61.2	219	33.0	12.6	20.0	66.8	53.6	60.2
November	16.8	210	30.9	7.0	15.8	59.7	49.3	54.5
December	11.7	193	28.8	5.7	12.6	63.4	52.3	57.8

(**Source:** Revenue Department, Collectorate Office, Nagpur, Maharashtra)

3.2 DATA SETS USED

The satellite images used in the present study are presented in Table 2. The other data sources like Landsat data, Digital Elevation Model (DEM), soil and rainfall data is presented in Table 3.

Table No. 2. Satellite data used for present study

Satellite-sensor	Date	Location		Product	Scale
		Path	Row		
Landsat 7- ETM+	10/10/2000	144	045	284	1:50000
		144	046		
Landsat 7- ETM+	14/09/2002	144	045	257	1:50000
		144	046		
Landsat 5- TM	10/10/2009	144	045	348	1:50000
		144	046		
Landsat 5- TM	28/09/2010	144	045	271	1:50000
		144	046		
Landsat 5- TM	01/10/2011	144	045	274	1:50000
		144	046		

(**Source:** https://www.earthexplorer.usgs.gov/)

Table No. 3. Description of the data and their sources

Sr. No.	Data type	Source	Description
1	Landsat data	www.earthexplorer.usgs.gov	LANDSAT 5 TM, 7 ETM+ (30 m resolution)
2	Digital Elevation Model (DEM)	www.bhuvan.nrsc.gov.in	Cartosat-1 DEM (30 m resolution)
3	Soil data	ICAR-NBSS&LUP, Nagpur	Soil map of Nagpur district with 23 soil series associations
4	Rainfall data	Revenue Department, Collectorate Office, Nagpur, Maharashtra	Rainfall data for a period of 18 years (1995-2012) with 13 rainguage stations
5	Toposheets	Survey of India	Topographic information

3.3 CHARACTERIZATION AND MAPPING OF LAND RESOURCES

3.3.1 Land use/land cover (LULC) mapping

The study of Land use/Land cover provides information about present land use and forms base line information for the sustainable land use planning and rural development (Krishna *et al.,* 1999). Remote sensing and GIS are very effective tools for land use/land cover and vegetation mapping (Skidmore *et al.,* 1991). Following steps have been carried out for preparation of land use/land cover map.

- Land use/land cover (LULC) map of the Nagpur district (2013-14) available at Bhuvan (Source: NRSC, Hyderabad) in WMS format was downloaded.
- The land use/land cover layer was georeferenced, digitized for various land use/land cover boundaries, corrected for digitization

errors and a polygon map has been prepared. The attributes were added for each polygon and a legend has been prepared.

3.3.2 Drainage morphometry

Evaluationofmorphometricparametersnecessitatespreparation of a drainage map, ordering of the various streams, measurement of the catchment area, length, perimeter of drainage channels, drainage density, drainage frequency, drainage intensity and bifurcation ratio, *etc*. The morphometric analysis in the study area was carried out using the Cartosat-1 DEM (30 m resolution) using TNT MIPS (2014) software..

3.3.2.1 Stream order

The stream order is a measure of the position of a stream in the hierarchy of the tributaries (Horton, 1945). The streams with no tributaries are designated as first order streams. The second order streams have only first order streams as tributaries. Similarly, the third order streams have first and second order stream as tributaries, and so on.

3.3.2.2 Stream length

Length of a stream indicates the area that contributes to that order of stream. The total length of the streams pertaining to any order is obtained from the digitized map and its average length (Lu) is calculated by dividing the total stream length with the number of streams (Nu) in that order.

3.3.2.3 Bifurcation ratio

Bifurcation ratio (Rb) is the ratio of the number of streams of any given order (Nu) to the number of streams in the next higher order (Nu+1). Lower bifurcation ratio values indicate low structural disturbance in the area (Strahler, 1964).

3.3.2.4 Drainage density

The drainage density (D) is the ratio of total length of channel segments within a district to the area of the district. It is expressed in terms of km km^{-2} and indicates the closeness of spacing of channels and thus provides a quantitative measure of the average length of stream channel in the district.

3.3.2.5 Drainage frequency and drainage intensity

The drainage frequency denotes the number of drainage lines per unit area, whereas, drainage intensity represents the spread of streams over an area obtained by multiplying drainage density and drainage frequency.

3.3.3 Slope Mapping

The word slope has two geomorphic applications. In general sense “slope” refers to any geometric element on the earth’s surface. In a restricted sense, “slope” also refers to the angle which any part of the earth surface makes with the horizontal datum. The inclination of the terrain is the result of several factors *viz*., relief, drainage, climate and geology operating in the area. The slope map of the study area has been generated using Cartosat-1 DEM (30 m resolution) using TNT MIPS (2014) software.

3.3.4 Physiography Mapping

The false color composite (FCC) generated by combining bands 2, 3, 4 of Landsat-5 TM and Landsat-7 Enhanced Thematic Mapper (ETM+) satellite data in conjunction with Survey of India toposheets (SoI) have been used for identification of various physiographic units. The existing physiography map was superimposed on the satellite data and the boundaries were rectified. Visual interpretation using image interpretation elements (Lillesand *et al.,* 2015) has been carried out using Landsat FCC and elevation and drainage network information available in the SoI toposheet.

3.3.5 Soil mapping

The soil map of Nagpur district (ICAR-NBSS & LUP, 1990) on 1:50000 scale was prepared and mapped as soil series association. The existing soil map was superimposed on physiography map and correlated with new physiographic units and their boundaries. During this process, the soil map has been upgraded and used in soil erosion studies.

3.4 COMPUTATION OF RUSLE FACTORS FOR SOIL EROSION ASSESSMENT

3.4.1 The rainfall erosivity factor (R-factor)

Rainfall erosivity factor (R-factor) is the quantitative expression of the erosivity of local average annual precipitation and runoff causing soil erosion. It is a measure of the erosive force of a specific rainfall. R-value is greatly affected by the volume, intensity, duration and pattern of rainfall, whether, for single storms or a series of storms and by the amount and rate of the resulting runoff (Gansari and Ramesh, 2016). Differences in the R factor reflect differences in precipitation patterns between regions. The value of rainfall erosivity factor used in RUSLE must quantify the effect of raindrop impact and must also reflect the amount and rate of runoff likely to be associated with the rainfall (Gansari and Ramesh, 2016). The rainfall erosivity factor is often determined from rainfall intensity if such data are available. In the present study, annual rainfall data of 18 years (1995-2012) for 13 weather stations (Tehsils) distributed over the district were collected from Revenue Department, Collectorate Office, Nagpur, Maharashtra and used to calculate R values (Ram Babu *et al.,* 1978):

$$R = 79 + (0.363 * P) \qquad (1)$$

Where,

P is annual precipitation

The point erosivity values and average annual precipitation from each weather station was interpolated using kriging techniques in Arc GIS software (version 10.2.2) to prepare kriged spatial map of rainfall erosivity and average annual precipitation (P) (Prasannakumar *et al*., 2012).

3.4.2 The Soil erodibility factor (K-factor)

Soil erodibility factor (K-factor) expresses the susceptibility to detachment and transport of soil particles (grains or crumbs), under an amount and rate of runoff for a specific rainfall, measured under standard condition. K values reflect the rate of soil loss per rainfall-runoff erosivity (R) index. The K-factor is empirically determined for a particular soil type and reflects the physical and chemical properties of the soil such as its mineralogical composition, particle size, permeability and the presence of organic matter, which contribute to its erodibility potential (Wischmeier and Smith, 1978) and computed as:

$$K = 1.2917 \times \frac{[(2.1 \times 10^{-4} \times M^{1.14} \times (12-a) + 3.2 \times (b-2) + 2.5 \times (c-3))]}{100} \qquad (2)$$

Where,

M = (% silt + very fine sand) * (100 - % clay)

a is the percent organic matter

b is the soil structure code and

c is the permeability class

In general, clay soils have low K value because these soils are resistant to detachment. Sandy soils also have low K values due to high infiltration rates and reduced runoff, and because of this, sediment eroded from these soils are not easily transported. Silt loam soils have moderate to high K values as the soil particles are moderately to easily detachable, infiltration is moderate to low, producing moderate to high runoff and the sediment is moderately to easily transported. Silt soils have the highest K values as the silt fractions are easily detached and transported, producing high runoff rates and quantities.

The soil map of Nagpur district has been used to compute soil erodibility factor. Twenty three soil series were tentatively identified and mapped as series associations. Soil erodibility value was assigned to different soil series based on soil data and a K value map has been generated based on proportion of soil series in the association.

3.4.3 Topographic factor (LS-factor)

At regional landscape scale, the topographic factor (LS-factor) expresses the effect of local topography on soil erosion rate, combining effects of slope length (L) and slope steepness (S). Thus, LS is the predicted ratio of soil loss per unit area from a 22.1 m long, 9 % (5.16°) slope under otherwise identical conditions. The Cartosat-1 Digital Elevation Model (DEM) with a resolution of 30 m has been used to calculate L and S parameters. In general, as the slope length (L) increases, the total soil loss and soil erosion per unit increases as a result of progressive accumulation of runoff in the down slope. As the slope steepness (S) increases, the soil erosion also increases as a result of increasing the velocity and erosivity of runoff. Breakes in slope were identified from DEM and utilized to locate channel networks, convergence flow areas, and soil erosion and deposition areas (Farhan *et al.,* 2013).

The spatial analyst toolkit of the Arc GIS software was used to generate raster layers of slope gradient (degrees) and from the hydrology toolkit the flow direction and then the flow accumulation were calculated. The output layers were then used in the GIS raster calculator interface to generate the LS factor map based on the equation using the flow accumulation grid. The equation is:

$$LS = \left(\frac{\text{Flowacc}\times\text{resolution}}{22.1}\right)^{0.6} \times \left(\frac{(\text{Sin(Slope)}\times 0.01745}{0.09}\right)^{1.3} \times 1.6 \qquad (3)$$

3.4.4 The crop management factor (C-factor)

The crop management factor (C-factor) expresses the effect of cropping and management practices on the soil erosion rate (Renard *et al.,* 1997) and is considered the second major factor (after topography) controlling soil erosion. It expresses the protection of soil by cover-type and density. C factor is, thus, a relation between erosion on bare soil and erosion observed under a vegetation condition. An increase in the cover factor indicates an increase in exposed soil, and, thus, increases in soil loss. The C values vary between 0 and 1 based on types of land covers. NDVI values have good correlation with C factor (De Jong, 1994; Tweddales *et al.,* 2000; De Jong *et al.,* 1999; De Jong and Riezebos, 1997).

Land use/land cover (LULC) map of Nagpur district (2013-14) available in WMS format at Bhuvan (Source: NRSC, Hyderabad, 2013) was imported in the Arc Map of Arc GIS software and digitized to develop LULC map. The C values for different land use/land cover are presented in Table 4.

Temporal data of LANDSAT 5 TM & 7 ETM+ images (1999, 2000, 2001, 2010, and 2011) were used to obtain an averaged Landsat raster image data of the district. Normalized Difference Vegetation Index (NDVI) initially proposed by Rouse *et al.,* (1974), is the ratio of spectral reflectance difference between near infra-red (NIR) and red bands [(Band 4 - Band 3) / (Band 4 + Band 3)] is derived from average Landsat 5, 7 TM+ image, which shows the highest correlation with the above-ground biomass (Lin *et al*., 2002). In this study, the table values of C (USDA, 1972 and Rao, 1981) were not taken as such for assigning C factor. Instead, the 20 modal pixel values of NDVI corresponding to the respective land use classes were taken into account in deriving C factor through linear regression model between C values and NDVI modal pixel values. The linear trend relationship between C and modal pixel values of NDVI is obtained as:

$$C = -2.180 * NDVI + 0.995 \quad R^2 = 0.94 \qquad (4)$$

Where, the corresponding C values for each land cover-type is obtained from the guide tables or computed using field observations (Table 4). Finally, this regression equation was used to determine the C factor map in spatial analyst tool in Arc GIS software. This was done to capture the vegetation component variability in a better way.

Table No. 4. C factor values for different land cover-types

Sr. No.	Land cover-type	C-Values
1	Mining	1
2	Crop Land	0.28
3	Forest	0.004
4	Degraded Forest	0.008
5	Plantation	0.28
6	Fallow	1
7	Scrub Land	0.7

(Source: USDA, 1972; Rao, 1981)

3.4.5 Conservation practice factor (P-factor)

Conservation practice factor (P-factor) in the RUSLE model expresses the effect of conservation practices that reduce the amount and rate of water runoff, by their influence on drainage patterns, runoff concentration, runoff velocity and hydraulic forces exerted by runoff on soil, which reduce soil erosion (Wischmeier and Smith, 1978; Rabia, 2012). The value of P factor ranges from 0 to 1, where, the value approaching to 0 indicates good conservation practice and the value approaching to 1 indicates poor conservation practice. Since, there is a lack of field data regarding the conservation practices that have been taken place in the Nagpur district, different types of agricultural management practices *viz*. strip cropping, contouring and terracing have been considered. To derive P factor map, land use/land cover map was integrated with slope map in GIS framework and value of P (Table 5) was assigned to each land use/cover type and slope class. The lower the P value, the more effective the conservation practices (Prasannakumar *et al.,* 2012). The P-factor values for different land use/land cover and slope are presented in Table 5.

Table No. 5. Support practices factor (P)

Land Use Type	Slope	P-Factor
Agriculture	0-5	0.10
	5-10	0.12
	10-20	0.14
	20-30	0.19
	30-50	0.25
Other Land	All	1.00

3.5. LAND DEGRADATION ASSESSMENT

3.5.1 Land Degradation Indicators

Land degradation assessment requires identification and inclusion of various indicators which may show that land degradation has taken place that may reflect in decline in yields of a crop and soil quality has changed. Rubio and Bochet (1998) have identified soil, climate, vegetation, topography and socio-economic as indicators of land degradation. In the present study, soil, vegetation cover, topography and moisture has been considered as indicators of land degradation and used in the assessment. Remote sensing has long been suggested as a time-and-cost-efficient technique for deriving soil erosion, vegetation and topography and climate analysis using ancillary data.

3.5.1.1 Soil Erosion

Many accurate soil erosion models are developed over the last four decades to assess soil erosion risk at catchment, regional and global scales. The Universal Soil Loss Equation (USLE) is widely used model worldwide to estimate soil erosion risk over the last 40 years. However, the requirements of the model, in terms of intensive data and computation, reinforce the elaboration of more accurate and less demanding ones, hence, Revised Universal soil Loss Equation (RUSLE) is considered the alternative improved version of the proto USLE model (Renard *et al.,* 1991; Renard *et al*., 1994; Renard *et al*., 1997; Farhan *et al.,* 2013). It accommodates more accurate methods to estimate rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), land cover management (C) and conservation practice (P) factors (Bhadur, 2009).

The flow chart of the methodology for computation of soil loss is given in Fig.2. The equation for soil loss is expressed as:

$$A = R*K*L*S*C*P \quad (5)$$

Where,

A = computed annual soil loss per unit area [$ton \cdot ha^{-1} \cdot yr^{-1}$].

R = runoff erosivity factor (rainfall) in [$MJ\ mm \cdot ha^{-1} \cdot hr^{-1} \cdot yr^{-1}$].

K = soil erodibility factor (soil loss per erosion index unit for a specified soil measured on a standard plot, 22.1 m long, with uniform 9% (5.16°) slope, in continuous tilled fallow) [$ton \cdot ha \cdot hr \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$].

L = slope length factor (ratio of soil loss from the field slope length to soil loss from standard 22.1 m slope under identical conditions) (dimensionless).

S = slope steepness factor (ratio of soil loss from the field slope to that from the standard slope under identical conditions) (dimensionless).

C = crop cover and management factor (ratio of soil loss from a specified area with specified cover and management to that from the same area in tilled continuous fallow) (dimensionless).

P = support practice factor (ratio of soil loss with a support practice-contour tillage, strip-cropping, terracing-to soil loss with row tillage parallel to the slope (dimensionless).

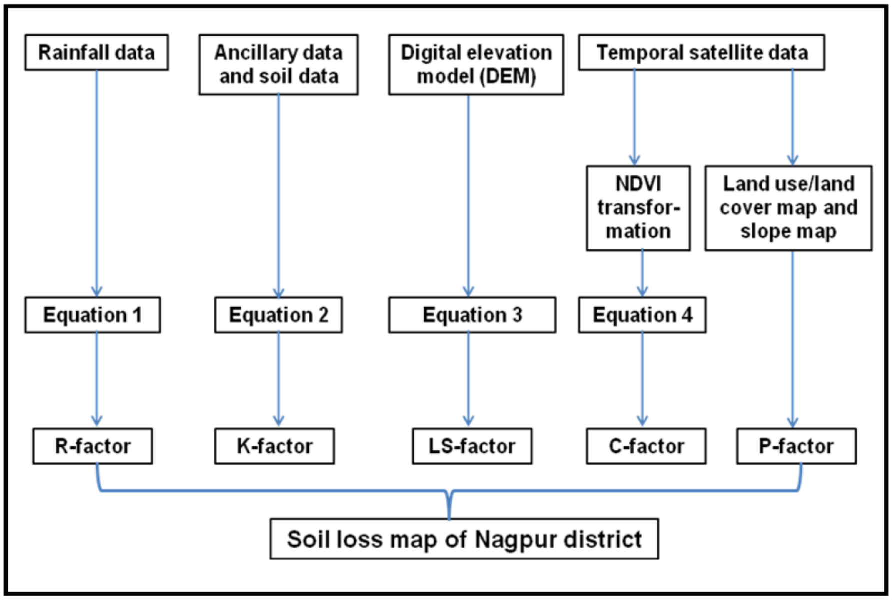

Fig.2. Flow chart of the methodology for soil loss estimation

3.5.1.2 Estimation of vegetation cover

Vegetation cover fraction of land degradation indicators is estimated from vegetation indices derived from spectral responses in the visible (VIS) and near-infrared (NIR) bands of LANDSAT satellite images.

Normalized Difference Vegetation Index (NDVI): Rouse *et al.* (1974) has initially proposed the Normalized Difference Vegetation Index "NDVI", a satellite-based vegetation index that correlates strongly with aboveground net primary productivity. The NDVI derived from the ratio of band 3 and band 4 in Landsat 5TM, 7 ETM+ satellite images data was use for monitoring vegetation changes in the study area over 5 years period (2000, 2002, 2009, 2010 and 2011).

$$\mathrm{NDVI} = \left(\frac{R_{NIR} - R_{RED}}{R_{NIR} + R_{RED}}\right) \qquad (6)$$

Where,

R_{NIR} and R_{RED} are the respective amounts of reflectance at near-infrared and red bands.

The formula is based on the fact that chlorophyll absorbs RED (Band 3), whereas, the mesophyll leaf structure scatters NIR (Band 4).

NDVI values, thus, range from -1 to +1, where, negative values correspond to absence of vegetation (Myneni *et al.,* 1995).

Soil-adjusted Vegetation Index (SAVI): An alternative method is based upon use of improved vegetation indices, *viz.,* "soil-adjusted" vegetation indices (SAVI) proposed by Huete, (1988). Graphically, a transformation technique is presented to minimize soil brightness which involves a shifting of the origin of reflectance spectra plotted in NIR-red wavelength space to account for first-order soil-vegetation interactions and differential RED and NIR flux extinction through vegetated canopies (Huete *et al.,* 2002). Hence, correction factor (L) is applied in SAVI. SAVI is given as:

$$\mathrm{SAVI} = \left(\frac{R_{NIR} - R_{RED}}{R_{NIR} + R_{RED}}\right) \times (1 + L) \qquad (7)$$

Where,

R_{NIR} and R_{RED} are the respective amounts of reflectance at near-infrared and red bands. L is a correction factor which ranges from 0 for very high vegetation cover to 1 for very low vegetation cover. The most typically used value is 0.5 which is for intermediate vegetation cover.

Enhanced Vegetation Index (EVI): Huete *et al.*(2002) made improvements in the vegetation indices with the use of a third channel in the blue region which allows the definition "atmospherically-resistant" vegetation indices. They implemented both approaches namely soil-adjustment and atmospheric-resistance and came with Enhanced Vegetation Index (EVI) which is defined as:

$$\mathrm{EVI} = G \times \left(\frac{R_{NIR} - R_{RED}}{L + R_{NIR} + (C1 \times R_{RED}) + (C2 \times R_{BLUE})}\right) (8)$$

Where,

R_{BLUE}, R_{RED}, R_{NIR} are respective reflectance at the blue, red and near-infrared bands and assigned values are G = 2.5, L= 1, C_1= 6, C_2=7.5

G is the gain factor, BLUE is the blue reflectance, L is the canopy background adjustment that addresses non-linear, differential NIR and RED radiant transfer through a canopy, and C1 and C2 are the coefficients of the aerosol resistance term, which uses the blue band to correct for aerosol influences in the red band (Pettorelli *et al.,* 2005).

3.5.1.3 Water stress indices

Land degradation, landscape functions and hydrologic balance are interrelated. Lack of plant cover and unfavorable soil-surface characteristics lead to reduced surface retention and infiltration resulting in reduced soil moisture content in the soil profile and increased rates of erosion (Lal, 1990). Fadil (2009) have used Normalized Differential Water Index (NDWI) for assessment of land degradation.

Normalized Difference Water Index (NDWI): The water content of a vegetation canopy can be estimated through the use of a combination of near infrared (NIR) and short-wave infrared (SWIR) bands (Gao, 1996; Ceccato *et al.,* 2001). The ratio between NIR and SWIR spectral region clearly enhanced water bodies to the brighter pixels (CPM, 2003). The combinations of SWIR and NIR are appeared useful as an indicator of canopy water stress in a semi-arid and arid environment (Fensholt and Sandholt, 2003). The Normalized Difference Water Index (NDWI) is given as:

$$\mathrm{NDWI} = \left(\frac{R_{SWIR} - R_{NIR}}{R_{SWIR} + R_{NIR}}\right) \quad (9)$$

Where,

R_{SWIR} and R_{NIR} are respective reflectance at short-wave infrared and near infrared bands.

Normalized Moisture Index (NMI): Jang (2004) proposed a new vegetation index combining NDVI and NDWI which has been used for the evaluation of thermal-water stress. The Normalized Moisture Index (NMI) is given as:

$$\mathrm{NMI} = (\mathrm{NDVI} + \mathrm{NDWI}) \quad (10)$$

Vegetation Condition Index (VCI): Vegetation monitoring from AVHRR time series is usually based upon a comparison of present NDVI with some reference values derived from the available archive data. For example, for a given week or 10-days period, NDVI can be scaled using maximum and minimum values to obtain a Vegetation Condition Index (VCI). It is given as (Kogan *et al.,* 2004):

$$\mathrm{VCI} = 100 \times \left(\frac{(\mathrm{NDVI} - \mathrm{NDVI}_{\mathrm{min}})}{(\mathrm{NDVI}_{\mathrm{max}} + \mathrm{NDVI}_{\mathrm{min}})}\right) \qquad (11)$$

Where,

$NDVI_{min}$ and $NDVI_{max}$ are the absolute minimum and maximum values, respectively observed during the years 2000, 2002, 2009, 2010 and 2011, after removal of high temporal frequency noise (clouds, sun and sensor angular effects).

3.5.2 Principal Component Analysis (PCA)

3.5.2.1 Land Degradation Indicators

Principal Component Analysis (PCA) originally known as Karhunen-Loeve transformation (KL-transformation) is used to compress multi-spectral datasets to reduce the data redundancy (Jensen, 1996). The transformation of the raw remote sensing data using PCA results in new principal component images that is more interpretable than the original image (Pal *et al.,* 2007).

A standard statistical based PCA modelling is performed using Arc GIS software among all land degradation indicators. The principal components (PCs) receiving higher percent Eigen values captures the maximum variation among the considered indicators with their respective factor loading/Eigen vector and being considered for further analysis. Among the indices used for each land degradation indicator namely vegetation and water stress retained for PCA, the weightages for indices were obtained by calculating the factor loading in their respective highest Eigen value PCs, as each PC explains a certain amount of variation among indices. The following steps were followed to develop degradation index through PCA. Highest variation as expressed by the Principal Components of land degradation indices (soil erosion, vegetation and water stress) were integrated using the 'PCA' tool in Arc GIS software to determine their per cent contribution in realistic computation of land degradation index. Each theme and its individual classes were assigned weights and ranks obtained through factor loading/Eigen vector obtained in PC1 input layer as per Symeonakis and Drake (2004) and Kiage *et al.,* (2007) and were based on their individual role in land degradation analysis.

In the present study, PC1, PC2 and PC3 were generated for each theme. Eigenvectors, Eigenvalues and percentage of Eigen values were computed for all the Principal Components. The scree plot table helped to distinguish between the different Principal Components.

A weighted overlay analysis was done using Arc GIS software. Areas with high soil erosion status, least vegetation and high water stress have been assigned higher ranks for land degradation. Similarly, areas with a low soil erosion status, high vegetation cover and low water stress were assigned low ranks for land degradation. The resultant composite land degradation index map generated was reclassified into different land degradation classes.

3.5.2.2 Land Degradation Index

Soil erosion: Soil erosion (SE) is one of the most important land degradation indicators and used in the computation of land degradation index (LDI). We have already discussed about soil erosion in the earlier section.

Vegetation index (VI): NDVI, SAVI and EVI were retained for PCA in Arc GIS software to obtain the best representing Principal Component *i.e.* PC1 layer for vegetation index (VI). The principal component, which captures maximum explained variability present within the three individual indices, was used as input for computation of Land degradation Index (LDI).

Water Stress Index (WI): Similarly, the three water stress indices (NDWI, NMI and VCI) were also retained for PCA to obtain the best representing Principal Component *i.e.* PC1 layer for Water Stress Index (WSI). The Principal component, which captures maximum explained variability present within the three individual indices, is used as input for computation of Land degradation Index (LDI).

The variability present within each index of vegetation and water stress is computed from the equation:

$$\% \text{ Eigen value (E)} = \frac{\text{((Factor loading of indices used for PCA (e))}}{\text{Total factor loading}} \times 100 \quad (12)$$

The major components which were significantly influencing in land degradation process, the three components *viz*., soil erosion, PC1 of vegetation index (VI) and PC1 of water stress index (WI) were further used as input for computation of land degradation index (LDI) through PCA.

The selected inputs *viz*. SE, PC-1 of VI and PC-1 of WI were subjected to PCA in Arc GIS software to obtain the best representing PC input for land degradation index (LDI). Again, we determined the per cent of Eigen value *i.e*. weightage using the statistical based PCA model, to know the fact that how much variability is explained by first PC component. PC1 layer represents the best combination which can capture maximum explained variability present within the three individual sub-indicators which was finally used as an input for “Land degradation Index (LDI)”.

3.5.3 Normalization of Maps

The selected inputs *viz*. SE, PC1 of VI and PC1 of WI were in different scales and in different ranges. In order to bring them to a common scale, each layer needs to be normalized. Hence, each input was normalized into 0 to 100 scale by using the following formula:

$$a+(x-A) \times (b-a)/(B-A) \quad (13)$$

Where,

x is the map taken

a = 0

b = 100

A is the lowest value of the map

B is the highest value of the map

Each map was transformed/standardized to a value between 0 (Least favorable soil erosion loss) and 100 (Most favorable soil erosion loss) scoring function. So the theoretical range of LDI is 0 to 100 *i.e*. the minimum value of LDI was 0 and maximum value of LDI was 100.

The normalized maps, using expert knowledge in a GIS framework, were reclassified into 0-40, 40-60, 60-80 and 80-100 and further represented by 1, 2, 3, and 4 classes, respectively, with reference to the increasing order of their importance to soil erosion loss. In this study, the reclassified maps were represented as S_{SE}, S_{PC1_VI}, and S_{PC1_WI} for soil erosion, vegetation index and water stress index, respectively.

3.5.4 Development of Land Degradation index (LDI)

Land Degradation index (LDI) has been worked out by using the following equation:

$$LDI = \Sigma\ WiSi \quad (14)$$

Where,

Wi = weight of i^{th} indicator using PCA and

Si = score of i^{th} indicator (reclassified map)

Here, the assumption is that higher index scores indicate higher degradation.

By inputting the parameters, the LDI is computed as:

$$LDI = (W_{SE} \times S_{SE}) + (W_{PC1\_VI} \times S_{PC1\_VI}) + (W_{PC1\_WI} \times S_{PC1\_WI}) \quad (15)$$

Where,

W_{SE}, W_{PC1_VI} and W_{PC1_WI} are the weightages of i^{th} indicators for soil erosion, vegetation index and water stress index respectively and

S_{SE}, S_{PC1_VI}, andS_{PC1_WI} are the score of i^{th} indicators for soil erosion, vegetation index and water stress index, respectively.

3.5.5 Classification of Land Degradation

The Land Degradation Index values were reclassified in to land degradation classes to know the realistic estimates and the status of land degradation, spatial extent and their distribution.

3.6 SOIL CHARACTERIZATION FOR VALIDATION OF SOIL EROSION LOSS

3.6.1 Ground truth Collection

Using available soil map and other ancillary data (soil erosion map, land use/ land cover map, toposheets, road map *etc*.), the area was traversed for identification of different land form units, the soil variability and present land use. This facilitates selection of the sites for profile study. Information about extent and distribution of different soils (series-wise) in the Nagpur district was collected from published survey literature/reports of Nagpur district. Using Survey of India (SoI) toposheet and available soil map (1:50000 scale) of Nagpur district, the area was traversed for selection of sampling sites in Nagpur district. Selection of sites was also made based on type and degree of land degradation using satellite images in the study area. Ground truth was done for site and soil profile characteristics covering both degraded as well as non-degraded areas of the district. A total of 70 sites were selected. The location of all the observation sites and their characteristics were given in Appendix-I. Sixty two surface soil samples were collected based on the degree of soil erosion. Five profile samples representing dominant soil series of the district were also used in the analysis. Various site and morphological characteristics like slope, stoniness, erosion, colour, texture and structure *etc*. were studied and recorded in the field (Soil Survey Staff 1995). Soils were classified accordingly to Keys to Soil Taxonomy (Soil Survey Staff, 2014). Nearly 2.0 kg representative soil samples were collected from each layer for laboratory analysis studies.

Soil samples were initially air dried in the laboratory at room temperature, ground using wooden mortar and pestle and screened through 2mm sieve. For certain characteristics like organic carbon samples were further ground and screened through a 0.2 mm (80 mesh) sieve as suggested by Jackson (1967).

3.6.2 Physical Properties

3.6.2.1 Particle size distribution

Particle-size distribution is determined as per the International Pipette method after the removal of organic matter, $CaCO_3$ and free iron oxides. Sand (2-0.05 mm), silt (0.05-0.002 mm) and clay (<0.002 mm) were separated using the procedure described by Jackson (1967). The textural class was determined using the USDA textural triangle as given in Soil Survey Manual (Soil Survey Division Staff, 2000). Further, sand fractionation was also done using dry sieving method for different fractions.

3.6.2.2 Saturated Hydraulic Conductivity

The disturbed soil samples are uniformly filled in a container and fully saturated and then leached with distilled water. The saturated hydraulic conductivity was determined by constant head method as described by Richards (1954) and calculated on the basis of Darcy's law as mentioned below.

$$K = \frac{Q + \Delta L}{T \times A \times \Delta H} \qquad (16)$$

Where,

K = Hydraulic conductivity ($cm.hr^{-1}$),

Q = Discharge ($ml.hr^{-1}$)

ΔL = Soil head (cm)

T = Time (hrs)

A = cross sectional area of the sample (cm^2)

ΔH = Constant head difference causing the flow (cm)

Where,

A is calculated by

A = 2*22/7*r (h+r),

h = soil head (cm),

r = radius of cylinder (cm)

3.6.3 Chemical properties

3.6.3.1 Soil pH

It was determined in 1:2.5 soil:water suspension with the help of glass electrode using ELICO pH meter (Jackson, 1967).

3.6.3.2 Soil EC

The clear supernatant extract obtained from the suspension used for pH (soil:water, 1:2.5) was utilized for a EC measurement by conductivity brigde (Richards, 1954).

3.6.3.3 Organic carbon (OC)

Organic carbon was determined by the Walkley and Black rapid titration method (Jackson, 1967). Ground soil samples passed through 80 mesh sieve were used for estimating organic carbon. Soil samples are oxidized by 1*N* potassium dichromate and the conc. H_2SO_4 acid is used to generate the heat of dilution. The amount of unutilized dichromate is determined by back titration with 0.5 *N* ferrous ammonium sulphate solutions.

3.6.4 Statistical correlation and regression analysis

Correlation and regression analysis of different soil properties with soil erosion were carried out as described by Panse and Sukhatme (1978) and Gomez and Gomez (1984) using MS Office Excel 2007.

3.7 DELINEATION OF PRIME AGRICULTURAL LAND

The land use/land cover (LU/LC) map, slope, drainage and soil map (1:50000) of Nagpur district, Maharashtra were used as a base information in conjunction with satellite remote sensing data. In the present study, LU/LC map (2013-14) of the district was downloaded from the Bhuvan Geoportal, digitized and used as a layer (Fig.4). Slope (Fig.6) and drainage maps (Fig.5) were generated using Cartosat-1DEM (30 m resolution). District soil map (Fig.8) and soil characteristics were derived from soil survey report NBSS&LUP, 1990). All the three maps were integrated using ArcGIS software. The slope and different soil/land characteristics in the agricultural lands were evaluated as per the criteria

(Table 6) proposed by USDA-NRCS (2007) to characterize the prime agricultural lands.

The data on pH, EC, Organic Carbon (OC), Exchangeable Sodium Percentage (ESP), $CaCO_3$, exchangeable cations (Ca, Mg, Na, K), water retention at Field Capacity (FC), Wilting Point (WP), Base Saturation (BS), Cation Exchange Capacity (CEC) and Bulk Density (BD) of surface (0-25 cm) and sub-surface (25-100 cm) of soils belonging to 23 soil series along with water logging, groundwater table, surface salinity were used in the study (Table 7b). The criteria for consideration of different soil characteristics (Table 6) were followed as per USDA-NRCS (2007) for delineating prime agricultural lands. . As the mapping units of the soil map of the district (Survey report of Nagpur district, 1990) was soil series association (two or more soil series occurring together in a map unit), each mapping unit has been assigned different weightage factor *viz*. for two series association weightage was assigned in 60:40 ratio for dominant and subdominant soils, respectively and for three series association, it was 50:30:20 for dominant, 1st subdominant and 2nd sub-dominant soils respectively. These weightages were used to derive representative soil data for each mapping unit.

The length of crop growing period (LGP) was added to know the duration of the moisture availability for crop production. LGP is the duration in days or months when precipitation exceeds 0.5 Potential Evapotranspiration (PET) and ends with utilization of stored moisture till it reaches 0.25 PET. The LGP for Agro Ecological zone (AEZ) pockets is worked out and added to the attribute table and LGP map is thus added (Naidu *et al.,* 1998). It was found that LGP of the district is 140-180 days (Mandal *et al.,* 2014), which was within acceptable range for qualifying prime lands. Similarly, soil properties like pH, EC, OC, ESP, $CaCO_3$, texture, flooding, permeability, water table, soil moisture regime, soil temperature regimes, *etc.,* were chosen as key parameters based on their importance to crop production and accordingly added to the attribute table of combined map. The criteria listed in Table 8 are used for delineation of prime lands. Other properties were well within acceptable limits and thus not considered as criteria for delineating prime lands (Table 7a). We have selected four parameters, namely, depth, slope, gravelliness and AWC (Table 8). Soil depth indicates the

Table No. 6. Soil characteristics and criteria to evaluate prime agricultural lands

Soil characteristics	Criteria
Soil Moisture Regime	Aquic or Udic or Ustic moisture regimes, Aridic or Torric moisture regimes with well developed irrigation water supply
Soil Temperature Regime	Hyperthermic or isothermic, or isohyperthermic, isomesicwith no thixotropics
pH (1 meter depth)	Between 4.5 and 8.4 in all horizons within 1 meter or in the root zone is less than 1 meter
EC and ESP	less than 4 dSm^{-1}in all horizon within 1 meter or in the root zone if root zone is less than 1 meter and the exchangeable sodium percentage (ESP) is less than 15.
Calcium Carbonate Equivalent	The soil has a weighted average calcium carbonate equivalent, in the fraction less than 1 inch in diameter, of less than 40 % between depths of 10 to 40 inches, or in the root zone, if less than 40 inches
Permeability	0.06 inch (0.15 cm) per hour in the upper 50 cm and mean annual soil temperature (MAST) at a depth of 50 cm is less than 140C. Permeability is not a limiting factor if the MAST is 140C or higher. Permeability rate is not a limiting factor for Vertisols and Vertic subgroups of Entisols and Mollisols
Coarse fragments	Less than 35 % of the surface layer
Water Table	The soils either have no water table or have a water table that is maintained at a sufficient depth during the cropping season to allow cultivated crops of the area to be grown
Flood	The soils are not flooded frequently during the growing season (less often than once in 2 years)
Slope	less than 5 %
Depth	more than 75 cm

(Source: USDA-NRCS, 2007**)**

Table No. 7a. Descriptive statistics of soil properties of soil series

Soil properties	**Mean**	**Minimum**	**Maximum**	**S.E.M.**	**Standard Deviation (SD)**	**Variance**	**Coefficient of Variance (CV)**
Sand (%)	38.9	4.8	70.8	2.0	18.4	337.8	0.5
Silt (%)	20.0	5.0	38.8	0.7	6.4	41.4	0.3
Clay (%)	41.1	15.0	74.6	1.7	15.7	246.7	0.4
Cation Exchange Capacity (CEC) $cmol(p^+)kg^{-1}$	33.9	6.88	69.4	1.7	15.2	231.4	0.4
pH	7.4	6.3	8.3	0.1	0.6	0.3	0.1
Electrical Conductivity (EC) (dS\cm)	0.3	0.16	0.6	0.0	0.1	0.0	0.4
Organic Carbon (OC) (%)	0.5	0.07	1.2	0.0	0.2	0.1	0.5
$CaCO_3$ (%)	4.0	0.4	18.2	0.7	3.6	13.2	0.9
Bulk Density (BD) (Mgm^{-3})	1.8	1.61	2.0	0.0	0.1	0.0	0.1
Base Saturation (BS) (%)	91.9	69.4	100	0.9	7.8	61.4	0.1
Ca ($cmol(p^+)\ kg^{-1}$)	23.4	3.6	49.7	1.3	11.7	137	0.5
Mg ($cmol(p^+)\ kg^{-1}$)	6.9	0.5	16.2	0.4	3.9	15.2	0.6
Na ($cmol(p^+)\ kg^{-1}$)	1.0	0.0	5.0	0.1	1.1	1.2	1.1
K ($cmol(p^+)\ kg^{-1}$)	0.4	0.03	1.3	0.0	0.2	0.1	0.6
Field Capacity (FC) (%)	26.3	10	53.0	1.3	11.6	135.2	0.4
Wilting Point (WP) (%)	13.6	5.1	27.8	0.7	6.6	44.1	0.5
Coarse fragments/ gravelliness (%)	13.4	0.7	77	2.2	18.6	345.0	1.4

(Source: ICAR-NBSS&LUP, Nagpur, 1990)

potential of soil to hold and supply moisture, nutrients and provide favourable rooting medium. Similarly, presence of gravels in sub-soil limits water, nutrient retention and availability to plants. Soil slope facilitates easiness for workability and undertaking cultural operations. The marginal lands (soils with depth <50 cm, gravel >35 per cent, slope >15 per cent with LGP <90 days) limits the choice of crops that can be grown and pose more inherent soil limitations leading to frequent crop failures. However, marginal lands can be productively used for non-agricultural uses (Naidu *et al.,* 2014).

The soil variability is the result of pedogenetic processes under different geological set up. Major soil variability in the district was due to basaltic rocks (ICAR-NBSS & LUP, 1990) and water erosion is the dominant soil erosion process. We hypothesized/assumed that prime lands in Nagpur district were mostly located around 4^{th}, 5^{th} and 6^{th} order streams. Thus, in-situ development and deposition of sediments near 4^{th}, 5^{th} and 6^{th} order streams would lead to formation of prime lands.

Table No. 7b. Some selected soil properties (weighted mean) of surface and sub-surface layers of different soil series of Nagpur district, Maharashtra

Soil series	Soil Depth (cm)	Drain-age	Layer	Sand (%)	Silt (%)	Clay (%)	Text-ure	BD (Mgm^{-3})	Gravels (%)	pH (1:2.5 H_2O)	EC (dSm^{-1})	OC (%)	$CaCO_3$ (%)	CEC (cmol(p^+)kg^{-1})	BS (%)	FC (%)	WP (%)	AWC (cmm^{-1})
Aroli (Arl)	Very deep (>150)	Mod. Well	Surface	41.0	18.1	40.8	c	1.8	4.6	7.5	0.2	0.3	0.0	28.8	93.7	25.4	12.9	22.5
			Sub-surface	29.2	26.0	44.8	c	1.9	2.3	7.7	0.2	0.2	0.0	32.8	92.9	26.1	13.7	
Baghbori (Bgb)	Deep (100-150)	Mod. Well	Surface	40.7	16.2	43.1	c	1.8	2.9	8.0	0.6	0.7	0.0	38.7	96.7	28.4	14.6	27.8
			Sub-surface	35.1	14.8	50.1	c	1.8	1.2	8.0	0.5	0.4	0.0	40.7	94.2	31.8	17	
Gaimukh (Gmk)	Mod deep (50-100)	Well	Surface	57.8	13.3	28.8	scl	1.7	2.0	6.3	0.1	0.5	0.0	16.0	74.3	17.3	8.6	16.5
			Sub-surface	50.2	14.1	35.7	sc	1.7	22.8	6.4	0.1	0.4	0.0	25.1	70.3	20.4	9.7	
Jam (Jam)	Very deep (>150)	Well	Surface	45.8	22.6	31.6	scl	1.7	<1.0	7.5	0.2	0.5	1.8	22.0	97.1	22.3	10.4	18.7
			Sub-surface	47.3	19.6	33.1	scl	1.8	1.7	7.5	0.2	0.4	2.3	24.8	98.8	21.6	11.1	
Karla (Krl)	Mod deep (50-100)	Mod. Well	Surface	12.8	25.8	61.4	c	1.8	4.3	7.8	0.3	0.6	3.6	57.7	96.7	48.1	24.7	29.6
			Sub-surface	10.8	24.2	65.0	c	1.8	9.6	7.8	0.3	0.5	4.9	58.5	97.4	51.8	26.2	
Kirnapur (Krn)	Deep (100-150)	Well	Surface	22.9	23.5	53.6	c	1.8	2.0	7.7	0.3	0.4	0.0	40.4	93.5	30.1	18.3	25.7
			Sub-surface	20.3	21.3	58.4	c	1.9	2.8	7.7	0.3	0.2	0.0	47.0	93.7	33.7	19.1	
Linga (Lng)	Very deep (>150)	Imperfect to poor	Surface	5.1	20.4	74.6	c	1.8	2.4	8.2	0.2	0.5	2.7	58.1	98.7	39.9	19.2	35.0
			Sub-surface	9.1	17.3	73.6	c	1.9	4.0	8.1	0.2	0.4	6.1	64.3	100.0	38.1	19.8	

Soil series	Soil Depth (cm)	Drain-age	Layer	Sand (%)	Silt (%)	Clay (%)	Text-ure	BD (Mgm^{-3})	Gravels (%)	pH (1:2.5 H_2O)	EC (dSm^{-1})	OC (%)	$CaCO_3$ (%)	CEC (cmol(p^+)kg^{-1})	BS (%)	FC (%)	WP (%)	AWC (cmm^{-1})
Panjra (Pjr)	Deep (100-150)	Mod. Well	Surface	17.1	30.2	52.7	c	1.7	3.6	7.8	0.3	0.6	2.0	47.3	96.0	38.0	17.3	32.2
			Sub-surface	20.7	34.7	44.6	c	1.8	3.7	8.1	0.3	0.5	12.5	39.9	95.5	32.6	15.7	
Sur (Sur)	Very deep (>150)	Mod. Well	Surface	64.4	17.3	18.3	sl	1.6	<1.0	6.9	0.2	0.2	0.0	7.7	88.6	14.7	6.0	13.8
			Sub-surface	66.1	14.7	19.2	sl	1.7	<1.0	6.9	0.2	0.2	0.0	8.6	83.2	13.5	5.9	
Wadhona (Wdn)	Very deep (>150)	Mod. Well	Surface	36.8	28.1	35.1	cl	1.7	4.6	7.8	0.3	0.3	4.0	32.0	96.4	24.1	10.2	21.8
			Sub-surface	38.3	27.7	34.0	cl	1.7	4.1	8.0	0.4	0.1	4.7	30.6	95.6	21.8	9.9	
Devadipar (Dvp)	Mod. deep (100-150)	Well	Surface	47.9	24.6	27.5	scl	1.7	6.8	7.8	0.2	0.4	0.0	22.9	95.6	16.5	8.2	9.0
			Sub-surface	47.9	15.0	37.1	c	1.8	7.0	8.1	0.2	0.3	0.0	27.5	93.0	18.3	9.5	
Gunjepar (Gjp)	Shallow (25-100)	Mod. Well	Surface	68.6	18.7	40.7	c	1.8	4.3	10.0	0.3	0.7	0.0	33.8	124.6	24.4	11.6	7.1
			Sub-surface	42.3	14.6	43.1	c	1.8	2.7	7.8	0.2	0.4	0.0	27.9	96.8	26.9	11.8	
Khapri (Kpr)	Mod deep (50-100)	Mod. Well	Surface	52.1	9.7	46.4	c	1.8	<1.0	8.3	0.3	0.8	1.7	43.7	101.9	24.6	12.4	16.8
			Sub-surface	39.1	10.2	50.8	c	1.8	<1.0	7.8	0.3	0.7	2.2	42.9	94.9	26.1	14.2	
Magarali	Mod deep (50-100)	Well	Surface	57.0	15.8	27.2	scl	1.6	38.8	7.0	0.1	0.5	0.0	24.5	93.4	15.6	8.1	8.5
			Sub-surface	47.3	21.1	31.6	scl	1.7	45.4	6.8	0.1	0.5	0.0	26.3	89.0	16.7	8.7	
Sewadoli (Sdl)	Shallow (25-50)	Well	Surface	46.7	20.9	30.8	scl	1.7	25.5	6.4	0.2	0.6	0.0	30.8	80.3	17.4	10.4	4.7
			Sub-surface	43.4	21.5	31.1	cl	1.7	28.6	6.5	0.2	0.5	0.0	31.1	82.9	19.5	12.5	

Soil series	Soil Depth (cm)	Drain-age	Layer	Sand (%)	Silt (%)	Clay (%)	Text-ure	BD (Mgm^{-3})	Gravels (%)	pH (1:2.5 H_2O)	EC (dSm^{-1})	OC (%)	$CaCO_3$ (%)	CEC (cmol(p$^+$)kg^{-1})	BS (%)	FC (%)	WP (%)	AWC (cmm^{-1})
Chankapur (Ckp)	V. shallow (<25)	Well	Surface	16.7	27.6	55.8	c	1.7	5.5	7.6	0.2	0.7	0.0	54.2	96.2	37.6	22.2	6.0
Muserkhapa (Msk)	V. shallow (<25)	Well	Surface	12.3	26.9	60.8	c	1.7	3.0	7.5	0.3	0.5	2.3	56.5	97.6	38.7	23.8	7.2
Pardi (Prd)	V. shallow (<25)	Well	Surface	56.9	23.2	19.9	sl	1.7	33.6	7.0	0.2	0.2	0.2	15.3	89.5	13.3	6.8	1.7
Ramtek (Rtm)	Shallow (25-50)	Well to excessive	Surface	79.2	21.0	31.8	scl	1.7	74.8	8.9	0.3	1	0.0	23.0	107.2	17.9	8.5	5.7
			Sub-surface	59.3	11.5	29.2	scl	1.7	63.0	7.0	0.2	0.5	0.0	20.5	84.1	14.8	6.9	
Ronga (Rng)	Shallow (25-50)	Well	Surface	55.9	20.1	24.0	scl	1.7	48.0	6.5	0.1	1.1	0.0	22.3	77.0	14.2	7.0	4.9
			Sub-surface	57.0	22.2	24.0	scl	1.7	68.8	6.6	0.3	0.8	0.0	20.8	72.7	13.9	6.9	
Semda (Smd)	Shallow (25-50)	Mod. Well	Surface	67.3	10.9	21.8	scl	1.6	31.2	6.5	0.1	0.4	0.0	12.7	85.2	11.7	5.9	3.1
Yenwa (Ynw)	V. shallow (<25)	Excessive	Surface	44.9	20.5	34.6	cl	1.8	8.0	6.3	0.1	0.9	0.0	29.4	85.2	27.6	13.8	3.7
Malegaon (Mlg)	Mod. deep (50-100)	Mod. Well	Surface	15.7	26.9	57.4	cl	1.8	1.6	7.1	0.2	0.6	1.2	54.4	96.0	41.4	22.4	22.6
			Sub-surface	13.5	23.9	62.6	cl	1.8	1.7	7.3	0.2	0.6	0.4	57.4	92.9	43.4	26.2	

(Source: ICAR-NBSS&LUP, Nagpur, 1990)

Table No. 8. Criteria for classification of prime and marginal lands

Sr. No.	Land category	Soil depth (cm)	Slope (%)	Gravelliness (%)	AWC (cm/m)
1	Prime land	>75	0-5	0-15	>20
2	Moderate prime land	50-75	5-15	15-35	10-20
3	Marginal land	<50	>15	>35	<10

(Source: Naidu et al. 2014,)

3.8 MULTICRITERIA ANALYSIS FOR PRIORITIZATION OF CONSERVATION MEASURES IN DEGRADED LANDS

The most flexible and intuitive methods of integrating expert knowledge into GIS are the multi-criteria analysis (MCA) mechanisms (Saaty, 1977; Malczewski, 1999). MCA is a formalized method, enables the quantitative and qualitative knowledge of experts to be integrated and translated into computer language, most often by means of weights, using formal and controlled procedures.

MCA has been widely used in geomorphology (Burton and Rosenbaum, 2003; Ni and Li, 2003; Ni *et al*., 2008) to study the effect of human, environmental and climatic factors over the land degradation risks in the area, for suggesting different conservation measures.

A weighted multi-criteria overlay analysis was performed using Arc GIS considering the land degradation attributes, slope, soil depth and soil texture. Status of erosion was given highest weightage (30 %) followed by slope (20 %), vegetation index (15 %), water stress index (15 %), Depth (10 %) and texture (10 %). Within each layer, a rating from 1.0 to 5.0 was assigned to the classes in the increasing order of their impact on land degradation. The flow chart of the Multi Criteria Analysis is given in Fig.3.

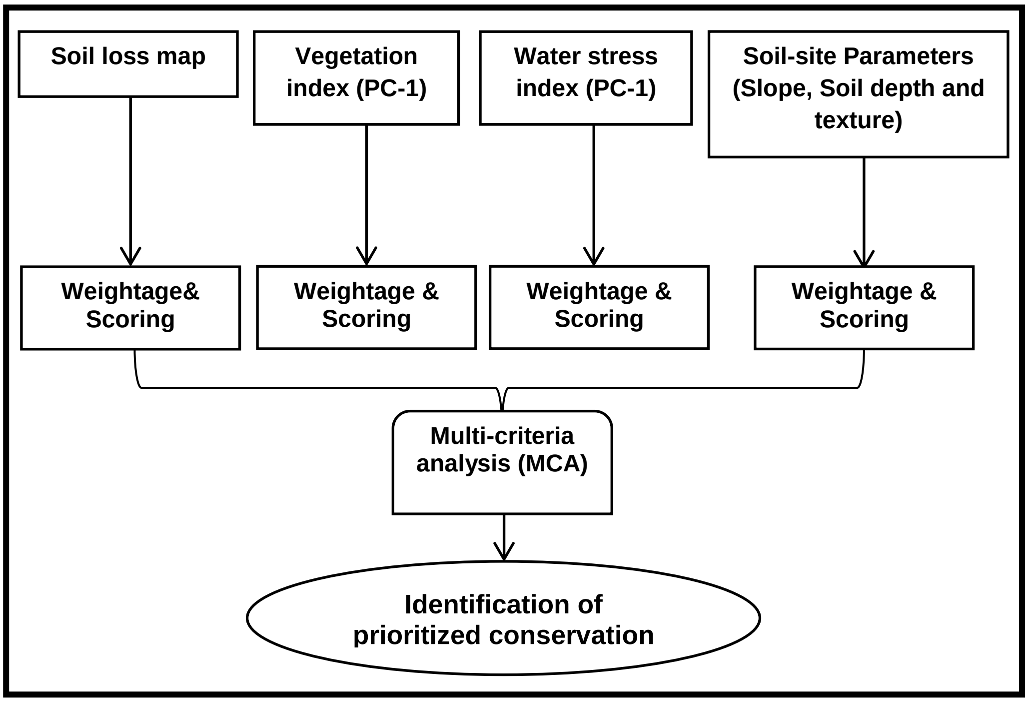

Fig.3. Flow chart of the methodology for multi-criteria analysis for prioritization of conservation measures in degraded lands

Chapter-IV

RESULT AND DISCUSSION

The present investigation was undertaken to characterize and map the degraded lands in Nagpur district of Maharashtra using remote sensing and GIS techniques. The results of the present investigation were presented and discussed under the following heads and sub-heads:

4.1 CHARACTERISATION AND MAPPING OF NATURAL RESOURCES

4.1.1 Land use/land cover mapping

4.1.2 Drainage morphometry

4.1.3 Slope mapping

4.1.4 Physiography mapping

4.1.5 Soil mapping

4.2SOIL EROSION ASSESSMENT AND MAPPING

4.2.1 Calculation of RUSLE factors

4.2.1.1 Rainfall erosivityfactor (R-factor)

4.2.1.2 Soil erodibilityfactor (K-factor)

4.2.1.3 Topographic factor (LS-factor)

4.2.1.4 Crop management factor (C-factor)

4.2.1.5 Conservation practice factor (P-factor)

4.2.2 Predicted soil loss

4.3 LAND DEGRADATION INDICATORS

4.3.1 Soil erosion

4.3.2 Vegetation index

4.3.3 Water stress index

4.3.4 Principal Component Analysis (PCA)

4.3.4.1 Vegetation indices

4.3.4.2 Water stress indices

4.4. LAND DEGRADATION ASSESSMENT

4.4.1 Selection of attributes/indicators

4.4.2 Grouping of Land degradation indicators

4.4.3 Normalization of maps

4.4.4 Development of Land Degradation Index (LDI)

4.4.5 Classification and extent of land degradation

4.5 SOIL-SITE CHARACTERISTICS FOR VALIDATION OF SOIL EROSION

4.5.1 Site characteristics

4.5.2 Soil characteristics

4.5.3 Correlation of soil properties with erosion

4.6 DELINEATION OF PRIME AGRICULTURAL LAND

4.6.1 Prime lands (PL)

4.6.2 Moderate prime lands (MPL)

4.6.3 Marginal lands (ML)

4.7 SUGGESTED SOIL AND WATER CONSERVATION MEASURES IN DEGRADED LANDS

4.1 CHARACTERISATION AND MAPPING OF LAND RESOURCES

4.1.1 Land use/land cover mapping

The land use/land cover map of the Nagpur district is shown in Fig.4 and the area under different categories of land use/land cover is presented in Table 9. Ten land use/land cover classes *viz*. agricultural land (crop, fallow and plantation), forest (deciduous, plantation and degraded), barren scrub land/wasteland, mining, habitation and water body have been mapped.

Table No. 9. Area and extent of different land use/land cover classes

Sr. No.	Land Use/land cover class	Area (ha)	Per cent (%)
1	Agriculture Crop Land	606520	61.3
2	Agriculture Fallow	18306	1.9
3	Agriculture Plantation	5388	0.5
4	Barren Scrub land/wasteland	53084	5.4
5	Forest Deciduous	213449	21.6
6	Forest Plantation	5202	0.5
7	Degraded forest	7946	0.8
8	Waterbody	33434	3.4
9	Habitation	42174	4.3
10	Mining	3729	0.4
	Total	989230	100

4.1.1.1 Agricultural land

Agricultural crop land under cultivation was mostly situated in the central, northern, western, eastern and some of the southern parts of the district comprising nearly level to very gently sloping alluvial plains and valleys, very gently to gently sloping plateau top, pediments and subdued plateau. The distribution pattern of each land utilization type in the study area indicates that the agricultural crop land occupies nearly 606520 ha (61.3 % of TGA). The single cropped area (mostly occurs on plateau top, subdued plateau and pediments) was distributed in the northern, central, southern, eastern parts in the tehsils of Kuhi, Bhiwapur, Umrer, Kamptee, Hingna, Parseoni, Saoner and Kalmeshwar, whereas, double cropped area (mostly occurs on alluvial plains, valleys) was noticed in Mauda, Kuhi, Saoner, Hingna and Katol tehsils. The agriculture fallow occupies 18306 ha (1.9 % of TGA) and agriculture plantation occupies 5388 ha (0.5 % of TGA). Fallow lands were distributed in the western part of Kuhi, Hingna tehsils and eastern parts of Katol, Narkhed and Hingna tehsils.

4.1.1.2 Forest lands

Three classes of forest *viz*. deciduous forest, forest plantation and degraded forest were identified in the district. Deciduous forest prevails in the northern, northwestern, south eastern, south western and western parts of the district, mostly, on hilly areas. Ramtek and Parseoni tehsils have the highest area under forest followed by Hingna, Katol, Kuhi and Narkhed tehsils. Deciduous forest occupies about 213449 ha (21.6 % of TGA), degraded forest occupies 7946 ha (0.8 % of TGA), whereas, forest plantation occupies 5202 ha (0.5 % of TGA).

4.1.1.3 Barren Scrub land/Wastelands

The wastelands like barren scrub land and barren rocky land occurs on physiographic units like escarpment, isolated hillocks, subdued plateau and pediments with an area of 53084 ha (5.4 % of TGA). Wastelands are distributed in isolated patches in the district.

4.1.1.4 Water bodies, Habitation and Mining

Water bodies occupy 33434 ha (3.4 % of TGA) area of the district. There were many small, medium and large size reservoirs spread across the district. Most of them were located at the base and in between hill ranges. There are many small villages, towns and cities covering an area of 42174 ha (4.3 % of TGA), whereas, mining occupies about 3729 ha (0.4 % of TGA).

4.1.2 Drainage Morphometry

The analysis of morphometric parameters of landscape helps to assess and evaluate erosion risk, soil and water conservation strategies, ground water potential, watershed characterization and other environmental parameters. The quantitative drainage morphometric analysis helps to understand the relationships among the different aspects of the drainage parameters and land resources distribution. Evaluation of morphometric parameters necessitates preparation of drainage map, ordering of the various streams, measurement of the catchment area, length and perimeter of drainage channels, drainage density, drainage frequency and bifurcation ratio etc. (Obi Reddy *et al.,* 2004).

The district is characterized by dendritic type of drainage pattern with a good network of small and medium drains throughout the area (Fig.5).Different morphometric parameters computed was presented in Table 10.

4.1.2.1 Stream order

The stream order is a measure of the position of a stream in the hierarchy of the tributaries (Horton, 1945). The data (Table 10) reveals that 3868 streams drain the area and highest number of streams (1995) belongs to first order and the number of streams decreased, in general, with the increase in order. However, the number of streams in previous order was higher than that in the next order. It has been observed that first order streams occurs mostly in the upper reaches of the district in the hilly terrain and higher order streams were located in the central and lower parts of the district, where, the topography is plain. This indicates that the soil loss by erosion was higher and soil development was less in upper reaches as compared to the lower reaches.

Table No. 10. Morphometric analysis of the study area

Area (km^2)	Perimeter (km)	Stream order	No. of streams of given order (Nu)	Total stream length (km)	Average Stream length (Lu) (km)	Bifurcation ratio (Rb)	Drainage frequency (Df) (km^{-2})	Drainage density (Dd) (km km^{-2})	Drainage intensity
9890.305	589.86	1	1995	5627.7	2.8	2.1	0.39	0.91	0.36
		2	940	1860.1	2.0	2.0			
		3	458	766.1	1.6	1.3			
		4	363	573.9	1.5	4.5			
		5	79	121.5	1.4	2.3			
		6	33	58.9	1.8				
			3868	9008.1	2.3				

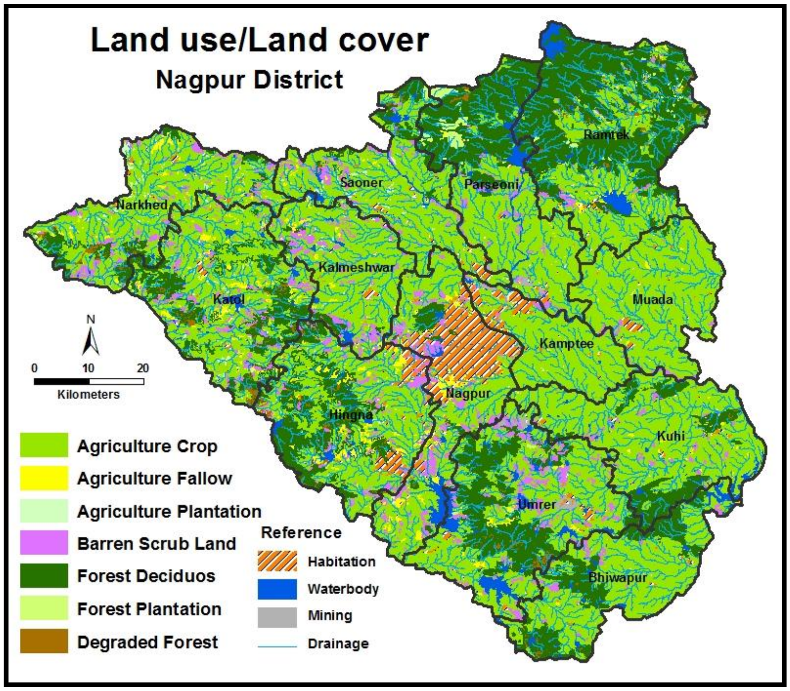

Fig.4. Land Use/Land Cover map of Nagpur district

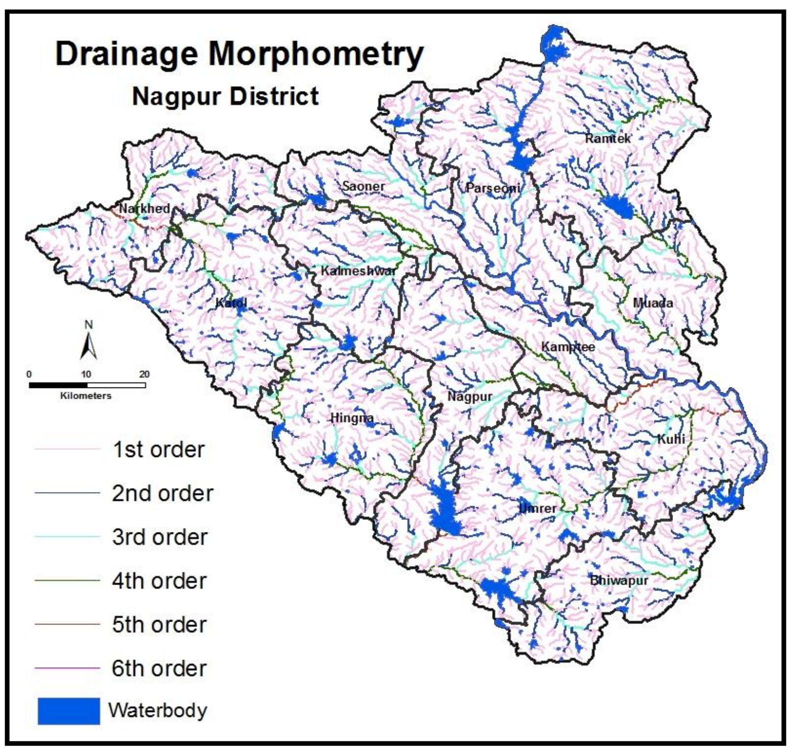

Fig.5. Spatial distribution of drainage classes of Nagpur district

4.1.2.2 Stream length

The average stream length denotes the size of components of a drainage network and the basin area contributing to it. It was observed that the total length of channels in the district was 9008 km and highest in the first order streams (Table 10). It decreased with increase in the order and was the lowest (58.9 km) in the sixth order. But, the average stream length (Lu) depicted different picture and lowest (1.4) in fifth order and highest (2.8) in the first orders streams. It was more or less same in remaining order channels.

4.1.2.3 Bifurcation ratio

Bifurcation ratio (Rb) is the ratio of the number of streams of any given order (Nu) to the number of streams in the next higher order (Nu+1). It was found that the values ranged between 1.3 and 4.5. The least value was observed in between 3rdand 4th order channels reflecting the least structural disturbances in the area (Strahler, 1964) and the highest was in between 4th and 5th order channels, indicating most disturbed area. The variation in the bifurcation ratio was attributed to the differences in the stages of development and topographic variations.

4.1.2.4 Drainage density

The drainage density (Dd) indicates the closeness of spacing of channels and therefore, provides a quantitative measure of the average length of streams channel. The factors affecting stream length are climate, permeability of rocks, resistance to weathering, vegetation *etc*. Higher the drainage density, more rough is the surface area and is more prone to erosion. Low drainage density indicates low relief and high resistance of soil material to erosion. The drainage density of the district was 0.91 km km^{-2}, which was moderately high associated with less drainage frequency of 0.39 indicating higher roughness of the area like escarpment and foot slopes.

4.1.2.5 Drainage frequency and drainage intensity

The Drainage frequency denotes the number of drainage lines per unit area, whereas, drainage intensity represents the spread of streams over an area. It was observed (Table 10) that moderate drainage frequency of 0.39 corresponds to moderately high drainage density of 0.91 and moderate intensity of 0.36. The higher drainage frequency was associated with sloping and undulating lands, whereas, low drainage frequency was associated with plain lands that were less affected by erosion. Thus, the drainage configuration of the area depicts the ruggedness of the area and indicates the erosion status, soil development and land use pattern of an area.

4.1.3 Slope Mapping

The study of slope characteristics of an area is essential as it controls the erosion, surface run-off and soil moisture. Hence, it affects soils formation which ultimately affects the land use of the area. Five slope classes *viz*. very gently sloping (1-3 %), gently sloping (3-8 %), moderately sloping(8-15 %), moderately steeply sloping (15-30 %) and steeply sloping (30-50 %) lands have been identified (Fig.6). The data (Table 11) indicate that maximum area was under very gently sloping land with an area of 709557 ha (71.7 % of TGA) followed by gently sloping and moderately sloping lands.

Table No. 11. Extent and distribution of slope classes

Sr. No.	Slope class	Area (ha)	Per cent (%)
1	Very gently sloping (1-3 %)	709557	71.7
2	Gently sloping (3-8 %)	143605	14.5
3	Moderately sloping (8-15 %)	41667	4.2
4	Moderately steeply sloping (15-30 %)	14981	1.5
5	Steeply sloping (>30 %)	84	0.01

4.1.4 Physiography Mapping

Based on the interpretation of Landsat 5, 7 TM+ data, SoI (Survey of India) toposheets and ground truth, seven physiographic units *viz*. plateau top, hills and ridges, escarpments, subdued plateau, pediments, alluvial plain and valley have been identified (Table 12 & Fig.7).

4.1.4.1 Plateau top

The plateau top was the most elevated portion in the landscape with erosional surfaces and the elevation ranges from 400 to 520 m above MSL and occupies an area of 20338 ha (2.1 % of TGA). It was mainly under forest and wasteland with scrub.

4.1.4.2 Hills and Ridges

These are elevated landforms in the study area having elevation in the range of 300 to 420 m above MSL and occupy an area of about 79765 ha representing 8.1 per cent of TGA. These landforms mainly occur in the northern part of the district, exhibiting highly structured rocks. The landform was rugged and covered with sparse vegetation situated mainly in north western part of the district having a Trappean character with basalt as the base material. The hills and ridges were mainly under deciduous forest and wasteland with scrubs.

4.1.4.3 Escarpments

Moderately sloping (8-15 %) and moderately steeply sloping (15-30 %) escarpments was adjacent to plateau top abruptly extending down from its fringe. The escarpment was prone to erosion and mass wasting. The elevation ranges from 280 to 450 m above MSL and occupies an area of 10068 ha (1.0 % of TGA). The escarpment generally supports degraded forest/open scrub, while, the eastern slope supports good growth of forest/vegetation. The northern aspect of escarpment was low in height merges with pediment surface, while, the southern aspect has slopes vertically and suddenly merges with valley.

4.1.4.4 Subdued Plateau

These are moderately elevated areas with undulating topography with an elevation ranging from 210 to 320 m above MSL. The subdued plateau occupies an area of 129998 ha (13.1 % of TGA) and mainly under deciduous forest, degraded forest and wasteland with scrub.

4.1.4.5 Pediments

The pediments are erosional surfaces and occur at an elevation of 250 to 350 m above MSL. It occupies an area of 167286 ha (16.9 % of TGA).

4.1.4.6 Alluvial Plain

The alluvial plain was a depositional surface with deposits of alluvium brought down by the river. The alluvial plain occurs at a lower elevation ranging from 210 to 250 m above MSL. The soils were deep to very deep, fine texture with shrink-swell properties. It occupies an area of 462257 ha (46.7 % of TGA).

4.1.4.7 Valleys

The valley was characterized by narrow strip of lower zone formed by fluvial actions. The sediments were transported from upper reaches and deposited along the river course. The elevation ranges from 200 to 240 m above MSL. It occupies an area of 40152 ha (4.1 % of TGA).

Table No. 12. Area and extent of different physiographic units in the study area

Physiography	Area (ha)	Per cent (%)
Plateau top	20338	2.1
Hills and ridges	79765	8.1
Escarpment	10068	1.0
Subdued plateau	129998	13.1
Pediments	167286	16.9
Alluvial plain	462257	46.7
Valley	40152	4.1

4.1.5 Soil Mapping

Soil mapping comprises the identification, description and delineation of different kinds of soils based on morphological observations in the field and laboratory investigations (Challa *et. al.,* 1995). Soil map provides a means of communicating our knowledge about the distribution of soil attributes and occurrence of different soil classes in nature. Information on soil properties becomes essential to know the soil degradation in terms of both physical as well as chemical degradation. Twenty three soil series were tentatively identified in the district and mapped as soil series association in different physiographic units (Fig.8). These soils vary in terms of morphological, physical and chemical characteristics.

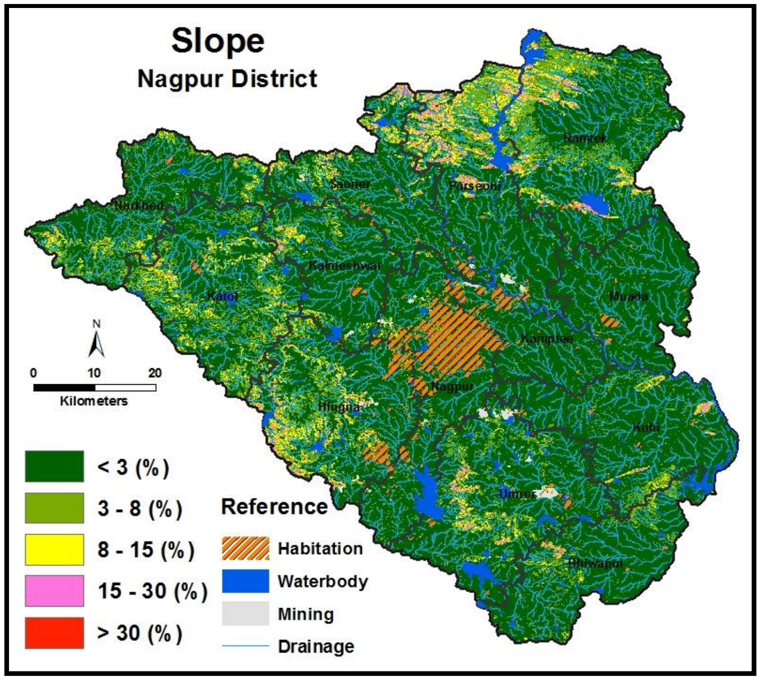

Fig.6. Slope map of Nagpur district (%)

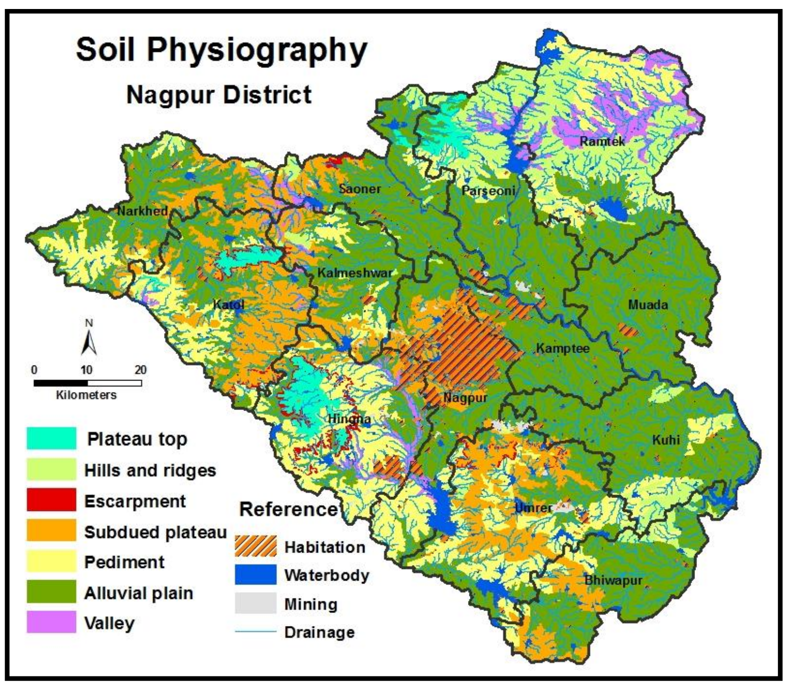

Fig.7. Physiographic units of Nagpur district

4.1.5.1 Soils of Plateau top

Malegaon (Meg) series

Soils of Malegaon were deep, moderately well drained, very dark gray, clayey soils occur on very gently to gently sloping plateau, Developed on weathered basalt. They have high shrink-swell potential, high clay content, neutral in reaction and non-calcareous. They have slight to moderate erosion hazards.

Muserkhapa (Msk) series

Soils of Muserkhapa were moderately deep, well drained, dark yellowish brown to dark brown, clayey soils occur on very gently to gently sloping plateau and developed on weathered basalt. They have high swell-shrink potential, high clay content, neutral in reaction and high base saturation. They have moderate to severe erosion hazards.

Rongha (Rng) series

Soils of Rongha were moderately deep, well drained, reddish brown, sandy loam to sandy clay loam textured soils, developed on mica schists and occur on nearly level to moderately sloping plateau. The soils were non-calcareous with high base saturation, medium in nutrient status and moderately eroded.

4.1.5.2 Soils of hills and ridges

Sewadoli (Sdl) series

Soils of Sewadoli were moderately deep, well drained reddish brown with sandy clay loam texture, developed over quartzitic mica schists on hills and ridges. The soils were non-calcareous with medium to high base saturation and moderately eroded.

Ramtek (Rtk) series

Soils of Ramtek were shallow, well to excessively drained, reddish brown, sandy loam to sandy clay loam texture, developed over micaeous schists and occur on moderately to strongly slopping hills and ridges. The soils were light textured, non-calcareous, low in nutrient status and severely eroded and were mostly under forests and grassland.

4.1.5.3 Soils of Escarpments

Chankapur (Ckp) series

Soils of Chankapur were shallow to moderately deep,well drained, very dark grayish brown tovery dark brown, clayey soils, developed onweathered basalt and occur on moderately to steeply sloping escarpments. The soils are loamy, non-calcareous, highly base saturated and moderately to severely eroded soils.

Yenwa (Ynw) series

Soils of Yenwa were shallow, well to excessively drained, dark red to dark reddish brown, clay loam soils. They were neutral in reaction, highly base saturated and non-calcareous. They occur on moderately sloping escarpments and developed over weathered basalt and severely eroded soils.

4.1.5.4 Soils of Subdued plateau

Semda (Smd) series

Soils of Semda were moderately deep, well drained, reddish brown with sandy loam to sandy clay loam texture developed over sandstone and occur on very gently to gently sloping subdued plateau. These soils were non-calcareous with medium to high base saturation and non-cracking.

Pardi (Prd) series

Soils of Pardi were shallow, well drained, dark yellowish brown, sandy loam to loam soils occur on very gently to gently slopingsubdued plateau and developed over weathered basalt. They were light textured, non-calcareous, highly base saturated soils. The soils are moderately to severely eroded andwere mostly found under wasteland or grass land.

4.1.5.5 Soils of Pediments

Magarli (Mgr) series

Soils of Magarli were well drained, moderately deep, dark brown in colour, loamy soils, developed on colluvium and occur on very gently to gently sloping pediment. The soils were non-calcareous, low in nutrient status and were susceptible to moderate erosion hazards and mostly under reserve forests.

Gunjapur (Gjp) series

Soils of Gunjapar were moderately deep, moderately well drained, brown to dark brown in colour, sandy clay loam to clay soils, developed over concretionary materials and occur on very gently sloping pediments. The soils were non-calcareous and medium in nutrient status, high in base saturation and susceptible to erosion.

Devdipar (Dvp) series

Soils of Devdipar were moderately deep, well drained, dark brown clay loam to sandy clay loam developed over ferruginous concretions and occur on nearly level to very gently sloping pediments. The soils were non-calcareous, highly base saturated and medium in nutrient status and moderately eroded.

Karla (Krl) series

Soils of Karla were moderately deep, moderately well drained, dark brown to dark grayish brown, clayey soils occur on nearly level to gently sloping pediments developed over weathered basalt. The soils were calcareous with high swell-shrink potentials with high base saturation and slightly eroded.

Khapri (Kpr) series

Soils of Khapri were deep, moderately well drained, very dark grayish brown in colour, clayey soils developed over sandstone and occur on nearly level to very gently sloping pediments. The soils were calcareous in nature and highly base saturated with slight to moderate erosion and are mostly under cultivation.

Jam (Jam) series

Soils of Jam were very deep, well drained brown to dark brown, sandy clay loam soils, developed on basaltic out wash and occur on nearly level to very gently sloping pediments. The soils were non-calcareous in nature, high in nutrient status and base saturation with moderate erosion hazard.

Gaimukh (Gmk) series

Soils of Gaimukh were deep, well drained, sandy clay loam, dark yellowish brown to dark brown developed over out wash material laid over quartzite mica schist on very gently sloping pediments. The soils were non-calcareous, high in nutrient status and medium in base saturation with moderate erosion hazard.

4.1.5.6 Soils on Alluvial plains

Panjra (Pjr) series

Soils of Panjra were very deep, moderately well drained, dark brown to very dark grayish brown, clayey soils, developed over basaltic alluvium and occur on very gently sloping alluvial plain. The soils were calcareous in nature with high base saturation and high swell-shrink potential with moderate erosion hazard.

Aroli (Arl) series

Soils of Aroli were very deep, moderately well drained, dark reddish brown, clayey soils developed over alluvium and occur on nearly level to very gently sloping alluvial plain. The soils were non-calcareous with high shrink-swell potentials and high base saturation with moderate erosion hazard.

Kirnapur (Krn) series

Soils of Kirnapur were very deep, well drained, brown to very dark grayish brown, clayey soils, developed over basaltic alluvium and occur on nearly level to very gently sloping alluvial plain. The soils were non-calcareous with high swell-shrink potential and high base saturation and moderately eroded.

Linga (Lng) series

Soils of Linga were very deep, imperfectly to poorly drained, dark to very dark grayish brown, clayey soils developed over basaltic alluvium and occur on level to gently sloping alluvial plain. The soils were calcareous with high shrink-swell potential and highly base saturated with slight to moderate erosion hazard.

Wadhona (Wdn) series

Soils of Wadhona were deep, moderately well drained, dark brown, medium textured soils which occur on nearly level to gently sloping alluvial plain, developed over alluvium. The soils were calcareous in nature with high base saturation and with slight erosion hazard.

4.1.5.7 Soils of Valley

Bagbori (Bgb) series

Soils of Bagbori were moderately deep, moderately well drained, dark to very dark grayish brown, clayey soils developed over basaltic alluvium and occur on nearly level to gently sloping valley. The soils were calcareous in nature with high base saturation and high shrink-swellpotential. These soils were slightly to moderately eroded and were partly under cultivation to crops like sorghum, paddy and pigeon pea and partly under forests.

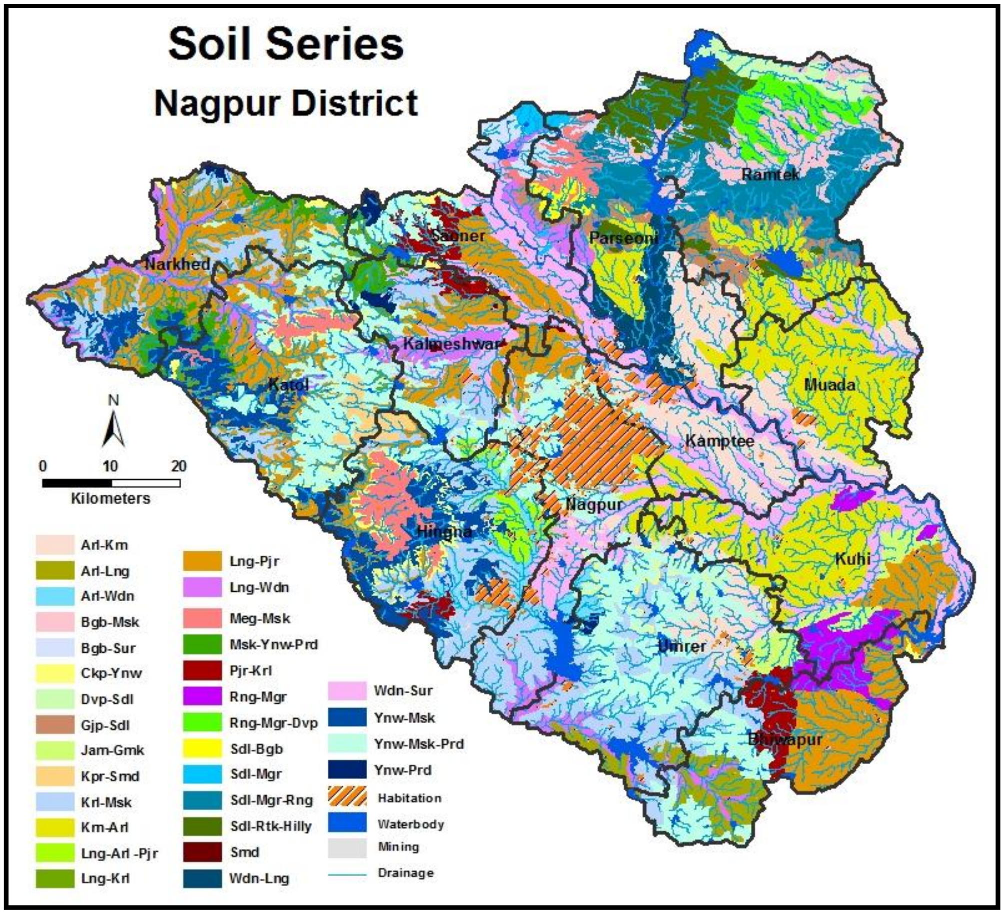

Fig.8. Soil series associations of the Nagpur district

Sur (Sur) series

Soils of Sur were very deep, well drained, dark brown to dark yellowish brown, medium textured soils occur on nearly level to gently sloping valley developed over alluvium. The soils were non-calcareous with medium to high base saturation and slightly eroded.

4.2 SOIL EROSION ASSESSMENT AND MAPPING

4.2.1 Computation of RUSLE Factors

RUSLE was a straightforward and empirically based model with an ability to predict long term average annual rate of soil erosion on slopes using data on rainfall pattern, soil type, topography, crop systems and management practices (Prasannakumar *et al.,* 2012). The model parameters were derived using remote sensing, ancillary and field data and computed RUSLE factors.

4.2.1.1 Rainfall erosivityfactor (R-factor)

The soil erosion rates, in many studies, have been found to be more sensitive to rainfall(Jain *et al.,* 2001; Dabral*et al.,* 2008). The daily rainfall data was considered as better indicator for soil erosion rate to characterize the seasonal distribution of sediment yield, while, the advantages of using annual rainfall include its ready availability, ease of computation and greater regional consistency (Shinde*et al.,* 2010).

The rainfall erosivity index (R factor) in the RUSLE model, is an index of rainfall erosivity which is the potential ability of the rain to cause erosion (Chen*et al.,* 2010).The average annual erosion index of the area calculated using the relationship given by Ram Babu*et al*. (1978) R=79+0.363*P,where, R is the average annual erosion index and P is the average annual rainfall distribution (mm) using data over 18 years period from 13 weather stations located in the study area. The data is presented in Table 13.

The estimated R factor values ranges from 359.3 and 513.0 MJ.mm.ha^{-1}.hr^{-1}.yr^{-1}. The lowest R factor was observed in Hingna tehsil, whereas, highest R factor was observed in Bhiwapur tehsil. The distribution of R values varied and consistent with annual precipitation across the district. The R factor values were interpolated using ordinarykrigging in Arc GIS software. The erosivity factor was reclassifiedinto five erosivity classes *viz*. <420, 420-440, 440-460, 460-480 and >480 MJ·mm·ha^{-1}·hr^{-1}·yr^{-1} and generated a surface map of R factor (Fig. 9). The distribution shows that R factor was higher in south-east part, whereas, R factor was found lower in western part of the study area.

Table No. 13. Average annual precipitation and rainfall erosivity

Station/Tehsils	Average P (mm)	(R) (MJ·mm·ha^{-1}·hr^{-1}·yr^{-1})
Nagpur City	1052.6	464.7
Nagpur Rural	1083.6	472.3
Kamptee	1039.6	456.4
Hingna	772.3	359.3
Katol	951.5	424.4
Narkhed	871.3	395.3
Saoner	999.8	441.9
Kalmeshwar	1019.5	449.1
Ramtek	997.2	441.0
Parshivni	1061.2	464.2
Mauda	1185.6	509.4
Umrer	1122.8	486.6
Bhivapur	1195.5	513.0
Kuhi	1067.3	466.4

(Source: Revenue department, Collectorate office, Nagpur, Maharashtra)

4.2.1.2 Soil Erodibility Factor (K Factor)

The soil erodibility factor (K) expresses the soil susceptibility to detach and transport of soil particles under an amount of rainfall and rate of run-off for a specific rainfall, measured under standard plot (Farhan*et al.,* 2013). The K Factor is a measure of the total effect of a particular combination of soil properties. The erodibility factor computed from representative soil samples identified from soil map of Nagpur district (ICAR-NBSS&LUP, 1990) was presented in Table 14. The data indicate that values of K factor for different soil series ranges between 0.02 and 0.26. Highest K value was observed in soils of Devdipar and lowest K value was observed in soils of Ramtek. The K factor map was reclassified into five erodibility classes *viz*. 0-0.08, 0.08-0.12, 0.12-0.15, 0.15-0.18 and 0.18-0.21 (Fig.10).

Table No. 14. Physical, chemical properties and estimated K-factor values of different soil series of Nagpur district

Sr. No.	Soil series	Organic matter (%)	Very fine sand (%)	Silt (%)	Clay (%)	Soil Structure code (b)	Soil permeability (c)	Particle size (M)	Soil erodibility (K)
1.	Malegaon	1.10	6.6	27.5	56.2	2	5	1493.6	0.19
2.	Muserkhapa	0.91	6.5	27.5	59.1	2	3	1390.6	0.12
3.	Chankapur	1.24	6.5	28.5	55.6	2	3	1554.0	0.13
4.	Pardi	0.09	5.7	23.2	19.9	1	2	2314.9	0.15
5.	Yenwa	1.48	25.0	20.5	34.6	1	2	2975.7	0.19
6.	Karla	1.02	5.6	26.0	60.6	3	4	1245.0	0.17
7.	Linga	0.88	4.8	20.6	74.6	3	5	645.2	0.15
8.	Panjra	1.05	5.5	30.2	53.0	3	4	1677.9	0.22
9.	Wadhona	0.69	5.5	27.8	34.7	2	3	2174.5	0.20
10.	Aroli	0.74	13.0	15.0	40.0	1	4	1680.0	0.14
11.	Kirnapur	0.71	9.5	25.0	50.6	1	4	1704.3	0.14
12.	Bagbori	1.45	13.0	17.5	41.0	2	6	1799.5	0.24
13.	Khapri	1.38	6.0	8.0	40.1	2	6	838.6	0.16
14.	Sur	0.29	6.9	17.0	17.5	1	2	1971.8	0.11
15.	Semda	0.83	15.3	11.0	19.2	2	2	2125.0	0.16
16.	Jam	0.81	14.3	23.0	30.5	1	4	2592.4	0.23
17.	Gaimukh	0.93	13.3	11.6	26.0	1	4	1842.6	0.15
18.	Gunjepar	1.10	16.9	5.0	24.2	2	6	1660.0	0.24
19.	Rongha	2.02	7.8	19.6	22.6	1	2	2120.8	0.09
20.	Magarli	0.88	7.3	13.6	26.5	2	2	1536.2	0.10
21.	Sewadoli	1.02	8.9	20.5	30.6	2	2	2040.4	0.14
22.	Ramtek	1.38	4.1	14.6	15	1	1	1589.5	0.02
23.	Devdipar	0.76	11.5	27.0	26.9	2	3	2814.4	0.26

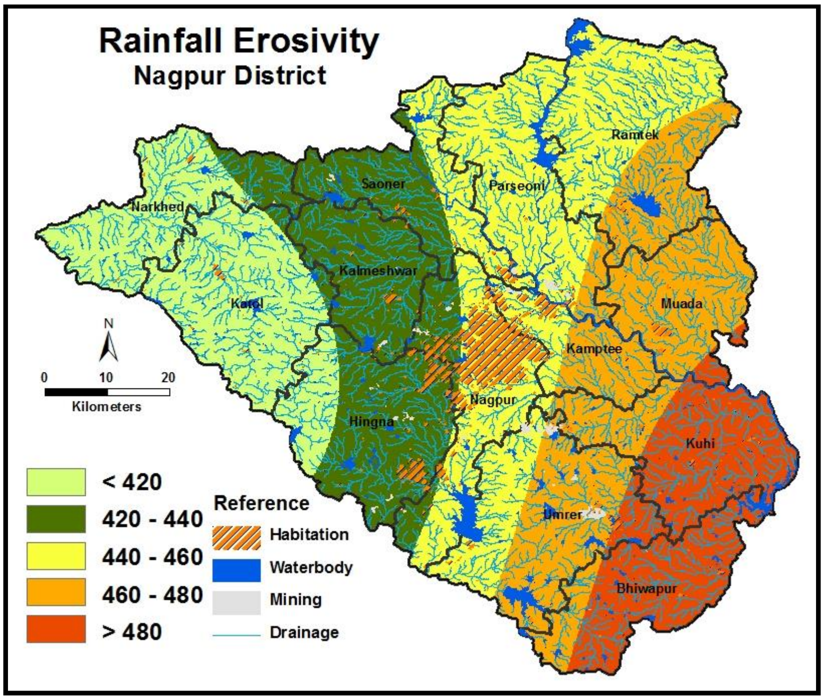

Fig.9. Rainfall erosivity(R Factor) of Nagpur district

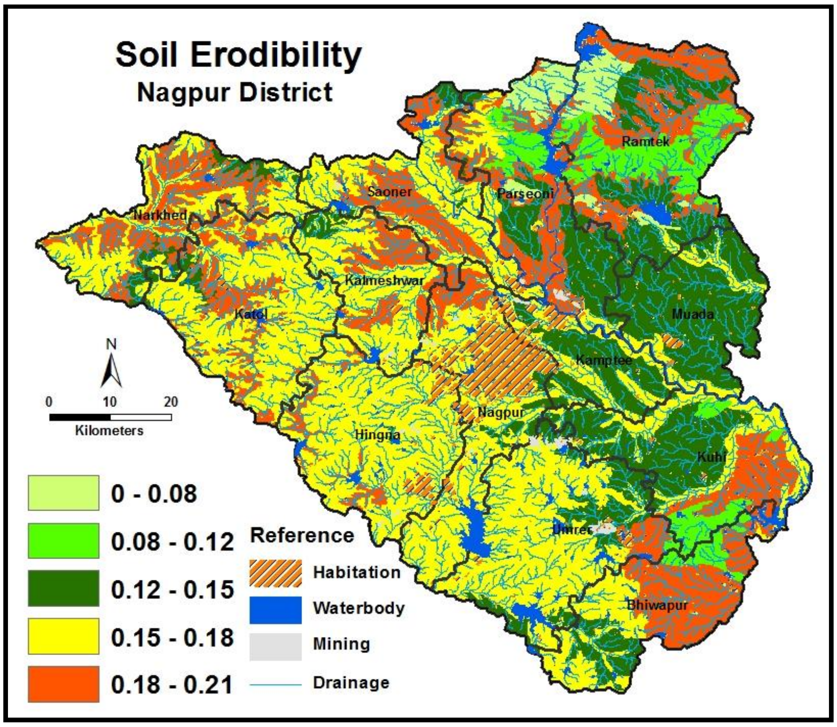

Fig.10. Soil erodibility(K Factor) of Nagpur district

4.2.1.3 Topographic Factor (LS factor)

Topographic factor represents the major influence of slope length and slope steepness on erosion process. LS factor was calculated by considering the flow accumulation and slope gradient in degrees as an input. The highest LS factor was observed in hills and ridges with moderately steep to steeply slopes, whereas, lowest LS value was observed in nearly level to very gently sloping alluvial plain and valley. The LS factor values were reclassified into five classes *viz*. 0-10, 10-20, 20-30, 30-40 and 40-50 and prepared a map using Arc GIS software (Fig. 11).

4.2.1.4 The Crop Cover and Management Factor (C factor)

The crop cover and management factor (C) represents the effect of cropping and management practices in different land cover system. Cover is usually referred to the vegetation, which has a strong influence on protecting soil from erosion. Information on land use permits a better understanding of the land utilization aspects which are vital for developmental planning/erosion studies. A significant and positive correlation was observed between C factor and NDVI values (Fig.13). Using this relationship, the C factor from each pixel was determined from NDVI values. The lowest C factor value was observed in deciduous forest, whereas, highest C factor value was observed in barren scrubland/wasteland. The C factor values were reclassified into seven classes *viz*. <0.15, 0.15-0.25, 0.25-0.35, 0.35-0.55, 0.55-0.75, 0.75-0.85 and >0.85 and prepared a map using Arc GIS software (Fig. 12).

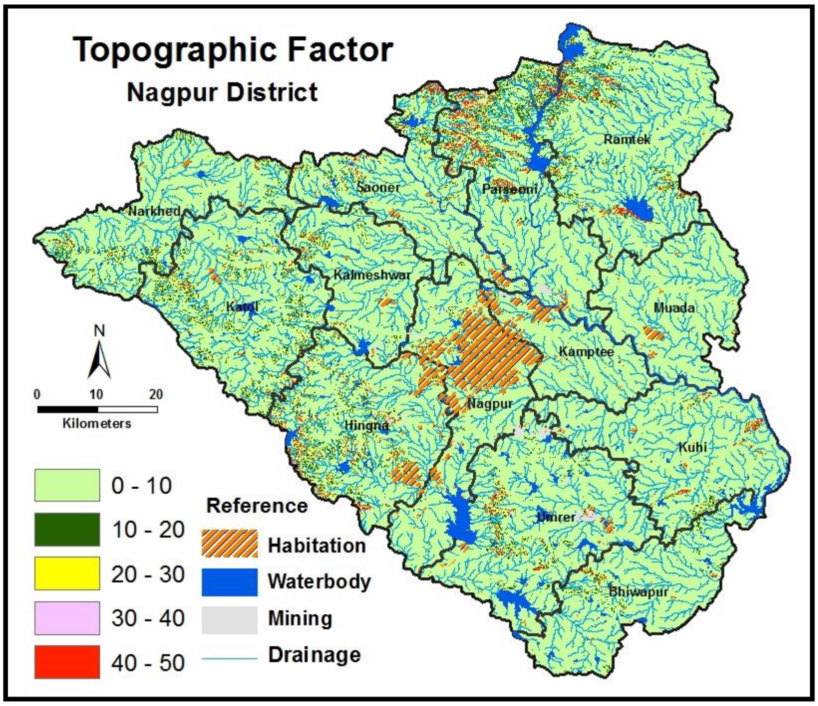

Fig.11. Topographic factor (LS Factor) of Nagpur district

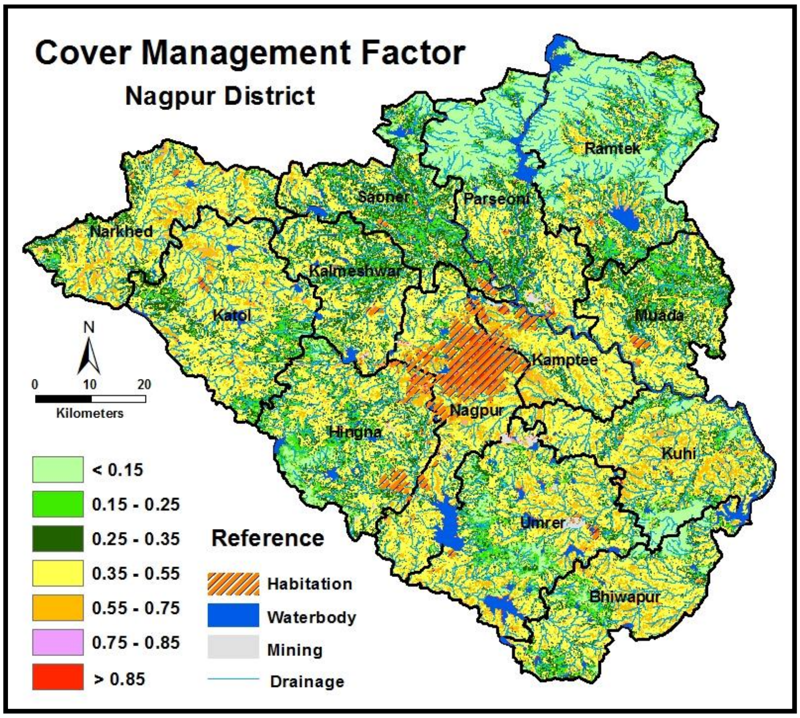

Fig.12. Cover management (C Factor) of Nagpur district

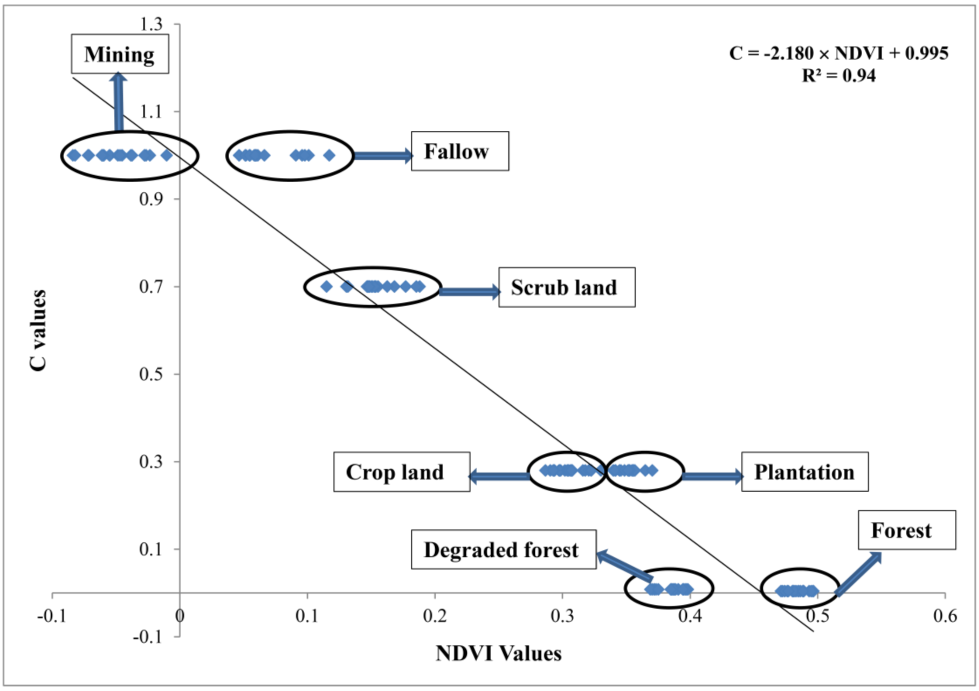

Fig. 13.Correlation between C-factor values and NDVI values.

4.2.1.5 The Conservation practices (P Factor)

The conservation practice factor (P) represents the ratio of soil loss by a support practice to that of up and down slopes and is used to account for the positive impacts of those support practices. The P factor account for control practices that reduce the erosion potential of the runoff by their influence on drainage patterns, runoff concentration, runoff velocity, and hydraulic forces exerted by runoff on soil (Gansari and Ramesh, 2016). Higher values of P factor corresponded to no conservation practices in forest and scrubland, and lower P values corresponded to agricultural crop land with conservation practices like bunding, whereas, agriculture land with higher slopes has higher P-factor as these lands are marginal lands cultivated along the slopes of foot hills without any conservation measures. The P factor values were reclassified into five classes *viz*. <0.10, 0.10-0.12, 0.12-0.14, 0.14-0.16 and 0.16-1.0 and prepared a map using Arc GIS software (Fig. 14).

4.2.2 Predicted Soil loss

GIS analysis has been carried out for RUSLE to estimate annual soil loss on a pixel-by-pixel basis. The data layers (maps) extracted for R, K, LS, C, and P factors of the RUSLE model were integrated within the raster calculator of the Arc GIS in order to quantify and generate the soil erosion risk map of Nagpur district, Maharashtra.

The total soil loss of the Nagpur district was found to be 211×10^5 $t.yr^{-1}$. The average annual soil loss of the district was estimated to be 21.4 $t.ha^{-1}.yr^{-1}$. The soil loss computed using the RUSLE model ranged between 0 to 105 $t.ha^{-1}.yr^{-1}$.The soil loss values have been reclassified into five classes *viz*. minimal (0-5 $t.ha^{-1}.yr^{-1}$), low (5-15 $t.ha^{-1}.yr^{-1}$), moderate (15-25 $t.ha^{-1}.yr^{-1}$), severe (25-50 $t.ha^{-1}.yr^{-1}$) and extreme (>50 $t.ha^{-1}.yr^{-1}$)(Table 15) and a map was prepared using Arc GIS software (Fig. 15).Majority of the area in the district (60.3% of TGA) was under minimal to low soil erosion, 4.3 per cent of TGA was under moderate, whereas, severe to extreme soil loss was observed to the extent of 27.4 per cent of TGA. The areas under very minimal to low soil loss need no immediate soil and water conservation measures as the soil loss was under tolerance limit of 4.5–11.2 t/ha/yr (Mannering 1981). Severe (25-50 $ton.ha^{-1}.yr^{-1}$) and extreme (>50 $ton.ha^{-1}.yr^{-1}$) soil erosion areas were located on moderate to very steep sloping lands of hills and ridges, escarpments in parts of Parseoni, Hingna, Ramtek, and Katoltehsils which needs immediate attention for soil and water conservation measures to improve the productivity of these lands.

Table No. 15. Area and proportion of each soil erosion risk class

Erosion risk class	Numeric range($t.ha^{-1}.yr^{-1}$)	Area (ha)	Percent (%)
Minimal	0-5	473430	47.9
Low	5-15	122497	12.4
Moderate	15-25	42716	4.3
Severe	25-50	79083	8.0
Extreme	>50	192176	19.4

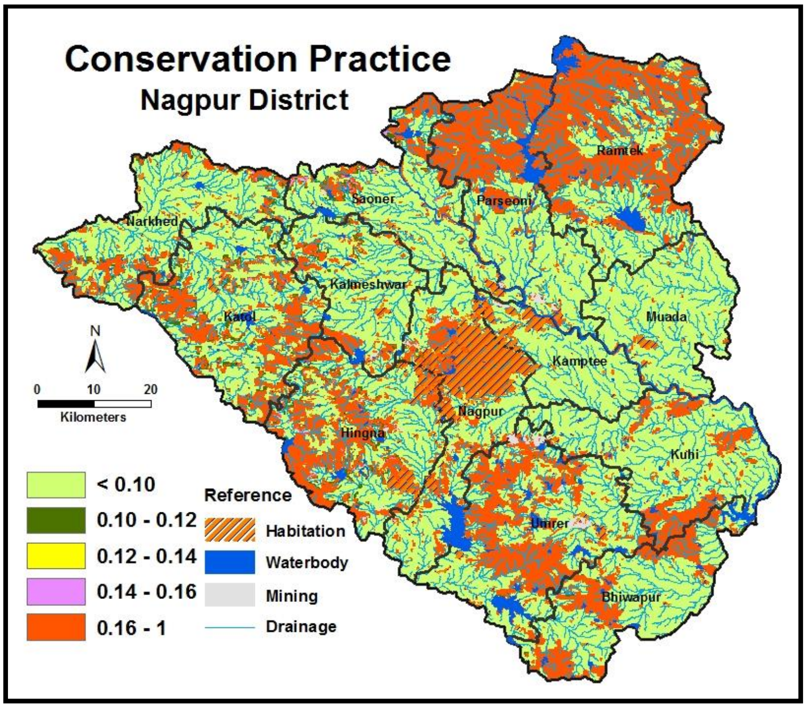

Fig.14. Conservation Practices (P Factor) of Nagpur district

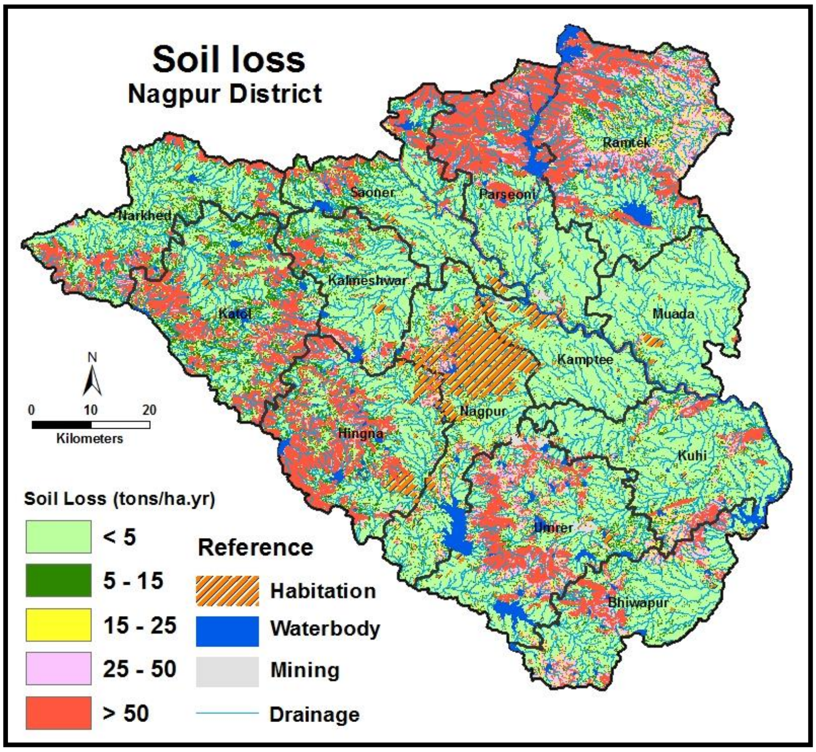

Fig.15.Annual soil loss of Nagpur district

4.3 LAND DEGRADATION INDICATORS

Realistic assessment of land degradation relies, first and foremost, on the identification of pertinent indicators. Finding indicators that are unambiguously related to certain land degradation process is important (Fadil, 2009). Unfavorable soil-surface characteristics and lack of adequate plant cover leads to reduced surface retention and infiltration and to higher surface runoff resulting not only in reduced soil moisture content in the soil profile, but also increases rates of soil erosion (Lal, 1990). It is clear that soil characteristics, vegetation cover and available soil moisture are influencing land degradation process. Several researchers have quantitatively evaluated several vegetation indices (Lacaze, 2004; Baugh and Groeneveld, 2006) and advocated combined use of vegetation cover, NDVI and slope as land degradation indicators for land degradation assessment (Rashid *et al.,* 2011). In the present study, quantitatively estimated soil erosion (excluding soil salinity and alkalinity), vegetation cover in terms of vegetation indices and surface moisture in terms of soil wetness indices have been used as potential land degradation indicators for land degradation assessment.

4.3.1 Soil Erosion

The results of average annual soil loss in Nagpur district of Maharashtra was presented and discussed in section 4.2 of this chapter. The soil erosion in raster layer was used for computation of Land degradation Index (LDI).

4.3.2 Vegetation Indices

Vegetation is one of the most important bio-physical indicators and being considered by many researchers to measure the extent of land degradation (Mahmoudzadeh, 2007; Vrieling*et al*., 2008; Rashid *et al*., 2011)**.** The decrease in erosion rates with increasing vegetation cover is exponential (Gyssels*et al*., 2005)**.** Plant and residue cover protects the soil from raindrop impact and splash, tends to slow down the movement of surface runoff and enables excess surface water to infiltrate.

Although many new vegetation indices have been established with the purpose of reducing the sensitivity to atmospheric conditions and substrate reflectivity, we have selected three mostly used vegetation indices *viz*. NDVI, SAVI and EVI as indicators of vegetation cover. The NDVI shows a strong dependence on the red reflectance, whereas, SAVI responds primarily to near infrared variations. However, both NDVI and SAVI showed limitations in the detectability of very low vegetation cover in semi-arid areas(Saltz*et al*., 1999). An improvement in vegetation index is proposed by Huete *etal*. (2002) in the form of Enhanced Vegetation Index (EVI) derived from Landsat 5, 7 TM+ satellite spectral bands comes from the use of a third channel *i.e.* blue region of "atmospherically-resistant" and "soil-adjusted" approaches. In the present study, for estimation of vegetation cover, three indices *viz*. NDVI, SAVI and EVI have been used and generated using Arc GIS software.

Normalized Difference Vegetation Index (NDVI):NDVI values ranged from -0.36 to 0.55. The low NDVI values (-0.36 to 0.1) shows the water body, habitation and mining areas in the district which covers 8.1 per cent of TGA. The NDVI map was reclassified into five classes *viz*. -0.36-0.1, 0.1-0.2, 0.2-0.3, 0.3-0.4 and 0.4-0.55 (Fig.16).Higher values of NDVI (0.4-0.55) were found in areas covered with deciduous forests in steep mountains in Ramtek, Parseoni, and Hingna, and small patches of Kuhi and Bhiwapur tehsils comprising 11.3 per cent of TGA. The moderate NDVI values ranged from 0.2-0.4 were found in Saoner, Mauda, Kalmeshwar, Hingna, Katol, Narkhed and patches in Kuhi, Bhiwapur and Ramtek tehsils comprising 66.2 per cent of TGA. The lower NDVI values, ranging from 0.1-0.2, were distributed in tehsils of Narkhed, Katol, Umrer, Nagpur, Kuhi and Bhiwapur, comprising 14.4 per cent of TGA.

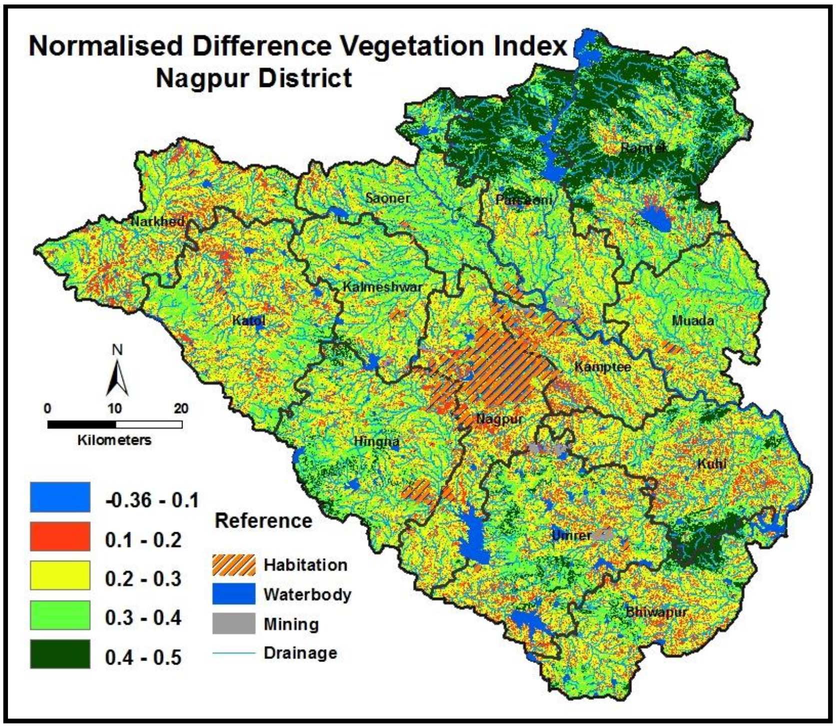

Fig.16.Normalised Difference Vegetation Index

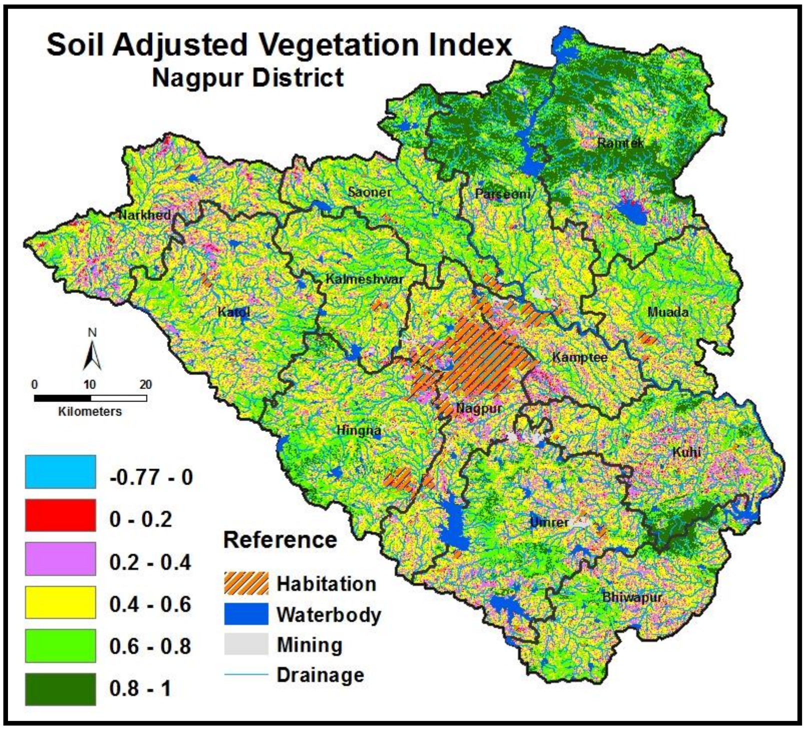

Fig.17.Soil Adjusted Vegetation Index

Soil Adjusted Vegetation Index (SAVI)**:** SAVI values ranged from -0.77 to 1.0. The negative value of SAVI (-0.77 to 0) shows the water body in the district, which covers 3.4 per cent of TGA. The SAVI map was reclassified into sixclasses*viz*. -0.77-0.0, 0-0.2, 0.2-0.4, 0.4-0.6, 0.6-0.8 and 0.8-1.0 (Fig.17).Higher values of SAVI (0.8-1.0) were found in areas covered with deciduous forests in steep mountains in Ramtek, Parseoni and small patches in Hingna, Kuhi, Bhiwapur, Katol and Umrer tehsils, which was found to be 9.2 per cent of TGA. The moderate SAVI values ranged from 0.4-0.8were found in Saoner, Mauda, Kamptee, Kalmeshwar, Hingna, Katol, Narkhed, Bhiwapur and Kuhi tehsils covering 64.7 per cent of TGA. The SAVI values in the range of 0.2-0.4 were concentrated in tehsils of Narkhed, Bhiwapur, Nagpur, Umrer and some parts of Kuhi and Kamptee covering 22.7 per cent of TGA.

Enhanced Vegetation Index (EVI)**:** The EVI values ranged from 0 to 1. The EVI map was reclassified into five classes *viz*. 0-0.2, 0.2-0.4, 0.4-0.6, 0.6-0.8 and 0.8-1.0 (Fig.18). The EVI values in the range of 0.0-0.2 represents areas under water body, habitation and mining areas in the district covering 10.1 per cent of TGA.The moderate EVI values in the range of 0.2-0.6were found in Saoner, Mauda, Kamptee, Kalmeshwar, Hingna, Katol, Narkhed, Bhiwapur and Kuhi tehsils accounting 67.0 per cent of TGA. Higher values of EVI (0.6 to 1.0) were confined to areas covered with deciduous forests in steep mountains in Ramtek, Parseoni, and small parts of Hingna, Kuhi, Bhiwapur, Katol and Umrer tehsils accounting 22.9 per cent of TGA.

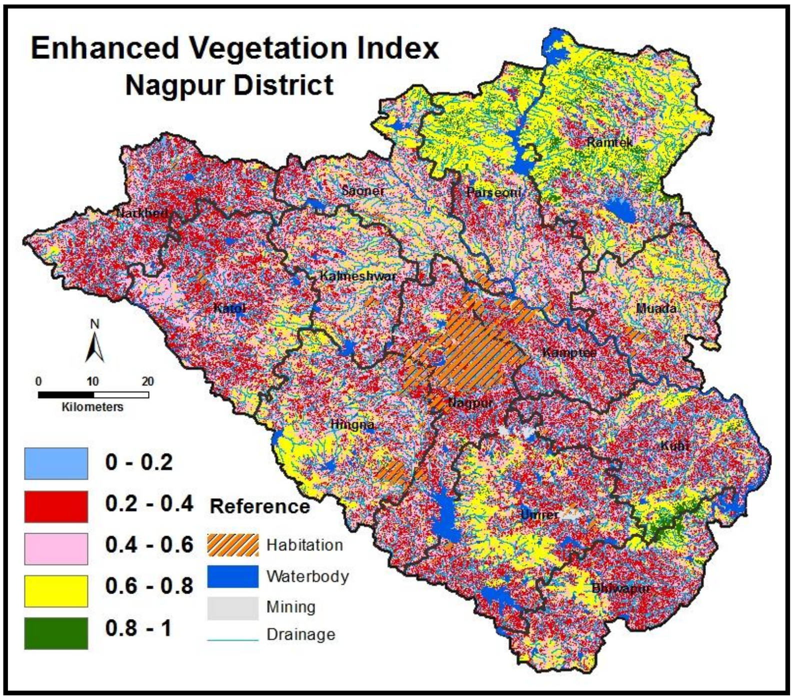

Fig.18.Enhanced Vegetation Index

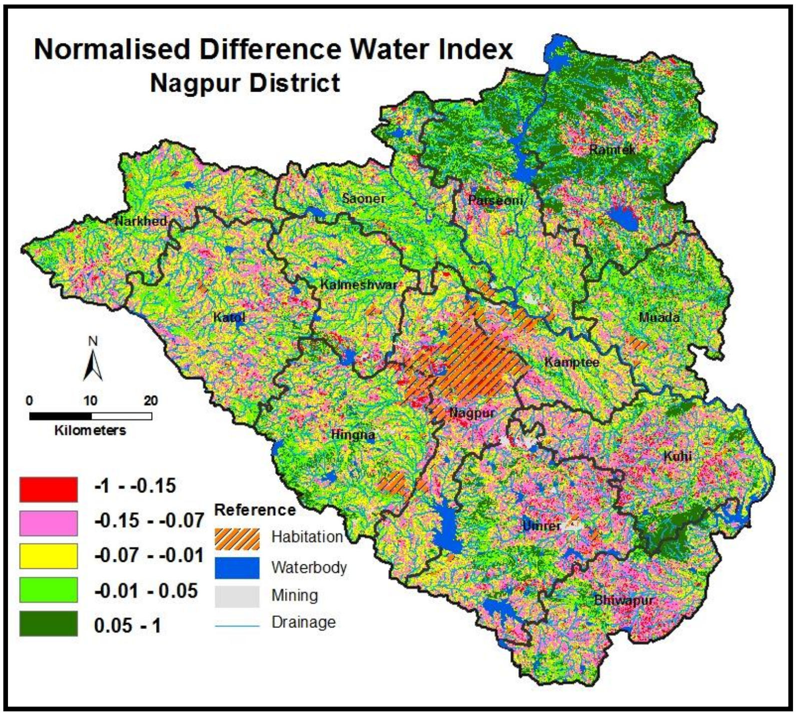

Fig.19.Normalised Difference Water Index

4.3.3 Water Stress Indices

Normalized Difference Water Index (NDWI)**:** NDWI values ranged from -1 to +1 and the map was reclassified into five classes *viz*. -1.0 to -.0.15, -0.15 to -0.07, -0.07 to -0.01, -0.01 to 0.05 and 0.05 to 1.0 (Fig.19). Higher values of NDWI (0.05 to 1) *i.e*. lower water stress was found in deciduous forests having steep mountains and majority of area was in Ramtek and Parseoni and small parts of Kuhi, Mauda, Umrer, Bhiwapur and Hingna tehsils, accounting 12.2 per cent of TGA. The moderately high values of NDWI *i.e*. moderately high water stress in the range of -0.01 to 0.05 was observed in Saoner, Parseoni, Mauda, Narkhed, Umrer and some parts of Kalmeshwar, Hingna, Umrer and Bhiwapur tehsils comprising 24.5 per cent area of TGA. The moderately low NDWI values in the range of -0.07 to -0.01 *i.e*. moderately low water stress were found in Kuhi, Kamptee, Kalmeshwar, Katol, Bhiwapur, Narkhed, Umrer, Hingna and some parts of the Mauda, Parseoni, Ramtek and Nagpur tehsils and covers the highest area comprising 50.0 per cent of TGA. The low values of NDWI in the range of -1.0 to -0.15 associated with the highest water stress has been observed in small patches of the district covering 5.2 per cent of TGA.

Normalized Moisture Index (NMI)**:** The NMI values ranged from -1 to +1 and reclassified into Five classes *viz*. -1.0 to -0.05, -0.05 to 0.12, 0.12 to 0.25, 0.25 to 0.5 and 0.5 to 1.0 (Fig.20). Highest values of NMI (0.5-1.0) with lowest water stress were found in the highly dense vegetation hilly areas in forests having steeply sloping mountains and majority of area was in Ramtek, and Parseoni and small parts in Kuhi, and Bhiwapur tehsils covering 6.1 per cent of TGA. The NMI in the range of 0.25-0.5 which considered as the moderately low water stress region were found in Saoner, Mauda, Kalmeshwar, Hingna, Parseoni and Ramtek tehsils and small patches in Umrer, Bhiwapur, Narkhed and Kuhi tehsils (40.5% of TGA). The moderate water stress with NMI in the range of 0.12 to 0.25 was observed in Narkhed, Kuhi, Kamptee, Bhiwapur, Umrer and Katol tehsils and small parts in Mauda, Ramtek, Nagpur and Parseoni tehsils of the district accounting for 44.5 per cent of TGA. High water stress area with the lowest values of NMI (-1.0 to 0.12) was observed in patches and covered small area in the district i.e. 0.7 per cent.

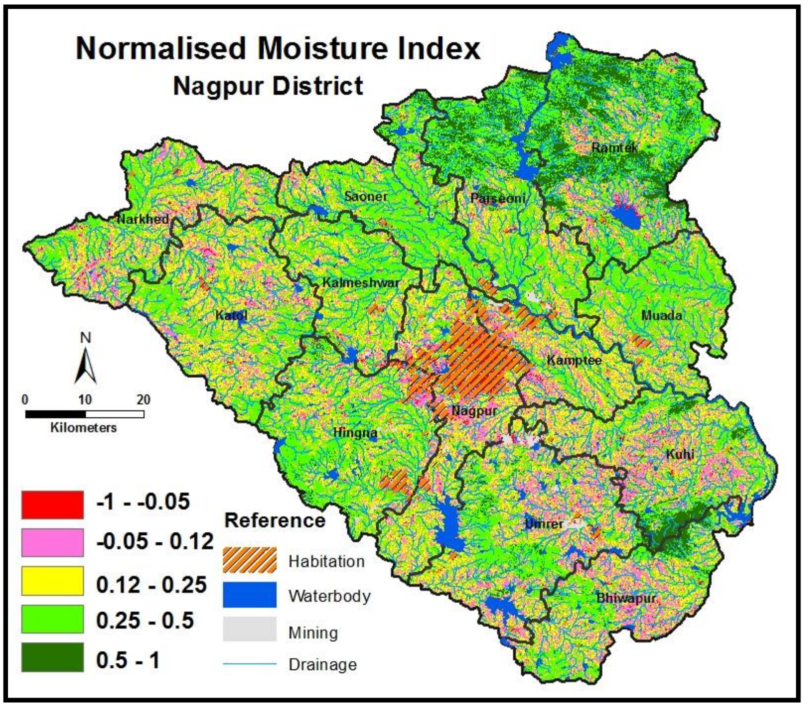

Fig.20.Normalised Moisture Index

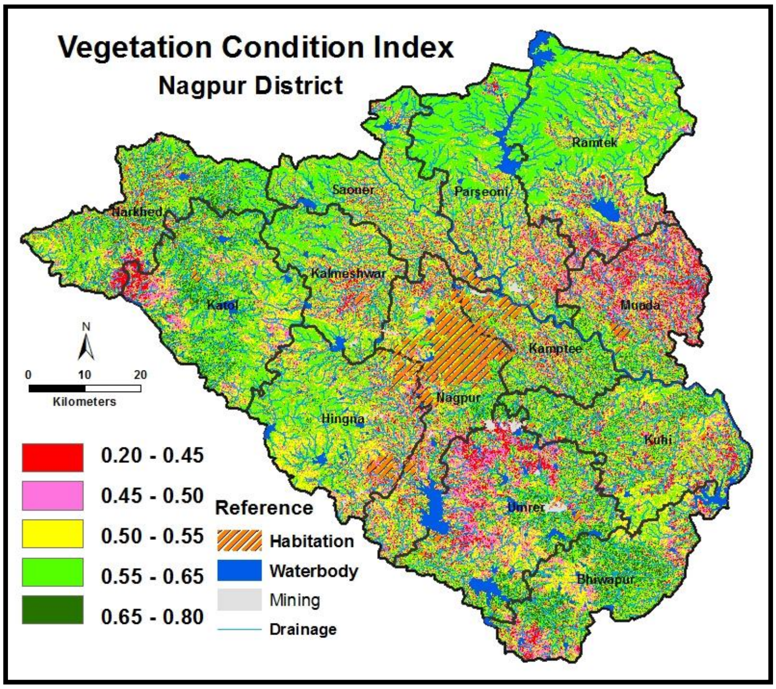

Fig.21. Vegetation Condition Index

***Vegetation Condition Index (VCI)*:** The VCI ranged from 0.20 to 0.80 and reclassified into five classes *viz*. 0.2-0.45, 0.45-0.50, 0.50-0.55, 0.55-0.65 and 0.65-0.80 (Fig.21). The lowest value of VCI (0.20-0.50) was observed in Mauda, Umrer and Ramtek tehsils and small parts of Narkhed, Katol and Kalmeshwar tehsils (25.3% of TGA), whereas, moderate values (0.50-0.55) were observed in Hingna, Umrer, Bhiwapur, Katol, and Kuhi and small parts in Ramtek, Saoner, Parseoni, Mauda and Narkhed tehsils covering 27.8 per cent area in the district. The VCI values in the range of 0.55-0.65 was observed in majority parts of Ramtek and Parseoni tehsils and some parts of Hingna, Saoner, Kalmeshwar and Katol tehsils covering 32.7 per cent of TGA. The higher values of VCI in the range of 0.65-0.80 was observed in Narkhed, Katol, Bhiwapur and Kamptee tehsils and some parts of Umrer, Kuhi and Mauda tehsils accounting for 6.1 per cent of TGA.

4.3.4 Principal Component Analysis

A statistical model PCA is used to create a minimum data set (MDS) to reduce the indicator load in the model and avoid data redundancy (Mukherjee and Lal, 2014).Two indicators *viz*. vegetation indices and water stress indices have been used and PCA was run independently on both the indicators using Arc GIS software. All these indicators were weighted according to the relative importance of each index in fulfillment of the goal of computing land degradation Index for the study area.

4.3.4.1 Vegetation Indices

The three vegetation indices *viz*. NDVI, SAVI and EVI reflecting the vegetation cover are the most important biophysical indicators of soil erosion and therefore needs to be considered when attempting to measure the extent of land degradation. The three vegetation indices *viz*. NDVI, SAVI and EVI were retained for Principal Component Analysis (PCA) based statistical modelling and generated best representing layer (Principal Component, PC) for vegetation Indices (Fig.22). The Eigen values, per cent Eigen values and accumulative Eigen values of

Principal Components of Vegetation Indices is presented in Table 16. The analysis indicated that PC1 layer has explained 99.33 per cent of variation. The factor loading/Eigen Vector for vegetation Indices of PCA is presented in Table 17. The analysis indicate that among the three indices, SAVI has higher factor loading/Eigen Vector (0.68) and per cent Eigen Values (41 % of TGA) compared to EVI (0.65 and 39 %, respectively) and NDVI (0.33 and 20 %, respectively).

Table No. 16. Percent and accumulative Eigen values representing PC layers of vegetation index

Component	Eigen Value	% of Eigen Values	Accumulative of EigenValues
PC1	**0.047**	**99.33**	**99.33**
PC2	0.0003	0.61	99.94
PC3	0.00003	0.05	100.00

Table No. 17. Factor loading/Eigen vector for vegetation indices of PCA

Vegetation Indices	Factor loading/Eigen vector (e)	% Eigen values (E)
NDVI	0.33	20
SAVI	0.68	41
EVI	0.65	39
Total	1.66	

4.3.4.2 Water Stress Indices

The three water stress indices *viz*. NDWI, NMI and VCI were retained for Principal Component Analysis (PCA) based statistical modelling and generated best representing layer (Principal Component, PC) for water stress Indices (Fig.23). The Eigen values, per cent Eigen values and accumulative Eigen values of Principal Components of Water Stress Indices is presented in Table 18. The analysis indicated that PC1 layer has explained 82.84 per cent of variation .The factor loading/Eigen Vector for water stress indices of PCA is presented in Table 19. The analysis indicate that among the three indices, NMI has higher factor loading/Eigen Vector (0.93) and per cent Eigen Values (71 % of TGA) compared to NDWI (0.37 and 28 %, respectively) and VCI (0.002 and 1 %, respectively). Several researchers have used NDWI, NMI and VCI for detection and delineation of water bodies(Tucker, 1980; McFeeters, 1996; Gao, 1996; Xu, 2006), soil moisture(Fensholt and Sandholt, 2003)and further related to the soil erosion and degradation studies (Arshad and Martin, 2002; Lacaze, 2004). Therefore, the amount of soil moisture can be an indicator of biophysical elements *i.e*. soil depth, texture, *etc*. which ultimately can be helpful in showing the erosion hazards in the area (Arshad and Martin, 2002). The water content of a vegetation canopy can also be estimated through the use of a combination of near infrared (NIR) and short-wave infrared (SWIR) bands (Gao, 1996; Ceccato*et al*., 2001). This combination has appeared useful as an indicator of canopy water stress in a semi-arid and arid environment (Fensholt and Sandholt, 2003).The maximum (+1) NDWIvalue is calculated for maximum soil moisture in deep soils and minimum value (-1) for dry lands *i.e.* rocky, sandy or barren in shallow soils of the study area. Jang (2004) has used Normalized Moisture Index (NMI) by combining NDVI and NDWI for evaluation of thermal-water stress of forests.

Table No. 18. Percent and accumulative Eigenvalues representing PC layers of water stress index

Component	Eigen Value	% of Eigen Values	Accumulative of EigenValues
PC1	**0.016**	**82.84**	**82.84**
PC2	0.002	12.66	95.50
PC3	0.0009	4.49	100.00

Table No. 19. Factor loading/Eigen vector for water stress indices of PCA

Water stress Indices	Factor loading/Eigen vector (e)	% Eigen values (E)
NDWI	0.37	28
NMI	0.93	71
VCI	0.002	1
Total	1.302	

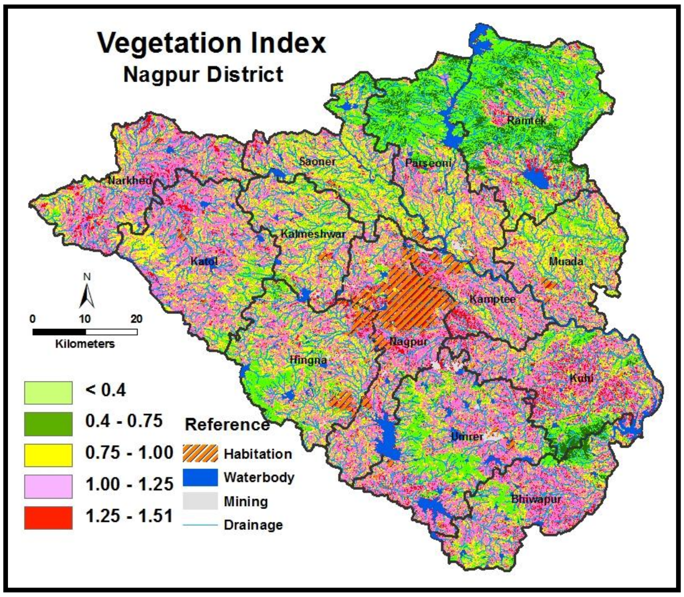

Fig.22. Vegetation Index of Nagpur district

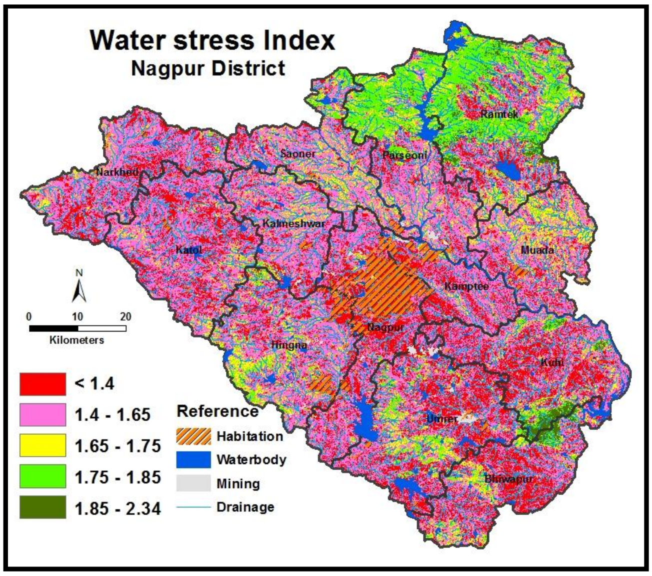

Fig.23. Water Stress Index of Nagpur district

4.4 LAND DEGRADATION ASSESSMENT

4.4.1 Selection of attributes/indicators

Land degradation assessment requires identification and inclusion of various indicators of land degradation/desertification (Fadil, 2009). Rashid *et al.* (2011) has worked in Badgam district of Kashmir Himalaya, India integrated vegetation condition, elevation and land use/land cover information to assess the land degradation scenario using ArcGIS spatial analyst module. Although each individual indicator is helpful in describing the extent and severity of land degradation, it is highly useful and land degradation assessment will be more realistic if combined more indicators. In the present study, the soil erosion in terms quantitative soil loss, Principal Component-1 (PC1) of Vegetation Index and Principal Component-1 (PC1) of Water Stress Index have been considered for more realistic land degradation estimates and included in the development of Land Degradation Index.

4.4.2 Grouping of Land Degradation Indicators

The three layers *viz*. soil erosion, PC1 of Vegetation Index and PC1 of Water Stress Index were combined in PCA of Arc GIS software and resulted in three Principal Components that best explained variability in the data used (Table 20). The analysis indicated that PC1 has explained 80.7 per cent variability. The factor loading/Eigen vector generated from PCA for land degradation index (LDI) is presented in Table 21. The analysis indicated that higher Factor loading/Eigen vector (0.95) is observed for soil erosion component with a per cent Eigen value of 70 followed by Vegetation Index and Water Stress Index. The soil erosion factor influenced more in land degradation assessment compared to other variables may be because several soil and terrain attributes are considered during computation of soil erosion.

Table No. 20. Percent and accumulative Eigenvalues representing PC layers of Land Degradation Index (LDI)

Component	Eigen Value	% of Eigen Values	Accumulative of EigenValues
PC1	**756.33**	**80.65**	**80.65**
PC2	177.99	18.98	99.63
PC3	3.48	0.37	100.00

Table No. 21. Factor loading/Eigen vector for land degradation index (LDI) of PCA

Land Degradation Index (LDI)	Factor loading/Eigen vector (e)	% Eigen values
Soil erosion (SE)	0.95	70
Vegetation Index (VI)	0.30	22
Water stress Index (WI)	0.11	8
Total	1.35	

4.4.3 Normalization of the maps

After determining the highly weighted PC layers, each of the land degradation indicators (SE, VI and WI) is scored on the basis of characterization and performance of degradation severity. Each map is normalized to a scale of 0 to 100 in order to take all maps into one scale by using following formula:

$$a+(x-A) \times (b-a)/(B-A) \quad (14)$$

Where,

x is the map taken

a = 0

b = 100

A is the lowest value of the map

B is the highest value of the map

Each land degradation indicator map has been transformed/standardized to a value between 0 (non-degraded) and 100 (highly degraded) scoring functions, hence the minimum value of LDI was 0 and maximum value of LDI was 100. By integrating the expert knowledge into GIS, the normalized land degradation indicator maps were reclassified into 0-40, 40-60, 60-80 and 80-100 which represented from non-degraded to highly degraded class.

In order to integrate each land degradation indicator to compute land degradation index, the soil erosion indicator map was reclassified into 1, 2, 3 and 4 classes, respectively with increasing order of their importance to land degradation severity, whereas, the land degradation indicator maps *viz*. PC1 of Vegetation Index and Water Stress Index map were reclassified in to 4, 3, 2 and 1, where, higher values indicate their importance to land degradation severity. In this case, the reclassified maps for soil erosion index, PC1 of Vegetation Index and PC1 of Water Stress Index were represented by S_{SE} (Fig. 24), S_{PC1_VI} (Fig. 25) and S_{PC1_WI} (Fig. 26), respectively.

4.4.4 Development of Land degradation Index

Each PC explained a certain amount (%) of variation in the land degradation indicator data set. This percentage is divided by the total percentage of variation explained by all PCs with highest eigenvectors which provided the weighting factor for variables chosen under a given PC. The LDI was calculated by using weighting factor for each indicator as follows.

$$LDI = \Sigma Wi\ Si$$

Where,

Wi is the PC weighting of i^{th} factor and

Si is the score of i^{th} indicator (The reclassified map)

Here, the assumption is that higher index scores means higher degradation and vice-versa.

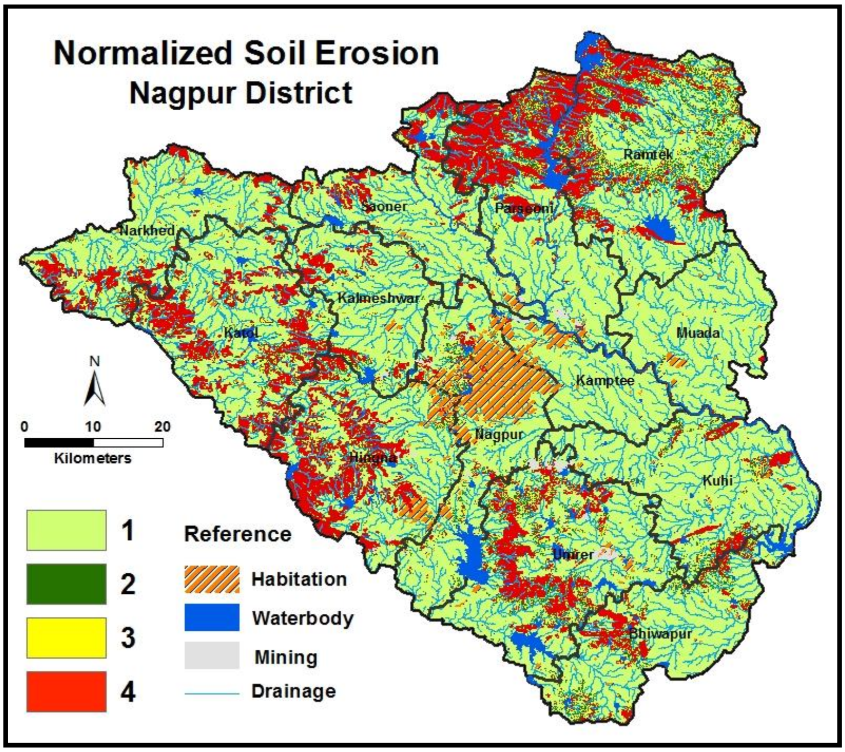

Fig.24. Reclassified map of Normalized soil erosion loss

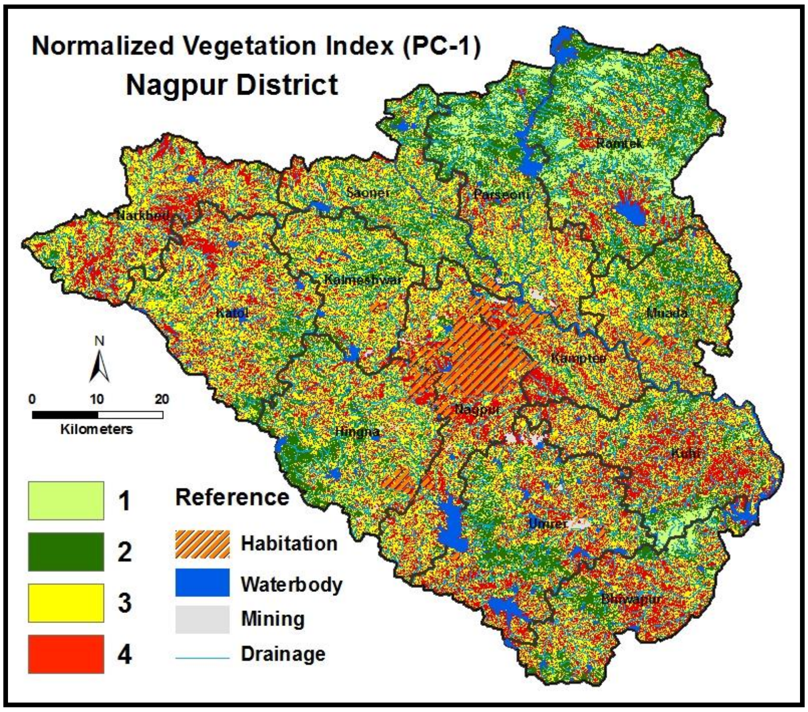

Fig.25. Reclassified map of Normalized Vegetation Index (PC-1)

In our case, LDI equation is expressed as:

$$LDI = (W_{SE} \times S_{SE}) + (W_{PC1\_VI} \times S_{PC1\_VI}) + (W_{PC1\_WI} \times S_{PC1\_WI})$$

Where,

W_{SE}, W_{PC1_VI} and W_{PC1_WI} are the weightages of ith indicators for soil erosion index, vegetation index and water stress index, respectively and $S_{SE,}$ $S_{PC1\_VI,}$ and$S_{PC1_WI}$are the score of ith indicators for soil erosion index, vegetation index and water stress index, respectively.After putting the weightages computed for each land degradation indicator, we get

$$LDI = [0.70 \times S\ (erosion) + 0.22 \times S\ (VI) + 0.08 \times S\ (WI)$$

The results indicated that Land Degradation Index values ranged from 0.99 to 4.0 (Fig. 27).

4.4.5 Classification and extent of land degradation

The Land Degradation Index (LDI) computed was reclassified into four classes *viz*. non-degraded, slightly degraded, moderately degraded and severely degraded lands in Arc GIS software and a land degradation map was generated (Fig.27). The spatial extent of land degradation and their distribution is presented in Table 22. The data indicate that 44.8 per cent of the TGA was under non-degraded lands, 25.0 per cent of TGA was under slightly degraded lands, 5.2 per cent of TGA was under moderately degraded lands, whereas, 17.0 per cent of TGA was under highly degraded lands. Major area of moderately to highly degraded lands was observed in Parseoni, Ramtek, Hingna, Katol, Umred, Narkhed, Saoner and Bhiwapur tehsils.

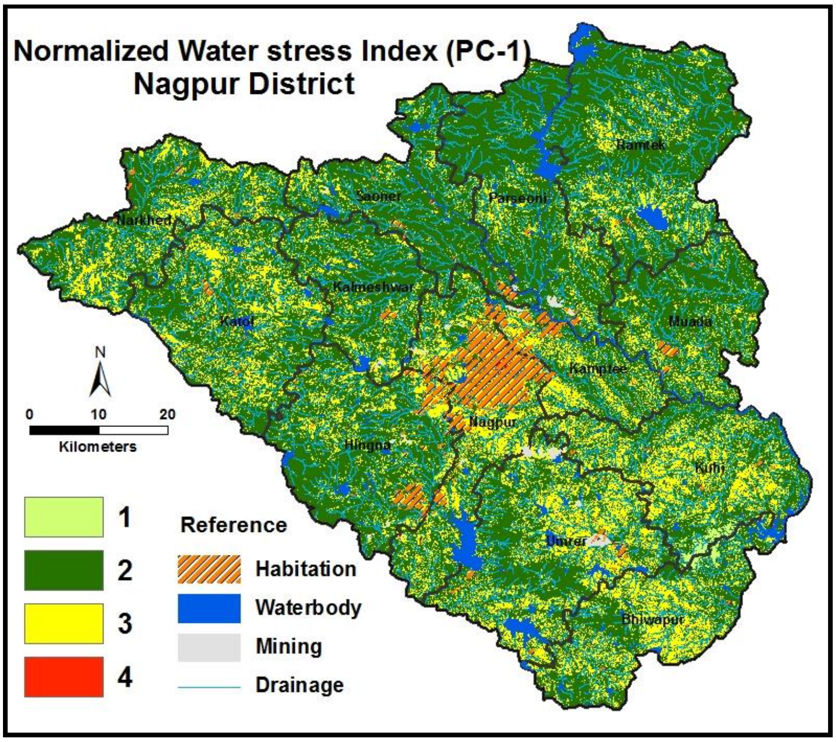

Fig.26. Reclassified map of Normalized Water Stress Index (PC-1)

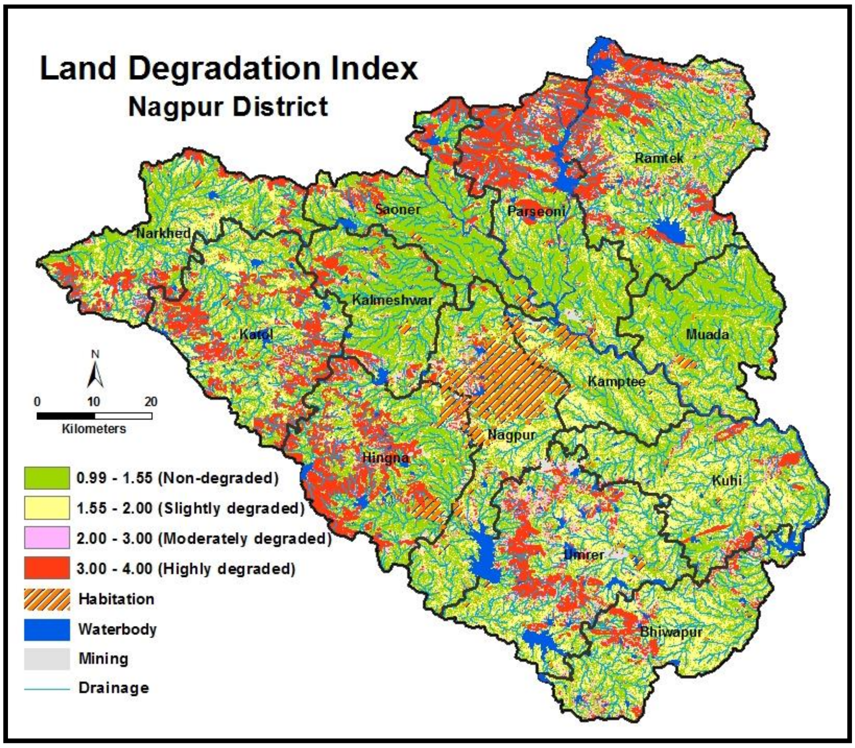

Fig.27. Land Degradadtion Index of Nagpur district

Table No. 22. Tehsil-wise distribution and extent of degraded lands of the study area

Tehsil	Non degraded		Slight degraded		Moderately degraded		Highly degraded	
	Area (ha)	% of TGA	Area (ha)	% of TGA	Area (ha)	% of TGA	Area (ha)	% of TGA
Mauda	45075	4.6	12821	1.3	428	0.04	334	0.03
Ramtek	43533	4.4	25020	2.5	10826	1.1	27561	2.8
Saoner	41257	4.2	7030	0.7	1897	0.2	9525	1.0
Kuhi	36125	3.7	33132	3.4	2774	0.3	5305	0.5
Hingna	35932	3.6	12023	1.2	4847	0.5	27260	2.8
Kalmeshwar	35091	3.6	8059	0.8	1831	0.2	5187	0.5
Katol	33838	3.4	23609	2.4	5258	0.5	23944	2.4
Parseoni	33607	3.4	12248	1.2	4434	0.4	28363	2.9
Narkhed	33160	3.4	20684	2.1	2363	0.2	11271	1.1
Umrer	30623	3.1	33612	3.4	8746	0.9	18092	1.8
Nagpur	29431	3.0	16737	1.7	3313	0.3	3657	0.4
Bhiwapur	26379	2.7	28440	2.9	4202	0.4	7329	0.7
Kamptee	19147	1.9	14064	1.4	224	0.0	225	0.02
Total	443198	44.8	247479	25.0	51141	5.2	168051	17.0

Table No. 23. Physiography-wise extent and distribution of Land degradation Index

Physiographic units	Non degraded		Slight degraded		Moderately degraded		Highly degraded	
	Area (ha)	% of TGA	Area (ha)	% of TGA	Area (ha)	% of TGA	Area (ha)	% of TGA
Plateau top	5107	0.5	3917	0.4	1335	0.1	9979	1.0
Hills and ridges	17291	1.8	13024	1.3	9674	1.0	39776	4.0
Escarpment	287	0.03	203	0.02	390	0.04	9188	0.9
Subdued Plateau	34076	3.4	38153	3.9	16024	1.6	41745	4.2
Pediment	63684	6.4	46018	4.7	13040	1.3	44544	4.5
Alluvial plain	288282	29.1	153546	15.5	6693	0.7	13736	1.4
Valley	20622	2.1	9244	0.9	2826	0.3	7460	0.8

These areas were associated with pediments, subdued plateau and hills and ridges under deciduous forest. These areas have erosional surfaces with moderately to steeply sloping lands. Slightly and non-degraded areas were observed mainly in alluvial plains followed by pediments and subdued plateau mainly under agriculture. The extent of land degradation under different physiography was presented in Table 23 and the extent of land degradation under different land use/land cover is presented in Table 24.

Table No. 24. Land use-wise extent and distribution of Land degradation Index

Land use/ Land cover	Non-degraded		Slight degraded		Moderately degraded		Highly degraded	
	Area (ha)	% of TGA	Area (ha)	% of TGA	Area (ha)	% of TGA	Area (ha)	% of TGA
Agriculture crop land	378574	38.3	214117	21.6	6445	0.7	7384	0.7
Agriculture Fallow	5940	0.6	11214	1.1	480	0.1	672	0.1
Agriculture plantation	4295	0.4	1009	0.1	33	0.001	51	0.01
Forest deciduous	31919	3.2	25224	2.6	29279	3.0	127027	12.8
Forest plantation	544	0.1	493	0.1	413	0.04	3752	0.4
Degraded forest	735	0.1	945	0.1	1639	0.2	4627	0.5
Barren scrub land/ wasteland	7343	0.7	11115	1.1	11702	1.2	22924	2.3

4.5 SOIL-SITE CHARACTERISTICS FOR VALIDATION OF SOIL EROSION

4.5.1 Site characteristics

Site characteristics of different soils observed during ground truth collection were presented Appendix-I. The important observations are discussed in following sections.

4.5.1.1 Slope

Slope or relief influences soil development and controls soil erosion thus affecting land use and crop yield. Slope steepness and slope length are the features of topography that govern the amount of water that runs off or enters the soil. In general, higher slopes with steeply to very steep slopes have been observed in hills and ridges, escarpments mainly under forest. Very gently to gently sloping lands have been observed on plateau top and pediments. These landforms were associated with erosional surfaces, whereas, nearly level to very gently slopes have been observed in alluvial plain and valleys. Higher erosion has been noticed with higher slopes, whereas, slight erosion was observed in alluvial plains and valley. The slope map was validated with field observations. The results indicate that 76.0 per cent of observed values were within the respective classes.

4.5.1.2 Erosion

Soil erosion is governed by slope, physical and chemical characteristics of soils and land use/land cover. Erosion reduces the pedon thickness by washing off the top soil. The available water and nutrient storage are also affected by erosion. It was observed from the data that six erosion classes *viz*. very slight, slight, moderate, severe, very severe and extremely severe erosion have been noticed in the district. The soils of plateau top, hills and ridges, escarpment and pediments were moderately to highly eroded because of steep slopes and degraded forests, whereas, soils of alluvial plain and valleys were minimal to slightly eroded. Plateau top, undulating land, alluvial plain, flood plain and valleys were very slight to moderately eroded due to lower slopes, vegetative cover and field bunding. The erosion map was validated with field observations. The results indicate that 76.0 per cent of observed values were within the respective classes.

4.5.1.3 Drainage

Drainage is a property that is influenced by soil properties like texture, structure, porosity and hydraulic conductivity. Generally, the soils developed on higher slopes are well drained to excessively drained, whereas, those developed on gentle slopes exhibit poor drainage. The high clay content and dominance of montmorillonite impart poor drainage conditions to majority of black soils (Gupta *et al.,* 1991).

The distribution of drainage classes reveals that soils with three drainage classes occurs in the district *viz*. well drained, moderately well drained and somewhat excessively drained. Well drained to excessively drained soils have been observed in plateau top, hills and ridges, escarpments, subdued plateau and pediments, whereas, moderately well drained soils have been observed in alluvial plain and valleys.

4.5.1.4 Surface stoniness

Higher surface stoniness is considered as a hindrance to farming operations. But it may also be beneficial in the sense that it may help in reducing the runoff velocity, conserving the moisture by reducing evaporation and may keep the soils cool by reducing heat influx, particularly in rainfed area. It was observed that stoniness was higher (15-40 %) in soils developed on plateau top, escarpments, isolated hillocks and foot slopes. However, it was less than 3 per cent in most of the soils on undulating lands, alluvial plains and valleys.

4.5.2 Soil Characteristics

4.5.2.1 Physical characteristics

Particle size distribution: The data shows that soils developed on different physiographic units vary in their content of soil separates. This may be attributed to various geomorphic processes operating under different slope conditions. The finer material from elevated parts of district is brought down and deposited at lower elevations and plains. The amount of clay in most of the soils is high, which may be due to basalt which is easily weatherable (Murthy *et al.,* 1994).

The soil texture refers to the distribution of primary particles (sand, silt and clay) in the soil. The texture of soils of Nagpur district varies from sandy loam to clay. Majority of the soils (more than 75%)

were rich in clay content which varies from 51.3 to 71.9 per cent (Appendix III).

The data pertaining to particle-size analysis of selected soils (Appendix III) indicate that soils of Aroli, Karla, Kirnapur, Panjra, Linga and Malegaon have fairly moderate to high amount of clay which developed over pediments, alluvial plains and valleys. These soils have been developed from basaltic parent material which on weathering produces high amount of clay (Eswaran*et al.,* 1988, Sannigrahi *et al.,* 1992; Gaiykwad and Tamgadge, 1993). The dominant clay minerals in the soils are smectite which imparts high shrink-swell properties to the soils leading to formation of wide (2-4 cm) cracks on drying in upper soil layers and development of slickensides/pressure faces in the sub-soils.

The soils of Semda, Sewadoli, Wadhona, Magarali, Rongha, Gaimukh, Yenwa, Ramtek, Pardi, Muserkhapa and Sur series have relatively high sand content than silt and claywhich developed over the plateau top, escarpment, isolated hillocks and foot slopes. The reason for high sand contents in soils of Rongha and Gaimukh series may be attributed to quartzite/schist parent material from which these soils were developed. On the contrary, the soils of Sur series were developed over recent fluvial deposits along Sur River which could be the reason for high sand content in the soil.

Saturated Hydraulic Conductivity: The saturated hydraulic conductivity of soils is a good indicator of internal drainage conditions of the profile. It is influenced by texture, structure and moisture content of soils. It affects movement of water in the soil profile and hence affects crop growth and surface runoff. The data reveals that saturated hydraulic conductivity of the soils of the district varies from 0.15 to 1.87 $cm.hr^{-1}$.

Descriptive statistics of soil physical properties: The descriptive statistics of soil physical properties of surface layer were presented in Table 25. The data indicate that mean value for sand, silt and clay content recorded were 41.9, 24.3 and 33.7 per cent, respectively with a range of 5.2 to 81.9, 5.8 to 40.8 and 6.2 to71.9 per cent, respectively.

Clay has the largest variation (CV = 0.61) followed by sand (CV = 0.55) and silt (CV = 0.31). The average saturated hydraulic conductivity was recorded as 0.8 cm/hr and ranging from 0.2 to 1.9 $cm.hr^{-1}$.

Table No. 25. Descriptive statistics of soil physical properties

Soil properties	Minimum	Maximum	Mean	Standard Deviation	CV	Skewness	Kurtosis
Sand (%)	5.2	81.9	41.9	23.17	0.55	-0.17	-1.3
Silt (%)	5.8	40.8	24.3	7.62	0.31	0.01	-0.5
Clay (%)	6.2	71.9	33.7	20.41	0.61	0.11	-1.5
HC (cm/hr)	0.2	1.9	0.80	0.42	0.56	0.65	-0.7

4.5.2.2 Chemical characteristics

Soil pH: Soil pH (soil reaction) reflects the availability of different plant nutrients and regulates many physico-chemical properties of soils. The pH of soils is mostly related to the nature of parent material, climate and the topography of the landscape, which determine soil composition. The soil pH varies from 5.8 to 8.5. More than 75 per cent soils have neutral to alkaline soil pH and only 10 per cent samples have soil pH 6.4 or less. Relatively low soil pH was observed in forest soils or soils developed over sand stone/schist parent materials. Higher pH value in soils may be due to basalt as parent material, which is alkaline in nature (Chinchmalatpure*et al.,* 2000), higher content of calcium carbonate and accumulation of soluble salts due to washing from upper elevation (Arnold and Venkateshwarlu, 1982).

The data indicate that soils of Pardi, Sewadoli, Ramtek, Rongha, Gaimukh, Sur and Yenwa series were moderately acid to neutral (5.7 to 7.0) in reaction, whereas, soils of Kirnapur, Aroli, Malegaon, Panjra, Linga, Muserkhapa and Magarali series were neutral to strongly alkaline 6.8 to 8.5 (Appendix III).

Electrical conductivity (EC): The electrical conductivity is a measure of soluble salt concentration in the soils. Higher amount of salts in the soils restrict the nutrient uptake and thus affects the plant growth. The electrical conductivity (1:2.5 soil:water) in soils of Nagpur district varies from 0.1-1.2 dSm^{-1}(Appendix III). The data pertaining to electrical conductivity of selected soil series also indicate that all the soils have very low electrical conductivity (<1.25 dSm^{-1}) which is under safe limits and does not affect plant growth. The increase in EC of soils of alluvial plains and valleys may be attributed to the deposition of salts washed from elevated areas and its movements down the profile along with percolating water.

Organic Carbon (OC): The presence of organic matter in soil is a symbol of life in soil. It contains, retains and supplies all essential plant nutrients and thus, asserts an abiding influence on sustenance of soil fertility including erodibility and compaction. The organic carbon content of soils varied from a 0.2 to 3.8 per cent. Higher organic carbon content was observed in soils under forest as compared to those under cultivation and wastelands, which may be attributed to the addition of organic matter through leaf fall and less oxidation of carbon due to undisturbed condition of the forest land. Organic matter acts as a major factor regulating the availability of the nutrients in the soils (Stevenson, 1982) as well as to improve soil structure, infiltration rate, nutrient retention and to reduce soil erosion (Smith and Elliott, 1990).

Descriptive statistics of soil chemical properties: The descriptive statistics of soil chemical properties of surface layer are presented in Table 26. The pH ranges from 5.8 to 8.5 with a mean of 7.4, EC ranged from 0.1 to 1.2 dSm^{-1} with a mean of 0.3 dSm^{-1} and organic carbon content ranged from 0.2 to 3.8 with a mean of 0.9 per cent. Higher variation was observed in organic carbon content followed by EC and pH.

Table No. 26. Descriptive statistics of soil chemical properties

Soil properties	Minimum	Maximum	Mean	Standard Deviation	CV	Skewness	Kurtosis

pH	5.8	8.5	7.4	0.7	0.09	-0.28	-0.7
EC (dSm^{-1})	0.2	1.2	0.3	0.2	0.69	2.82	13.1
OC (%)	0.2	3.8	0.9	0.7	0.73	2.08	4.9

4.5.3 Correlation of soil properties with erosion

The statistical correlation between soil erosion and various soil properties has been worked out (Table 27). The results indicate that a significant and negative correlation between organic carbon and soil erosion (r=-0.86**) and clay and soil erosion (r=-0.79**) was observed, whereas, significant and positive correlation was observed between slope and soil erosion (r=0.82**). The regression equations constructed between soil OC, clay and slope and soil erosion (Table 27) indicate that 73, 63 and 68 per cent variation in OC, clay and slope, respectively, was expressed by soil erosion. Similarly, a significant and positive correlation (r=0.96**) was observed between Land Degradation Index and soil erosion. The regression coefficient indicates that 91.3 per cent variation in soil erosion was expressed by Land Degradation Index.

Table No. 27. Correlation and regression of soil properties with soil erosion

Soil/land properties	Correlation coefficient (r)	Regression equation	Regression coefficient (R^2)
Organic Carbon (without forest)	-0.86**	Y = -103.4X + 78.21	0.73
Clay	-0.79**	Y = -1.320X + 78.10	0.63
Slope	0.82**	Y = 5.187X + 5.074	0.68
Land Degradation Index	0.96**	Y= 0.025X + 1.44	0.91

****indicates significance at p = 0.01**

4.6 DELINEATION OFPRIME AGRICULTURAL LAND

Agricultural prime land has been defined as land that has the best combination of physical and chemical characteristics for producing food, feed, fiber, forage, oilseed, and other agricultural crops with minimum inputs of fertilizer, pesticides and labour, without intolerable soil erosion (USDA-NRSC, 2007). These lands have the best combinationof soil properties, growing season, and moisture supply needed to produce sustained high yields of crops in an economic manner if these lands are treated and managed according to acceptable farming methods. Marginal lands are those lands having limitations, which in aggregate, are severe for sustained application of a given use and increased inputs to maintain productivity or benefits will be only marginally justified (CGIAR, 1999). Theutilization of prime land for other uses puts pressure on marginal lands which generally are more fragile, erodible, and less productive and cannot be easily cultivated. The conversion of prime agricultural land to non-agricultural use is continuing at an alarming rate and planners need such information in quantitative form. Unfortunately, data on such land use changes are not readily available. The recent trend in land use in some areas has resulted in loss of some prime land to industrial and urban uses (Sturdevant *et al*.,2001). The significant reduction in the area under culturable waste lands indicates clearly the conversion of even marginal lands for agricultural purposes (Naidu *et al*., 2014).Further, there is a need to adopt multifunctionality concept of agriculture and agriculturalwater management to defend environmental and social assets against the extreme consequences of structural change on farms (Wilson, 2008). The multi-functionality of crop production system refers to the fact that crop production activity is not limited to produce food and fiber and it may also have other functions. For that purpose, landhas been classified into different classes according to their potential for raising crops or for other purposes. It will help in identifying the potential to use a given piece of land for different purpose, based on bio-physical limitations of the land such as soils, climate and topography that cannot be removed or improved by acceptable level of management. Land with higher capability has more options for use and also likely to have reasonableresilience to adaptation *vis-à-vis* climate change. In present study, attempt has been made to categorize and map the agricultural prime and marginal lands in Nagpur district, Maharashtra for different uses and management.

Land Use/land cover and Land/soil characteristics:The land use land cover of the study area was shown in the previous section (Table 9) The soils of Nagpur district, Maharashtra are mostly derived from basaltic rock. The soils vary from shallow to very deep, majority of soils are imperfectly drained to well drain and fine textured, neutral to alkaline in reaction (Table 7b). In general, these soils have low to medium organic carbon, but rich in bases and have high water and nutrient retention capacity. The length of growing period (LGP) in the district varies between 140 and 180 days (Mandal *et al.,* 2014). The area qualifies for hyperthermic soil temperature and ustic moisture regimes. The district has no history of floods or inundations on agricultural lands. Due to dominance of smectitic group of clay minerals in soils, these soils swell when moist; and shrink and develop deep and wide cracks on drying. The permeability of soil may be considered good enough to meet the requirement of prime lands. On comparing the soil characteristics with the criteria for prime land (Table 6), it is observed that most of the soil parameters of different soilseries are well within the requirements of prime agriculture land except soil depth and coarse fragments/gravels. Naidu *et al.* (2014) considered four land characteristics *viz.* soil depth, gravelliness, slope and length of growing period (LGP) while delineating prime lands in Andhra Pradesh. Considering this, we used four land characteristics, *viz.* soil depth, slope, available water capacity (AWC) and gravelliness for categorization ofagricultural lands of Nagpur district into prime, moderate prime and marginal lands (Table 8).

Matching of soil characteristics of different soil series of Nagpur district (Table 7b) with the criteria (Table 8), six soil series (Aroli, Baghbori, Kirnapur, Linga, Panjra, and Wadhona) meet all the requirements of prime land, nine soil series (Gaimukh, Jam, Sur, Karla, Devadipar, Gunjepar, Khapri, Magarali, and Malegaon series) qualify for moderate prime land whereas the other eight soil series (Sewadoli, Chankapur, Muserkhapa, Pardi, Ramtek, Rongha, Semda and Yenwa) are grouped under marginal lands due to very shallow to shallow soil depth, moderate to strong gravelliness and/or low available water capacity. The tehsil-wise distribution of soil series association in prime land has been shown in table 29.

4.6.1 Prime lands (PL)

The Prime, moderate prime and marginal lands of Nagpur district have been delineated (Fig. 28) based on multi-criteria approach stated in chapter 3 (Table 7b) and streams and tehsil boundaries were overlaid to understand the tehsil-wise distribution of prime lands. The prime land data (Table 28) indicate that nearly 470418 ha of agricultural lands in the district qualify for prime lands. Kuhi and Mauda tehsils have more than 50000 ha prime lands followed by Saoner and Bhiwapur tehsils which comprises 50000-40000 ha and then by other tehsils of Nagpur district which have less than 40000 haprime lands.

Table No. 28. Area and extent of prime agricultural land in Nagpur district

Tehsil Name	Prime land (%)	Moderate prime land (%)	Marginal land (%)
Kuhi	61379 (6.2)	--	686 (0.07)
Mauda	57052 (5.8)	--	--
Saoner	41039 (4.2)	1446 (0.2)	6950 (0.7)
Bhiwapur	41021 (4.2)	3803 (0.4)	1899 (0.2)
Parseoni	38941 (3.9)	2729 (0.3)	503 (0.05)
Narkhed	38282 (3.9)	8350 (0.8)	8152 (0.8)
Kamptee	31858 (3.2)	--	1004 (0.1)
Ramtek	30727 (3.1)	7075 (0.7)	1882 (0.2)
Umrer	29858 (3.0)	17104 (1.7)	7080 (0.7)
Katol	28465 (2.9)	7497 (0.8)	23205 (2.4)
Kalmeshwar	28091 (2.8)	6191 (0.6)	8338 (0.8)
Nagpur	24647 (2.5)	9671 (1.0)	6760 (0.7)
Hingna	19060 (1.9)	21231 (2.2)	8240 (0.8)
Grand Total	470418 (47.6)	85096 (8.6)	74700 (7.6)

Kuhi, Mauda, Saoner, Bhiwapur tehsils have large area under prime agricultural lands but only Mauda tehsil has better irrigation facilities (50.5%) (Table 30). Kuhi, and Bhiwapur tehsils have less than

20% irrigated area and hence, priority to water resources development may be given so that crops of economic benefits can be raised (Jagdish-Prasad *et al.,* 1996) and potential of prime lands is utilized.

It is interesting to note that the stream orders *viz*. 4th, 5th and 6th occur mostly in Kuhi, Mauda and Kamptee tehsils which have the highest percentage of the prime lands followed by Bhiwapur, Parseoni and Narkhed, Ramtek, Umrer and Katol, which have 4th and 5th stream orders, and then by Hingna, Nagpur, Kalmeshwar tehsils which have only 1st, 2nd and 3rd orders streams. The soils of Aroli, Linga,

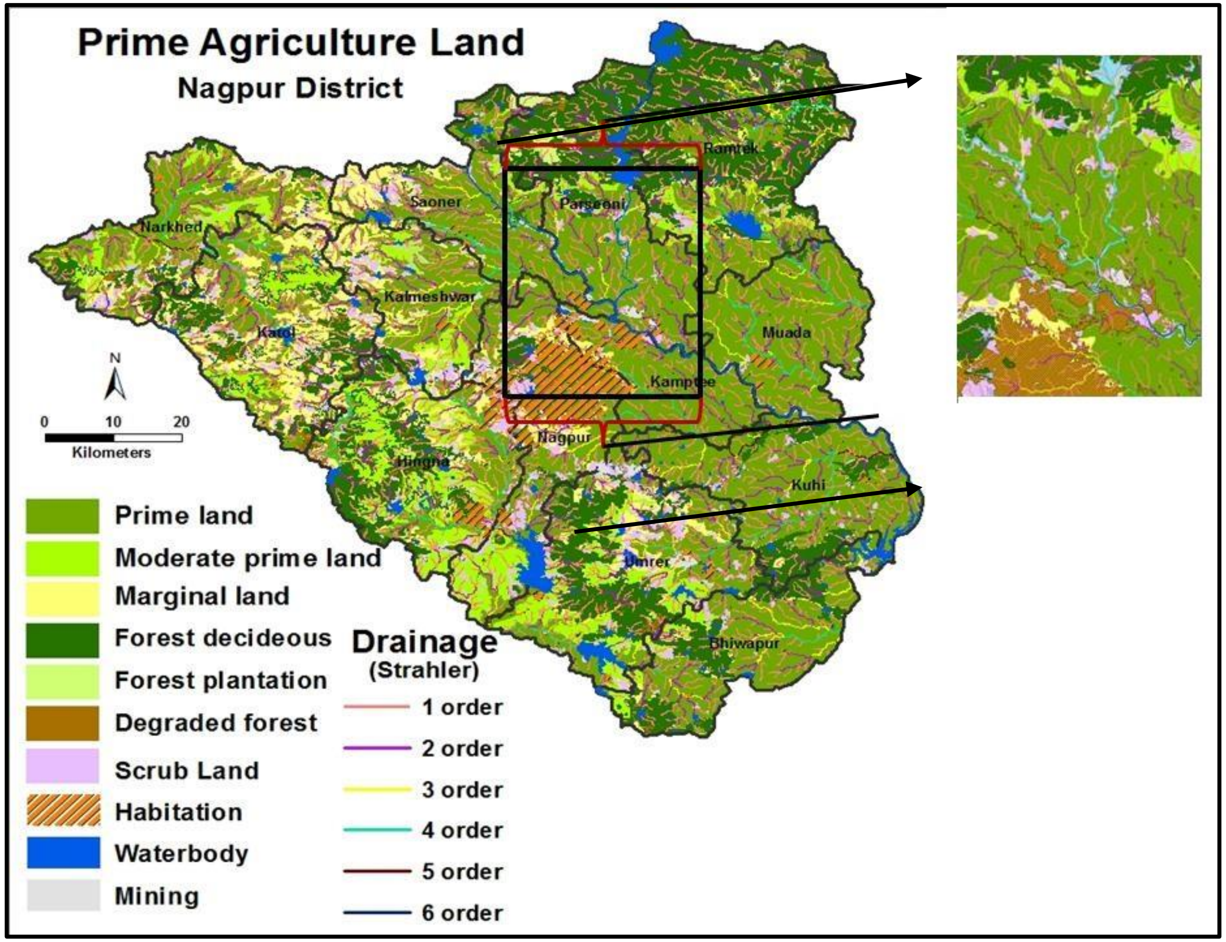

Fig. 28. Classification of Prime and Marginal lands of Nagpur district

Karla, Kirnapur, Baghbori, Sur, Wadhona, Jam, Gaimukh, and Panjra series were dominant in these categories of lands, which have deep to very deep soils, very low gravel per cent, high AWC, very low slope per cent. It appears that stream order has positive correlation with occurrence of prime lands. This could be due to the erosion of soil materials from the upstream areas and its deposition downstream. Thus, stream order could be used as an indicator for identification of prime lands in this region.

Table No. 29. Tehsil-wise soil series association distribution in prime lands of Nagpur district

Tehsil Name	Soil series association
Kuhi	Arl-Krn, Krn-Arl, Jam-Gmk, Lng-Pjr, Wdn-Sur
Mauda	Arl-Krn, Krn-Arl, Wdn-Sur, Wdn-Lng
Saoner	Bgb-Sur, Lng-Krl, Lng-Pjr, Lng-Wdn, Pjr-Krl, Wdn-Lng, Wdn-Sur
Bhiwapur	Arl-Lng, Lng-Pjr, Lng-Wdn, Pjr-Krl, Wdn-Sur
Parseoni	Arl-Krn, Bgb-Sur, Lng-Krl, Lng-Wdn, Krn-Arl, Bgb-Msk, Wdn-Lng, Wdn-Sur
Narkhed	Lng-Krl, Lng-Pjr, Lng-Wdn
Kamptee	Arl-Krn, Krn-Arl, Wdn-Sur
Umrer	Arl-Krn, Krn-Arl, Arl-Lng, Jam-Gmk, Lng-Wdn, Wdn-Sur, Pjr-Krl
Ramtek	Arl-Krn, Krn-Arl, Bgb-Msk, Wdn-Sur
Katol	Lng-Krl, Lng-Pjr, Lng-Wdn, Wdn-Sur
Kalmeshwar	Lng-Krl, Pjr-Krl, Lng-Pjr, Wdn-Sur, Lng-Arl-Pjr
Nagpur	Arl-Krn, Krn-Arl, Arl-Wdn, Lng-Arl-Pjr, Lng-Pjr, Lng-Wdn, Wdn-Sur
Hingna	Arl-Krn, Arl-Wdn, Lng-Arl-Pjr, Lng-Pgrl, Pjr-Krl, Wdn-Sur

4.6.2 Moderate prime lands (MPL)

The area under moderate prime lands was estimated to be 85096 ha. Hingna tehsil has largest area of moderate prime lands (21231 ha) followed by Umrer (17104 ha) and Nagpur tehsil (9671 ha). The proportion of moderate prime lands to TGA was more in Hingna (2.1%), Umrer (1.7%) and Nagpur (1.0 %) tehsils having streams upto 3^{rd} order.

The major constraints identified under MPL were moderate soil depth (50-100cm), high to moderate proportions of gravelliness and low to moderate AWC. The dominant soil series association observed under this category are Krl-Msk and Meg-Msk soil series associations cover

86.3 % (73421 ha) area of total MPL. These soil associations have high AWC (>20 cmm-1) and low gravelliness per cent (<15%), but owing to limitations of depth, these associations were put under category of moderate prime land (MPL). Similarly, Dvd-Sdl, Gjp-Sdl and Kpr-Smd soil series associations, comprising 13.5 per cent area (11526 ha), have low gravelliness (<15%) but limitations of AWC and soil depth. Since soil depth cannot be improved through management, these lands would continue to be in MPL category. Shallow rooted crops with strong root penetrating capacity can be suggested in these soils. The scientific land leveling may be done wherever possible to overcome slope constraints.

Table No. 30. Tehsil-wise extent of irrigated area (ha)

Tehsil Name	Irrigated area (ha)
Kuhi	11327
Mauda	37150
Saoner	14690
Bhiwapur	4830
Parseoni	13015
Narkhed	8099
Kamptee	8271
Umrer	23666
Ramtek	19312
Katol	7423
Kalmeshwar	7762
Nagpur	6333
Hingna	4536

4.6.3 Marginal lands (ML) *(Other than forest, Wasteland and settlements)*

The extent of marginal lands(other than forest, wastelands and settlements) in Nagpur district was about 74700 ha. Katol tehsil has largest area (232050 ha) followed by Kalmeshwar (8338 ha), Hingna (8240 ha) and Narkhed (8152 ha). The share of marginal lands to TGA was more in Katol (2.4 %) followed by Kalmeshwar (0.8%), Hingna (0.8 %) and Narkhed (0.8 %). The major limitations in marginal lands are shallow depth, high gravelliness per cent, moderate to steep slopes, very low AWC *etc*. The LU/LC and slope maps indicate that Parseoni, Ramtek, Hingna and Katol tehsils have relatively large area under sloping lands (slopes >15%). The area is drained mostly by 1st and 2nd order streams which further confirm our findings that stream order has close relation with occurrence of prime agricultural lands. These marginal lands are not suitable for intensive cultivation and can be utilized for pasture development, agroforestry, multipurpose trees, hardy grasses (Deb Roy *et al.*, 1980; Umrani *et al.*, 1987; Jagdish Prasad, 1993; Saxena *et al.*, 2000; Solanke *et al.*, 2005), urban/industrialization and developing special economic zone (SEZ). However,because of increasing pressure on lands more marginal lands are being brought under cultivation and these lands are unable to sustain productivity and lead to ecosystem imbalances.

Based on the categories of lands, different land use options have been suggested (Table 8). In moderate prime lands choice of crop variety could fetch rich dividends under suitable agromanagements. The use of mulching for water conservation, drip and sprinkler irrigation could support the suggested options. These are indicative/illustrative options which could be refined to suit site-specific conditions. The quantitative information and maps showing spatial distribution of prime, moderately prime and marginal lands will help the planners and administrators in taking policy decisions like target areas for increasing productivity, water resources development, pasture developments,*etc*.

Table No. 31. Suggested tehsil-wise land use plan for moderate prime lands (MPL) and marginal lands (ML)

Tehsils	Limitations/characteri-sticsof MPL	Land Use options	Limitations/character-sticsof ML	Land Use options
Kuhi	--	--	Gravelliness > 35 % Depth < 50 cm AWC=10-20 cmm^{-1}	Agroforestry, Leafyvegetable, Horsegram, custard apple,ber,multi-purposetree species, neem, Acacia spp., Pongamia spp.
Mauda	--	--	--	--
Saoner	Gravelliness 15-35 % Depth 50-82 cm AWC=12-30 cmm^{-1}	Wheat, Sorghum, millets, soybean, rape seed, coriander, pearl millets, cowpea, fodder crops, groundnut,	Gravelliness 6.5-38 % Depth 15-30 cm AWC=10-22 cmm^{-1}	Ber, subabul, multi-purposetreespecies, neem, Acaciaspp.
Bhiwapur	Gravelliness 5.75% Depth 55 cm AWC 37 cmm^{-1}	Pigeon pea, black gram, cow pea, groundnut, linseed, floriculture, fodder crops, soybean	Gravelliness 11-51% Depth 22.5-50 cm AWC 12-27 cmm^{-1}	Energy plantation, custardapple,Aonla, multi-purpose tree, pastures, neem, Acaciaspp.,Pongamia spp.
Parseoni	Gravelliness 2-12% Depth 37-65 cm AWC 16-29 cmm^{-1}	Wheat, sorghum, millets, cow pea, cluster bean, gram, chilli, tomato, brinjal, other vegetables	Gravelliness>35 % Depth 15-47 cm AWC 12-27 cmm^{-1}	Aromatic tree species, multi-purpose tree species, neem, Acacia spp.,Pongamia, spp., solar harvesting, water harvesting
Narkhed	Gravelliness 6-15 % Depth 55.6 cm AWC 16-35 cmm^{-1}	Maize, chilli, vegetables, Sorghum, pea, groundnut,green gram, pigeonpea	Gravelliness 6.5-18.5 % Depth <30 cm AWC 19-27 cmm^{-1}	Multi-purpose tree species, Energyplantation, afforestation
Kamptee	--	--	Gravelliness 11.62 % Depth 22.5 cm AWC 22.4 cmm^{-1}	Afforestation, silvi-pastoral system, tree species, fodder

Tehsils	Limitations/characteri-sticsof MPL	Land Use options	Limitations/characteri-sticsof ML	Land Use options
Umrer	Gravelliness 5.75 % Depth 55.6 cm AWC 37.2 cmm^{-1}	Sorghum, chilli, sunflower, cluster bean, cowpea, groundnut,green gram, pigeonpea,vegetables, onion	Gravelliness 6.5-51 % Depth 15-22.5 cm AWC 12-27 cmm^{-1}	Horse gram, custard apple, multi-purpose tree, species, neem, Acaciaspp., Pongamia spp., afforestation, agroforestry
Ramtek	Gravelliness 12-48 % Depth 37-52 cm AWC 17-37 cmm^{-1}	Vegetable crops, gram, sorghum, linseed, maize, groundnut, fodder crops, pigeonpea	Gravelliness>38 % Depth <51 cm AWC <13 cmm^{-1}	Horse gram, custard apple, multi-purpose tree, species, agri-silvi-pasturesystem, energy plantation,solar harvesting, water harvesting
Katol	Gravelliness 3-15 % Depth 55-65 cm AWC 13-17 cmm^{-1}	Wheat, gram, green gram, black gram,sorghum, maize, chilli, vegetables, pigeonpea, groundnut, leafy vegetables	Gravelliness 6-12 % Depth 15-27 cm AWC 22-27 cmm^{-1}	Energy plantation, custard apple, multi-purpose tree species, agri-silvi-pasture system
Kalmeshwar	Gravelliness 6-15 % Depth 55.6 cm AWC 29-37 cmm^{-1}	Maize, fodder crops, pigeonpea, green gram, horticultural crops,pea,sugarcane,sunflower	Gravelliness 10-37 % Depth <30 cm AWC 10-22 cmm^{-1}	Afforestation, agri-silvi-pasture system, energy plantation
Nagpur	Gravelliness 5.75% Depth 55.6cm AWC 37.2cmm^{-1}	Pigeonpea, cow pea, gram, sorghum, groundnut, vegetables,green gram, onion, othervegetables, brinjal, leafy vegetables, soybean	Gravelliness 6.5-18 % Depth <30 cm AWC 19-27 cmm^{-1}	Custard apple, ber, subabhul, multi-purpose tree species, agri-silvi-pasture system
Hingna	Gravelliness 2.2-14.5 % Depth <55.6 cm AWC 16-37 cmm^{-1}	Groundnut, pigeonpea, soybean, gram, chillies, sunflower, green gram	Gravelliness <6.5 % Depth <25 cm AWC 22.5-27.5 cmm^{-1}	Custard apple,aromatic plant, multi-purpose tree species, agri-silvi-pasture system

4.7 SUGGESTED SOIL AND WATER CONSERVATION MEASURES FOR DEGRADED LANDS

The land resources inventory of the study area identified landforms like plateau top, hills and ridges, subdued plateau, escarpments and pediments with erosional surfaces at upper elevations comprising 407455 ha (41.1 % of TGA). These landforms were mostly on moderately sloping to steeply sloping lands (5.7 % of TGA) under sparse vegetation comprising deciduous and degraded forest and wasteland like barren scrub and barren rocky land (6.2 per cent of TGA) with more runoff and accelerated soil erosion. Soil loss computed using RUSLE model indicated that the study area has moderate, severe and extreme soil loss areas to the extent of 31.7 per cent of TGA. Besides, the land degradation assessment indicated that the study area has moderately to highly degraded lands to the extent of 22.2 per cent of TGA which needs urgent interventions like soil and water conservation measures for management of these lands to improve the productivity of these lands.

An 'expert system' is a computer-based system which transfer expertise and produce recommendations, much like a human expert (Malczewski, 2004). Among the most flexible and intuitive methods of integrating expert knowledge into GIS are the multi-criteria analysis (MCA) mechanisms (Saaty, 1977; Malczewski, 1999). MCA enables the quantitative and qualitative knowledge of expertsthat facilitates knowledge mining and its translation into computer language, most often by means of weights. Each weight represents the importance that the expert attributes to a given factor in affecting the phenomena studied. It allows flexibility when working with large number of variables and constitutes a powerful decision making tool (Malczewski, 2004).

The weightages for different parameters are given in Table 32. A weighted multi-criteria overlay analysis has been performed and five conservation units (C1 to C5) have been delineated (Table 33 & Fig. 29) which is identified with different conservation measures. The units are validated with field information.

To suggest suitable conservation measures, the distribution pattern of soil erosion and degradation under different land use type on each physiographic unit was studied. It was observed that moderately to highly degraded lands occur on moderately to moderately steeply sloping hills and ridges, escarpments and very gently to gently sloping plateau top and subdued plateau. These areas are mainly under deciduous forest, degraded forest and wasteland with scrubs. Afforestation with suitable tree species need to be taken up and vegetative barriers like Khus/Guinea/Marvel and staggered contour trenches in plateau top and subdued plateau and continuous contour trenches in escarpments needs to be taken up to reduce the runoff and soil erosion and conserve more moisture. Agroforestry and silvipasture need to be taken up in plateau top and subdued plateau which are under cultivation to improve the productivity of these lands. Conservation tillage and mulching (cotton stable or wheat straw) are recommended to control the down-stream erosion/off site erosion. Farm pond (on line or impounding type) could be constructed to provide life saving/supplemental irrigation.

The gently sloping pediments are erosional surfaces and susceptible to soil erosion. The pediments which are under deciduous forest, degraded forest and wasteland are moderately to highly degraded and management of these land units are very important for soil and water conservation to improve the productivity. Agroforestry, agro-horticulture silivipasture and afforestation programmes with suitable tree species should be taken up (Potdar *et al.*, 2003). The drain-line treatment *viz*. gully plugging, loose boulder structures, check dams, Kolhapuri Type weirs, spill ways and other suitable engineering structures should be taken up to conserve rain water soil loss. For cultivated lands, field treatments should include vegetative bunds, strip cropping, ploughing across the slope, deep ploughing, mulching, graded bunding, land levelling, land mulching, vegetative hedges*etc*., where, the slope is comparatively stable. Nala bunding, impounding type embankment on the streams, weirs *etc*. can be constructed. Surface storage of water (wherever feasible) should be emphasized as this physiographic unit provides better sites for storage and regulation of runoff.

Table No. 32. Weightage for the themes and rating considered for classes in overlay analysis

Sr. No.	Theme	Weightage (%)	Layer class	Class Value	Rating
1	Average annual soil loss(tons/ha/yr)	30	Minimal	<5	5.0
			Low	5-15	4.0
			Moderate	15-25	3.0
			Severe	25-50	2.0
			Extreme	>50	1.0
2	Slope (%)	20	Very gently sloping	0-3	5.0
			Gently sloping	3-8	4.0
			Moderately sloping	8-15	3.0
			Moderately steeply sloping	15-30	2.0
			Severely sloping	>30	1.0
3	Vegetation Index	15	Very high vegetation		5.0
			High vegetation		4.0
			Medium vegetation		3.0
			Less vegetation		2.0
			Very less vegetation		1.0
4	Water stress index	15	Very low to low		5.0
			Medium		4.0
			Severe		3.0
			Very severe		2.0
			Extremely severe		1.0
5	Soil depth (cm)	10	Very shallow	10-25	1.0
			Shallow	25-50	2.0
			Moderately shallow	50-75	3.0
			Moderately deep	75-100	4.0
			Deep to very deep	>100	5.0
6	Surface texture	10	Clay		5.0
			Clay loam		4.0
			Sandy clay loam		3.0
			Sandy loam		2.0
			Gravelly sandy clay loam		1.0

Alluvial plain and valleys which occur on nearly level to very gently sloping lands are under non-degraded and slightly degraded with minimal to low erosion. These landforms are mainly under cultivation and some patches under wasteland with scrub. The soils are deep to very deep, fine with shrink-swell properties and highly productive and needs to be protected from further degradation. Tree plantations would be a suitable measure along the field boundaries in wastelands. In crop land, soil and crop management practices form core of the treatments to minimize the risk of erosion. The field boundaries should be properly established to check field erosion and practices followed should include ploughing across the slope, deep ploughing and mulching. For improvement of soil structure, application of organic manures such as FYM and green manuring should be followed.

Table No. 33. Site characteristics and suitable conservation measures in prioritized conservation units

Prioritized Conservation units	Average annual soil loss	Landform	Slope	Soil depth	Texture	Present Land Use/ land cover	Suggested Control measures
C1	Extreme	Hills and ridges, escarpments	Strongly sloping to steeply sloping	Extremely shallow to very shallow	Gravelly sandy clay loam, Sandy loam,	Open forest, fallow lands, waste lands, scrub lands	Continuous contour trenches, Bench Terracing, gully control structures, afforestation. rock fill structures
C2	Severe	Subdued plateau, pediments	moderately sloping	Shallow to Moderately deep	Sandy loam, sandy clay loam	Open forest, scrub lands, fallow lands, cropped area, forest lands	Continuous contour trenches, afforestation,graded bunding,rock fill structures, drainage channeldiversion,horticulture practices
C3	Moderate	Plateau top, subdued plateau, pediments	Gently sloping	Moderately deep to deep	Sandy clay loam, Clay loam	Fallow lands, wastelands and open forest, cropped area	Staggered trenches, Contour cultivation, contour vegetative barriers, graded bunding, land levelling, land mulching, residue cover, diversion of drainagechannel, grassland development, inter-cropping *etc*.
C4	Low	Alluvial plain, Pediments	Very gently sloping to nearly level	Deep to very deep	Clay loam	Wasteland,cropped area	Countour strip cropping, intercropping, vegetative bunding, countour cultivation, mulching
C5	Minimal	Alluvial plain and valley	Very gently to nearly level	Deep, Very deep	Clay	Cropped area	Field bunding, mulching

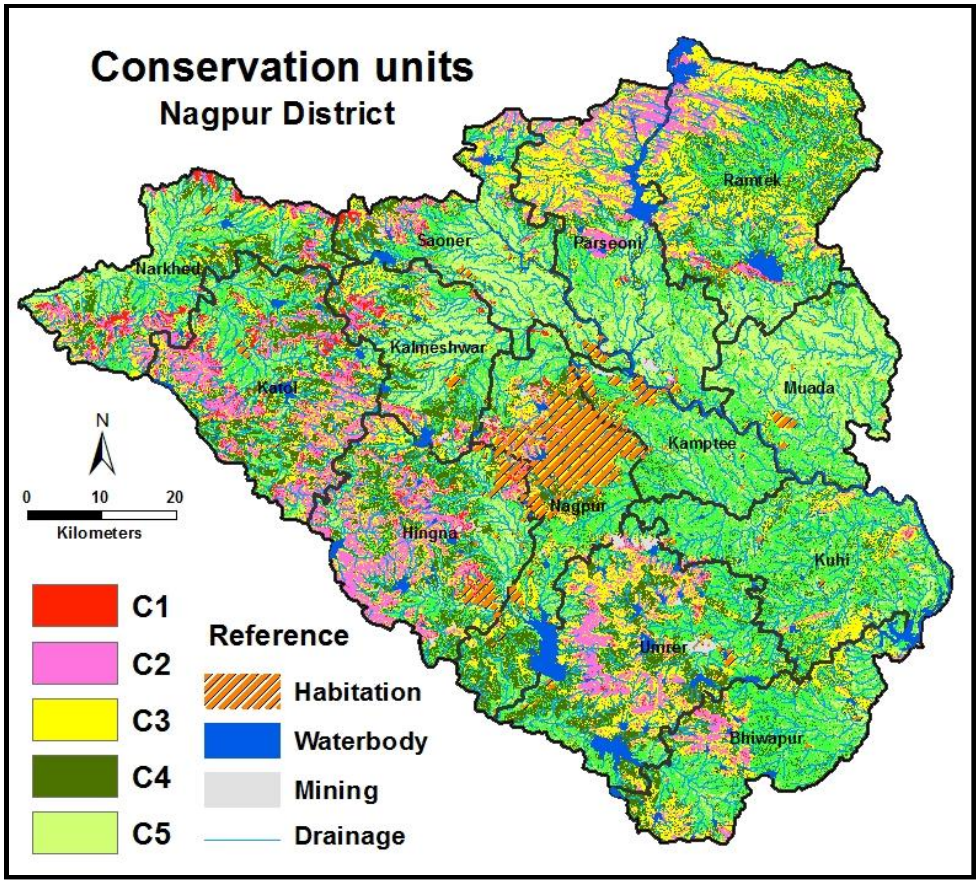

Fig.29. Conservation Units of Nagpur district

Chapter - V

SUMMARY AND CONCLUSION

The present investigation was undertaken to characterize and map soil erosion and degraded lands in Nagpur district of Maharashtra using remote sensing and GIS techniques to prioritize and suggest suitable soil and water conservation measures for management of degraded lands in Nagpur district, Maharashtra. Landsat 5 (TM) and Landsat 7 (ETM+) temporal data, Cartosat-1 Digital Elevation Model (DEM) with 30 m resolution, land use/land cover, soil, climatic data, Survey of India (SoI) toposheets have been collected and processed using image processing software *viz*. TNT MIPS and Arc GIS software to compute and integrate RUSLE factors to assess soil loss. For Land degradation assessment, important land degradation indicators have been identified using satellite (Landsat 5, Landsat 7 TM+) data and land degradation index was developed to generate land degradation status map. Besides, the prime agriculture lands have been delineated using established criteria and a multi-criteria analysis was carried out using soil, vegetation and water stress parameters to delineate prioritized conservation units. The results of the present investigation are summarized as following:

- Ten land use/land cover classes *viz*., agricultural land (crop, fallow and plantation), forest (deciduous, plantation and degraded), barren scrub land/ wasteland, waterbody, habitation and mining have been identified accounting for 63.7, 22.9, 5.4, 3.4, 4.3, 0.4 per cent of TGA, respectively.
- Morphometric analysis carried out using Cartosat-1 DEM (30 m resolution) indicates that in the study area, the drainage pattern was dendritic in nature and drained by 3868 streams with 9008 km channel length. The least bifurcation ratio in between 3rd and 4th order channels was observed which indicated the least structural disturbance in the area and was highest between 4th and 5th order channels denoting most disturbed area. The drainage density (0.91 km km^{-2}) and frequency (0.39 km^{-2}) indicated ruggedness of escarpments and foot slopes.
- The slope map of the study area has been generated using Cartosat-1 DEM (30 m resolution) and five slope classes *viz*. very gently sloping (1-3 %), gently sloping (3-8

%), moderately sloping (8-15 %), moderately steeply sloping (15-30 %) and steeply sloping (>30 %) lands have been identified accounting 71.1, 14.5, 4.2, 1.5, 0.01 per cent of TGA, respectively.

- Visual interpretation of Landsat FCC in conjunction with SoI toposheet has revealed seven major physiographic units *viz.* plateau top, hills and ridges, escarpment, subdued plateau, pediments, alluvial plain and valley. Based on the soil-physiography relationship, 23 soil series are tentatively identified in different physiographic units.
- RUSLE factors *viz*. R, K, LS, C, P are derived using meterological data, Landsat images, soil information, Cartosat-1 DEM, published literature and expert knowledge. The R factor values ranges from 359.34 to 512.95 $MJ.mm.ha^{-1}.hr^{-1}.yr^{-1}$. The values of K factor for different soil series ranges between 0.02 and 0.26. The LS factor ranged from 0 to 50. The C factor, generated using the relationship between C-factor and NDVI, ranged from 0-1. The P-factor varied from 0.1 to 1.0.
- The RUSLE factors are integrated in GIS framework to compute soil loss. The total soil loss of the Nagpur district was found to be 211×10^5 $t.yr^{-1}$. The soil loss varied from 0 to 105 $t.ha^{-1}.yr^{-1}$ with an average annual soil loss of 21.4 $t.ha^{-1}.yr^{-1}$.
- The soil loss values have been reclassified into five classes *viz*. minimal (0-5 $t.ha^{-1}.yr^{-1}$), low (5-15 $t.ha^{-1}.yr^{-1}$), moderate (15-25 $t.ha^{-1}.yr^{-1}$), severe (25-50 $t.ha^{-1}.yr^{-1}$) and extreme (>50 $t.ha^{-1}.yr^{-1}$) and a soil loss map was generated.
- Majority of the area in the District (60.3 % of TGA) was under minimal to low soil erosion, 4.3 per cent of TGA was under moderate, whereas, severe to extreme soil loss was observed to the extent of 27.4 per cent of TGA.
- Severe (25-50 $ton.ha^{-1}.yr^{-1}$) and extreme (>50 $ton.ha^{-1}.yr^{-1}$) soil erosion areas are located on moderate to very steep sloping lands of hills and ridges, escarpments in parts of Parseoni, Hingna, Ramtek, and Katol tehsils which needs immediate attention for soil and water conservation measures to improve the productivity of these lands.
- The vegetation indices like NDVI, SAVI and EVI were derived using Landsat data and maps have been generated.

- NDVI values ranged from -0.36 to 0.55. The negative value of NDVI (-0.36 to 0.0) shows the water body, habitation and mining areas in the district which covers 8.1 per cent of TGA. The NDVI map was reclassified into five classes *viz*. -0.36-0.1, 0.1-0.2, 0.2-0.3, 0.3-0.4 and 0.4-0.55.
- SAVI values ranged from -0.77 to 1.0. The negative value of SAVI (-0.77 to 0.0) shows the water body, habitation and mining areas in the district, which covers 3.4 per cent of TGA. The SAVI map was reclassified into six classes *viz*. -0.77-0.0, 0.0-0.2, 0.2-0.4, 0.4-0.6, 0.6-0.8 and 0.8-1.0.
- The EVI values ranged from 0 to 1. The EVI map was reclassified into five classes *viz*. 0.0-0.2, 0.2-0.4, 0.4-0.6, 0.6-0.8 and 0.8-1.0.
- Soil wetness indices like NDWI, NMI and VCI were derived using Landsat data and maps have been generated.
- NDWI values ranged from -1 to +1 and the map was reclassified into five classes *viz*. -1.0 to -0.15, -0.15 to -0.07, -0.07 to -0.001, -0.001 to 0.05 and 0.05 to 1.0.
- NMI values ranged from -1 to +1 and reclassified into five classes *viz*. -1.0 to -0.05, -0.05 to 0.12, 0.12 to 0.25, 0.25 to 0.5 and 0.5 to 1.0.
- VCI ranged from 0.20 to 0.80 and reclassified into five classes *viz*. 0.2-0.45, 0.45-0.50, 0.50-0.55, 0.55-0.65 and 0.65-0.80.
- Principal Component Analysis (PCA) was run on both vegetation indices and water stress indices separately to reduce the data redundancy and generate best Principal Component. This has been done using Eigen values, per cent Eigen values, factor loading/Eigen vectors.
- The analysis indicated that PC1 layer has explained 99.33 per cent of variation of vegetation indices used. Among the three indices, SAVI has higher factor loading/Eigen Vector compared to other vegetation indices.
- The PCA was run on water stress indices (NDWI, NMI and VCI) and indicated that PC1 layer has explained 82.84 per cent of variation. NMI has higher factor loading/Eigen Vector and per cent Eigen Values compared to NDWI and VCI.

- Soil erosion in terms quantitative soil loss and Principal Component-1 (PC1) of Vegetation Index and Principal Component-1 (PC1) of Water Stress Index have been considered for more realistic land degradation estimates and included in the development of Land Degradation Index.
- PCA was run on three layers *i.e*. soil loss, PC1 of Vegetation Index and PC1 of Water Stress Index and resulted in three Principal Components that best explained variability in the data used.
- The analysis indicated that higher Factor loading/Eigen vector (0.95) was observed for soil erosion component with higher per cent Eigen value compared to Vegetation Index and Water Stress Index indicating that soil erosion factor influenced more in land degradation assessment compared to other variables.
- Land Degradation Index was computed based on weighting factor derived by dividing the per cent variation in the land degradation indicator data set with total percentage of variation explained by all PCs with highest eigenvectors.
- The Land Degradation Index (LDI) map was reclassified into four classes *viz*. non-degraded, slightly degraded, moderately degraded and severely degraded lands in Arc GIS software and a land degradation map was generated.
- The spatial extent of land degradation and their distribution indicates that 44.8 per cent of the TGA was under non-degraded lands, 25.2 per cent of TGA was under slightly degraded lands, 5.2 per cent of TGA was under moderately degraded lands, whereas, 17.0 per cent of TGA was under highly degraded lands.
- Significant and negative correlation between organic carbon and soil erosion (r = -0.86**) and clay and soil erosion (r = -0.79**) was observed, whereas, significant and positive correlation was observed between slope and soil erosion (r = 0.82**).
- Prime agricultural lands, with best combination of physical and chemical characteristics for producing food, feed, fibre, forage, oilseed, and other agricultural crops with minimum inputs of fertilizer, pesticides and labour, without intolerable soil erosion, have been delineated in the study area.

- Prime agricultural lands have been delineated using the criteria developed by NRCS of USDA. The area identified under prime lands was 470418 ha accounting 47.6 per cent of TGA. The area under moderate prime land was 85096 ha (8.6 per cent of TGA), whereas, area under marginal lands was 74700 ha (7.6 per cent of TGA).
- Five prioritized soil conservation units have been delineated using a weighted multi-criteria analysis in Arc GIS taking into account the soil, vegetation and moisture stress. Appropriate soil and water conservation measures have been suggested for each conservation unit.

Conclusion:

- Land degradation status of the Nagpur district was assessed using soil loss estimates, vegetation index and water stress index with the help of PCA studies. From the study, it can be concluded that nearly 22.2 per cent of area is affected by moderate to highly degraded lands and need immediate attention for its management.
- From the PCA studies, it is found that soil erosion is one of the main factors influencing the land degradation status of the Nagpur district, followed by vegetation and water stress indices.
- RUSLE model was used to estimate the soil loss of the Nagpur district and it has been found that nearly 27.4 per cent area was affected by severe to extreme soil loss.
- Suitable five soil and water conservation units have been suggested using weighted multi-criteria analysis taking into account the soil loss, vegetation index, water stress index, and soil-site parameters for degraded lands of the Nagpur district. Afforestation with suitable tree species, vegetation barriers, staggered contour trenches in plateau top and subdued plateau and continuous contour trenches in escarpments need to be adopted to reduce runoff, soil erosion and conserve more moisture.
- By using criteria developed by NRSC-USDA, prime agricultural lands have been delineated. It has been found that prime agricultural lands comprise nearly 47.6 per cent of total geographical area of the district.

Chapter - VI

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1. **Sonal. I. Thelkar**, Srivastava, R., Nagaraju, M.S.S.,Jagdish Prasad, Chattaraj, S., Obi Reddy, G. P. and Nasre, R.A. (2016),Soil Erosion Mapping In Nagpur District Of Maharashtra Using Remote Sensing And Gis Techniques. Presented in International Conference on Integrated Land Use Planning For Smart Agriculture - An Agenda for Integrated Land Management (ICILUPSA 2016), organised by Indian Society of Soil Survey and Land Use Planning (ISSLUP) held during November 10-13, at NBSS&LUP, Nagpur, Maharashtra, India,.
2. **Sonal I. Thelkar**, Srivastava, R., Patil, N.G., Nagaraju, M.S.S., Jagdish Prasad, Chattaraj, S., Obi Reddy, G. P. and Nasre, R.A. (2016),Categorization and delineation of agricultural prime and marginal lands of Nagpur district, Maharashtra for different uses. Journal of soil and water conservation, 2016.
3. Field of interest (in which you desire to work): Application of Remote Sensing and GIS techniques in Agriculture.

Place : Nagpur Date : Signature of student

APPENDIX - I

1.1.1 *Location and salient site characteristics of different observation sites*

LAB. No.	Location	Latitude	Longitude	Landform	Geology	Effective Depth (cm)	Surface Stoni-ness	Slope grad-ient (%)	Length of Slope	Erosion	Drainage	Present Land Use
RS-1648	Sawara	21.61	79.38	Pediment	Basalt	0-15	<3	3-8	50-150	Slight	Well drained	Dense forest
RS-1649	Chorbahuli	21.46	79.31	pediment	Basalt	0-15	<3	8-15	50-150	Moderate	Well drained	Wasteland
RS-1650	Murda	21.48	79.39	Pediment	Basalt	0-15	<3	1-3	50-150	Slight	Well drained	Paddy
RS-1651	Chorbahuli	21.48	79.32	Pediment	Basalt	0-15	3-15	20-25	0-50	Severe	Well drained	Moderately dense forest
RS-1652	Sirpur	21.38	79.37	Escarpment	Granite	0-15	3-15	15-30	50-150	Very severe	Well drained	Moderately dense forest
RS-1653	Mauda (Kahnan)	21.22	79.29	Pediment	Basalt	0-15	<3	1-3	150-300	Slight	Well drained	Cultivated
RS-1654	Kachurwahi	21.34	79.43	Subdude Plateau	Granite	0-15	<3	1-3	150-300	Slight	Moderately Well drained	Paddy
RS-1655	Salemeta	21.38	79.45	Pediment	Granite	0-20	<3	1-3	150-300	Slight	Permeable	Paddy
RS-1656	Kumbhapur	21.19	79.34	Pediment	Basalt	0-15	<3	1-3	150-300	Slight	Well drained	Paddy, Sugaecane
RS-1657	Nimba	21.40	79.09	Pediment	Basalt	0-15	<3	1-3	50-150	Slight	Well drained	Cultivated
RS-1658	Kolitmara	21.55	79.16	Pediment	Sanstone	0-15	3-15	3-8	50-150	Severe	Well drained	Dense forest
RS-1659	Bituli	21.43	79.17	Pediment	Basalt	0-15	<3	1-3	50-150	Slight	Well drained	Fallow Land
RS-1660	Ambajhar	21.52	79.11	Subdude Plateau	Granite	0-15	15-40	3-8	150-300	Moderate	Well drained	Dense forest
RS-1661	Dhawalapur	21.55	79.12	Pediment	Granite	0-15	<3	3-8	150-300	Moderate	Well drained	Orange
RS-1662	Nanda	21.44	78.79	Platue	Basalt	0-20	<3	3-5	50-150	Slight	Well drained	Jowar
RS-1663	Malegaon	21.44	78.73	Pediment	Basalt	0-20	<3	3-5	150-300	Slight	Well drained	Maize
RS-1664	Nimtalai (Kannan)	21.42	79.02	Pediment	Basalt	0-15	<3	20-25	50-150	Severe	Well drained	Cotton
RS-1665	Kirnapur (Saoner)	21.41	79.03	Pediment	Basalt	0-15	<3	1-3	150-300	Slight	Well drained	Soybean, tur

LAB. No.	Location	Latitude	Longitude	Landform	Geology	Effective Depth (cm)	Surface Stoni-ness	Slope grad-ient (%)	Length of Slope	Erosion	Drainage	Present Land Use
RS-1666	Khapa	21.40	78.99	Pediment	Basalt	0-15	<3	1-3	50-150	Slight	Well drained	NR
RS-1667	Salai	21.43	78.80	Escarpment	Basalt	0-15	40-75	25-30	150-300	Severe	Excessively Well rained	wasteland
RS-1668	Gondkhairi	21.14	78.89	Pediment	Basalt	0-15	3-15	1-3	50-150	Slight	Well drained	Soybean, wheat, Vegetables
RS-1669	Khapri	21.16	78.89	Pediment	Basalt	0-15	3-15	3-8	100-150	Slight	Well drained	wasteland
RS-1670	Tinkheda	21.41	78.49	Valley	Basalt	15	<3	1-3	50-150	Slight	Well drained	Sugarcane
RS-1671	Ghogra	21.29	78.43	Pediment	Granite	0-15	3-15	8-15	150-300	Moderate	Well drained	Moderatelydense forest
RS-1672	Mohgoan	21.40	78.70	Pediment	Granite	0-15	<3	3-8	50-150	Moderate	Well drained	groundnut
RS-1673	Mohdi (Longa)	21.50	78.57	Escarpment	Basalt	0-15	3-15	15-30	50-150	Moderate	Well drained	Wasteland
RS-1674	Khapa	21.32	78.43	Undulating pediment	Basalt	0-15	15-40	15-30	50-150	Severe	Well drained	Wasteland
RS-1675	Mathani	21.14	79.35	Pediment	Basalt	0-15	<3	1-3	150-300	Slight	Well drained	Cultivated
RS-1676	Sonpur	21.18	78.67	Pediment	Granite	0-15	15-40	8-15	50-150	Moderate	Well drained	Moderately dense forest
RS-1677	Ladegaon	21.22	78.56	Pediment	Basalt	0-15	<3	3-8	50-150	Moderate	Well drained	Wheat-soybean-wheat
RS-1678	Dongargaon (Katol)	21.29	78.60	Escarpment	Basalt	0-15	15-40	30-50	150-300	Very severe	Well drained	Scrub land
RS-1679	Walni	21.23	78.55	Pediment	Granite	0-15	15-40	15-20	50-150	Moderate	Well drained	Cultivated
RS-1680	Kawadas	21.04	78.81	Pediment	Basalt	0-20	15-40	8-15	150-300	Moderate	Well drained	Moderately dense forest
RS-1681	Kolar	20.91	79.01	Pediment	Basalt	0-20	<3	1-3	150-300	Slight	Well drained	wasteland
RS-1682	Butibori	20.88	79.19	Pediment	Basalt	0-15	15-40	3-8	50-150	Moderate	Well drained	wasteland
RS-1683	Paradgaon	20.93	79.19	Pediment	Basalt	0-18	3-15	3-8	50-150	Moderate	Well drained	Scrub land

LAB. No.	Location	Latitude	Longitude	Landform	Geology	Effective Depth (cm)	Surface Stoni-ness	Slope grad-ient (%)	Length of Slope	Erosion	Drainage	Present Land Use
RS-1684	Khapri	20.90	79.14	Pediment	Basalt	0-10	15-40	30-50	150-300	Very severe	Well drained	Moderately dense forest
RS-1685	Thana	20.91	79.12	Escarpment	Basalt	0-20	3-15	15-30	150-300	Very severe	Well drained	Moderately dense forest
RS-1686	Thara/ Phukeshwar	20.92	79.13	Pediment	Basalt	0-10	15-40	8-15	0-50	Severe	Well drained	Scrub land
RS-1687	Piperdol	20.83	79.21	Pediment	Basalt	0-15	<3	3-8	150-300	Modearte	Well drained	Moderately dense forest
RS-1688	Kawadasi	20.78	79.27	Escarpment	Basalt	0-15	15-40	30-50	150-300	Very severe	Well drained	Moderately dense forest
RS-1689	Heti	21.40	78.88	Pediment	Basalt	0-15	<3	3-8	50-150	Slight	Well drained	Jowar, soybean, orchards
RS-1690	Kawadasi / Kalan	20.77	79.31	Pediment	Basalt	0-15	3-15	3-8	50-150	Moderate	Well drained	Cultivated
RS-1691	Nad	20.72	79.27	Subdude Plateau	Basalt	0-10	15-40	3-8	150-300	Modearte	Well drained	Moderately dense forest
RS-1692	Suleghat	21.52	79.07	Escarpment	Basalt	0-15	40-75	30-50	50-150	Moderate	Well drained	Dense forest
RS-1693	Devali (Kanholi)	20.98	78.92	Platue top	Basalt	0-15	15-40	3-8	50-150	Very slight	Well drained	Moderately dense forest
RS-1694	Devali (Kanholi)	20.98	78.92	Pediment	Basalt	0-15	15-40	3-8	50-150	Severe	Well drained	Moderately dense forest
RS-1695	Kanholi	20.93	78.83	Pediment	Basalt	0-20	>75	15-20	50-150	Severe	Well drained	Culivated
RS-1696	Bazargaon	21.13	78.77	Valley	Basalt	0-20	15-40	3-5	150-300	Slight	Well drained	Wasteland
RS-1697	Ganeshpur near to Kondhali Katol	21.18	78.63	Pediment	Basalt	0-20	<3	3-5	50-150	Moderate	Well drained	Maize, orange
RS-1698	Dhamna	21.15	78.85	Pediment	Basalt	0-20	<3	1-3	150-300	Very slight	Well drained	Cotton,soybean, tur, bringle
RS-1699	Wasbodi	21.23	78.72	Pediment	Basalt	0-15	3-15	8-15	50-150	Moderate	Well drained	Wasteland
RS-1700	Wasbodi	21.24	78.71	Side slope	Basalt	0-15	15-40	15-30	0-50	Severe (gully erosion)	Well drained	Moderately dense forest

LAB. No.	Location	Latitude	Longitude	Landform	Geology	Effective Depth (cm)	Surface Stoni-ness	Slope grad-ient (%)	Length of Slope	Erosion	Drainage	Present Land Use
RS-1701	Chatrapur	21.45	79.24	Valley plain	Basalt	0-20	<3	1-3	50-150	Slight	Well drained	Paddy,tur, cotton, jowar, orchards
RS-1702	Badegaon	21.49	78.98	Pediment	Basalt	0-15	3-15	3-5	150-300	Slight	Well drained	Jowar
RS-1703	Mahaekund	21.51	79.00	Escarpment	Basalt	0-15	15-40	15-30	>25	Severe	Well drained	Dense forest
RS-1704	Saleghat	21.51	79.03	Platue top	Basalt	0-15	3-15	1-3	150-300	Slight	Well drained	Dense forest
RS-1705	Chargaon	21.46	79.15	Pediment	Basalt	0-15	3-15	8-15	150-300	Moderate	Well drained	Cultivated
RS-1706	Kannan	21.22	79.26	Pediment	Basalt	0-15	<3	1-3	150-300	Slight	Well drained	Cultivated
RS-1707	Mauda	21.14	79.41	Pediment	Basalt	0-15	<3	1-3	150-300	Slight	Well drained	Cultivated
RS-1708	Mahalgaon (Kadoli)	21.14	79.26	Pediment	Basalt	0-15	<3	1-3	50-150	Slight	Well drained	Sugarcane
RS-1709	Kalamana	21.07	79.14	Pediment	Basalt	0-15	<3	1-3	150-300	Slight	Well drained	Wasteland
NGP -5	Phetri, RHS of Phetri-Nag Road	21.2	79.00	Subdude plateau	Basalt alluvium	15+	15-40	1-3	150-300	Severe	Well drained	Forest land
NGP- 9	Pedhri	21.69	79.42	Valley	Basalt	15+	<3	1-3	50-150	Severe	Well drained	Jowar, tur
NGP- 23	Sirpur, Ramtek	21.38	79.39	Pediment	Granite, Quartzite Shale	0-5	>75	30-50	150-300	Severe	Excessively Well drained	Forest land
NGP- 36	Ghogra, Narkhed	21.29	78.41	Pediment	Basalt	42+	<3	1-3	150-300	Moderate	Well drained	Jowar
NGP- 40	Narkhed	21.46	78.54	Pediment	Basalt alluvium	40+	<3	1-3	150-300	Very slight	Moderately well drained	Cotton
NGP- 68	Mahalgaon, Ramtek	21.28	79.55	Pediment	Alluvium	100+	<3	1-3	150-300	Severe	Well drained	Wasteland
NGP -80	Junewani, Hingna	21.05	78.92	Pediment		15+	40-75	8-15	150-300	Severe	excessively Well drained	Wasteland
NGP-121	Vikhni	20.77	78.95	Pediment with narrow valley		32+	<3	1-3	150-300	Moderate	Moderately well drained	Cotton

APPENDIX - II

Morphological characteristics of soil samples

LAB. No.	Depth (cm)	MunsellColour (M)	Texture (Surface)	Structure	Consistence			porosity		Nodules		Calcareousness (Surface)
										conca	conir	
					D	M	W	S	Q	S, Q	S, Q	
RS-1648	0-15	10YR 3/2	clay	m2sbk	vh	vfr	vsvp	f	m	m	m	nil
RS-1649	0-15	10YR 3/2	sandy loam	m1sbk	vh	vfr	so po	c	c	vf	m	nil
RS-1650	0-15	10YR 4/2	clay	m3sbk	vh	vfr	vsvp	vf	m	f	m	nil
RS-1651	0-15	10YR 4/4	clay	m1sbk	h	fr	s p	c	c	f	m	nil
RS-1652	0-15	7.5YR 4/3	clay	m2sbk	sh	fi	so po	f	m	f	m	nil
RS-1653	0-15	10YR 3/2	clay	m2sbk	vh	vfr	vsvp	vf	m	f	m	nil
RS-1654	0-15	10YR 4/3	clay	m3sbk	vh	vfr	vsvp	vf	m	f	m	nil
RS-1655	0-20	10YR 4/3	clay	m3sbk	vh	vfr	vsvp	vf	m	f	m	nil
RS-1656	0-15	10YR 3/2	clay	m2sbk	vh	vfr	vsvp	vf	m	f	m	nil
RS-1657	0-15	10YR 4/2	clay	m2sbk	h	fr	vsvp	f	c	f	m	nil
RS-1658	0-15	10YR 3/4	silty loam	m2sbk	sh	fr	so po	c	m	f	m	nil
RS-1659	0-15	10YR 3/2	clay	m2sbk	vh	vfr	vsvp	vf	m	f	m	nil
RS-1660	0-15	5YR 4/4	clay loam	m2sbk	s	fr	so po	f	m	f	m	nil
RS-1661	0-15	7.5YR 4/3	silty loam	m2sbk	h	vfr	so po	c	m	f	m	nil
RS-1662	0-20	10YR 3/2	clay	m2sbk	vh	vfr	vsvp	vf	m	f	m	nil
RS-1663	0-20	10YR 3/2	clay	m2sbk	vh	fr	vsvp	vf	m	f	m	nil
RS-1664	0-15	10YR 5/4	clay	m2sbk	h	fr	vsvp	vf	m	f	m	efv.

LAB No.	Depth (cm)	Munsell Colour (M)	Texture (Surface)	Structure	Consistence			porosity		Nodules		Calcareous ness (Surface)
										conca	conir	
					D	M	W	S	Q	S, Q	S, Q	
RS-1665	0-15	10YR 4/4	clay	m2sbk	vh	vfr	vsvp	vf	m	f	m	nil
RS-1666	0-15	10YR 5/4	clay loam	m2sbk	vh		vsvp	vf	m	f	m	nil
RS-1667	0-15	10YR 4/4	clay loam	m2sbk	h	fr	s p	f	m	f	c	nil
RS-1668	0-15	10YR 3/2	clay	m2sbk	vh		vsvp	vf	m	f	m	nil
RS-1669	0-15	10YR 3/2	clay	m2sbk	sh	fr	s p	f	m	f	m	nil
RS-1670	15	10YR 3/2	clay	m2sbk	vh	vfr	vsvp	vf	m	f	m	nil
RS-1671	0-15	5YR 3/3	clay loam	m2sbk	sh	fr	so po	f	m	f	c	nil
RS-1672	0-15	5YR 3/3	clay loam	m2sbk	sh	fr	sssp	f	c	f	m	nil
RS-1673	0-15	10YR 4/3	clay loam	m2sbk	sh	fr	sssp	f	m	f	m	nil
RS-1674	0-15	7.5YR 3/4	clay loam	m2sbk	sh	fr	so po	f	m	f	m	nil
RS-1675	0-15	10YR 3/2	clay	m2sbk	vh	vfr	vsvp	vf	m	f	m	evf.
RS-1676	0-15	7.5YR 3/3	clay loam	m2sbk	sh	fr	so po	f	m	f	m	nil
RS-1677	0-15	10YR 3/2	clay	m2sbk	h		vsvp	f	m	fm	m	nil
RS-1678	0-15	10YR 4/4	sandy loam	m1sbk	s		so po	c	m	f	m	efv.
RS-1679	0-15	5YR 3/3	clay loam	m2sbk	sh		so po	f	m	c	m	nil
RS-1680	0-20	10YR 4/3	clay loam	m1sbk	h		sssp	vf	m	f	m	nil
RS-1681	0-20	10YR 3/2	clay	m2sbk	h		vsvp	f	m	f	m	nil
RS-1682	0-15	10YR 3/2	clay	m2sbk	vh	fi	vsvp	vf	m	f	c	nil
RS-1683	0-18	10YR 3/2	clay loam	m2sbk	h		sssp	vf	m	f	m	nil
RS-1684	0-10	10YR 3/3	clay loam	m2sbk	sh		sssp	f	m	c	f	nil
RS-1685	0-20	10YR 3/4	clay loam	m1sbk	sh	fr	sssp	m	m	c	m	nil
RS-1686	0-10	7.5YR 3/4	clay loam	m2sbk	s	fr	so po	f	c	fm	m	nil

LAB No.	Depth (cm)	MunsellColour (M)	Texture (Surface)	Structure	Consistence			porosity		Nodules		Calcareousness (Surface)
										conca	conir	
					D	M	W	S	Q	S, Q	S, Q	
RS-1687	0-15	10YR 3/2	clay loam	m1sbk	sh	fi	s p	f	c	f	c	nil
RS-1688	0-15	10YR 4/3	clay loam	m2sbk	sh	fi	sssp	f	m	vf	m	nil
RS-1689	0-15	10YR 3/2	clay	m2sbk	vh	vfr	vsvp	vf	m	f	m	nil
RS-1690	0-15	10YR 3/3	clay loam	m2sbk	sh	fr	sssp	vf	m	f	m	nil
RS-1691	0-10	10YR 3/2	clay	m2sbk	h	fi	s p	f	m	c	m	nil
RS-1692	0-15	7.5YR 3/3	clay loam	m2sbk	sh	fi	s p	f	m	c	m	nil
RS-1693	0-15	5YR 3/4	clay loam	m1sbk	sh	fr	so po	f	m	vf	m	nil
RS-1694	0-15	7.5YR 3/4	clay loam	m2sbk	sh	fi	s p	m	m	f	m	nil
RS-1695	0-20	7.5YR 3/4	clay loam	m1sbk	sh	fr	so po	f	m	f	m	nil
RS-1696	0-20	10YR 4/3	clay loam	m2sbk	sh	fi	sssp	fm	m	fm	m	nil
RS-1697	0-20	10YR 4/3	clay	m2sbk	h	fr	sssp	m	m	vf	m	nil
RS-1698	0-20	10YR 3/1	clay	m3sbk	vh	vfi	vsvp	vf	m	f	c	nil
RS-1699	0-15	10YR 4/3	clay loam	m2sbk	sh	sfr	sssp	f	c	f	c	nil
RS-1700	0-15	7.5YR 4/4	clay loam	m2sbk	s	fr	so po	f	m	f	m	nil
RS-1701	0-20	10YR 4/4	clay loam	m2sbk	vh	vfr	vsvp	f	m	f	m	nil
RS-1702	0-15	7.5YR 4/4	clay loam	m2sbk	sh	fi	sssp	f	m	f	m	nil
RS-1703	0-15	7.5YR 3/2	clay loam	m2sbk	sh	fi	sssp	f	m	f	m	nil
RS-1704	0-15	7.5YR 3/3	clay loam	m2sbk	sh	fi	sssp	vf	m	f	m	nil
RS-1705	0-15	7.5YR 3/2	sandy loam	m2sbk	sh	fr	so po	m	m	m	c	nil
RS-1706	0-15	10YR 3/2	clay	m3sbk	vh	vfr	vsvp	vf	m	f	m	nil
RS-1707	0-15	10YR 3/2	clay	m2sbk	vh	vfr	vsvp	vf	c	f	m	nil
RS-1708	0-15	10YR 3/2	clay	m2sbk	vh	vfr	vsvp	vf	m	f	m	nil
RS-1709	0-15	10YR 3/2	clay	m2sbk	vh	vfr	vsvp	vf	m	f	m	nil

Appendix - III

Physical and chemical characteristics of soil samples

LAB No.	MunsellColour (M)	Sand Fractions (%)					Total Sand (2-0.05 mm) (%)	Silt (0.05-0.002 mm) (%)	Clay (<0.002 mm) (%)	HC (cm hr^{-1})	pH	EC (dS.m^{-1})	OC (%)
		Very coarse (2-1 mm)	Coarse (1-0.5 mm)	Medium (0.5-0.25 mm)	Fine (0.25-0.05 mm)	Very fine (0.1-0.05 mm)							
RS-1648	10YR 3/2	2.83	9.22	12.94	15.89	4.89	45.77	28.77	25.46	1.03	6.4	0.158	1.58
RS-1649	10YR 3/2	7.06	17.87	13.97	22.44	4.17	65.50	9.98	24.52	1.37	6.2	0.143	0.89
RS-1650	10YR 4/2	1.79	15.84	9.19	10.72	3.69	41.22	25.10	33.68	0.95	7.3	0.120	0.64
RS-1651	10YR 4/4	5.09	13.57	21.06	24.25	7.98	71.95	17.64	10.41	1.41	7.0	0.354	1.64
RS-1652	7.5YR 4/3	5.75	16.84	22.06	21.85	8.28	74.77	18.69	6.54	1.36	5.9	0.128	2.32
RS-1653	10YR 3/2	0.83	0.82	9.78	13.02	2.00	26.46	18.53	55.01	0.34	7.6	0.258	0.47
RS-1654	10YR 4/3	1.16	3.31	2.71	10.68	3.48	21.34	17.15	61.51	0.46	7.3	0.207	0.28
RS-1655	10YR 4/3	1.39	3.30	7.13	16.64	5.86	34.33	19.06	46.61	0.35	7.2	0.224	0.37
RS-1656	10YR 3/2	0.52	1.49	1.67	2.88	1.70	8.25	38.06	53.69	0.34	7.8	0.218	0.54
RS-1657	10YR 4/2	3.30	4.37	11.29	9.74	4.07	32.77	21.25	45.98	0.43	7.7	0.211	0.57
RS-1658	10YR 3/4	2.55	10.10	3.05	7.59	5.82	29.11	20.55	50.34	0.48	8.1	0.298	1.39
RS-1659	10YR 3/2	1.85	4.32	1.76	8.96	4.62	21.52	18.06	60.42	0.39	7.8	0.189	0.64
RS-1660	5YR 4/4	2.58	3.55	5.45	23.19	16.43	51.21	28.95	19.84	1.12	6.7	0.078	0.97
RS-1661	7.5YR 4/3	2.44	1.55	6.82	9.08	3.22	23.11	20.07	56.82	0.27	7.5	0.497	0.5
RS-1662	10YR 3/2	0.63	1.21	0.99	1.69	1.69	6.21	40.76	53.03	0.42	7.8	0.207	0.97
RS-1663	10YR 3/2	0.93	2.55	3.34	5.81	4.92	17.54	22.62	59.84	0.32	7.8	0.181	0.57
RS-1664	10YR 5/4	2.06	11.60	1.88	25.41	5.82	46.77	19.69	33.54	0.87	7.9	0.371	0.64
RS-1665	10YR 3/2	4.23	11.17	12.11	19.69	12.14	59.34	17.45	23.21	1.04	7.9	0.197	0.37
RS-1666	10YR 5/4	1.42	10.64	2.04	14.40	14.03	42.54	20.76	36.7	0.78	8.0	0.169	0.2
RS-1667	10YR 4/4	3.91	3.74	1.89	3.18	4.13	16.85	28.47	54.68	0.36	6.8	0.233	0.58

LAB No.	MunsellColour (M)	Sand Fractions (%)					Total Sand (2-0.05 mm) (%)	Silt (0.05-0.002 mm) (%)	Clay (<0.002 mm) (%)	HC (cmhr^{-1})	pH	EC (dSm^{-1})	OC (%)
		Very coarse (2-1 mm)	Coarse (1-0.5 mm)	Medium (0.5-0.25 mm)	Fine (0.25-0.05 mm)	Very fine (0.1-0.05)							
RS-1668	10YR 3/2	1.17	1.07	1.40	3.24	3.29	10.18	32.05	57.77	0.37	8.2	0.224	0.67
RS-1669	10YR 3/2	1.93	7.61	9.76	19.65	14.32	53.27	33.44	13.29	0.85	7.6	0.399	0.57
RS-1670	10YR 3/2	1.27	1.01	9.88	1.77	2.27	16.20	32.54	51.26	0.46	7.7	0.266	0.8
RS-1671	5YR 3/3	2.66	6.62	7.14	30.95	8.19	55.56	20.12	24.32	0.82	6.9	0.074	0.86
RS-1672	5YR 3/3	5.63	16.06	7.14	7.40	8.15	44.38	26.17	29.45	1.13	6.5	0.126	1.09
RS-1673	10YR 4/3	10.10	1.41	3.36	27.32	21.52	63.70	22.81	13.49	1.44	6.9	0.080	0.51
RS-1674	7.5YR 3/4	1.53	2.38	0.65	1.98	1.90	8.44	25.13	66.43	0.56	7.7	0.198	0.63
RS-1675	10YR 3/2	1.03	0.09	0.85	2.19	2.26	6.42	34.87	58.71	0.44	7.8	0.214	0.47
RS-1676	7.5YR 3/3	4.15	10.28	9.54	15.31	12.42	51.71	31.88	16.41	1.41	6.4	0.071	0.83
RS-1677	10YR 3/2	0.63	1.70	3.04	4.58	5.28	15.23	28.45	56.32	0.46	7.9	0.151	0.67
RS-1678	10YR 4/4	3.19	6.47	7.06	19.86	15.67	52.23	18.97	28.8	0.27	7.1	0.071	0.5
RS-1679	5YR 3/3	3.22	7.05	5.15	19.21	9.25	43.89	20.73	35.38	0.97	7.4	0.139	0.68
RS-1680	10YR 4/3	1.83	4.37	5.75	10.31	10.48	32.73	25.04	42.23	0.74	6.8	0.083	1.25
RS-1681	10YR 3/2	1.84	1.63	12.28	12.77	11.20	39.73	25.30	34.97	0.92	7.6	0.459	2.46
RS-1682	10YR 3/2	3.43	4.73	12.35	12.49	12.60	45.61	26.34	28.05	1.06	6.7	0.130	0.68
RS-1683	10YR 3/2	3.13	2.56	10.76	22.76	12.79	52.01	28.98	19.01	1.38	6.9	0.097	0.29
RS-1684	10YR 3/3	2.32	2.15	1.27	3.19	7.37	16.30	35.75	47.95	0.41	7.4	0.380	2.56
RS-1685	10YR 3/4	4.73	5.34	4.33	4.67	9.94	29.01	43.99	27.00	0.39	6.9	0.332	3.82
RS-1686	7.5YR 3/4	4.95	7.62	5.63	9.52	8.87	36.58	33.14	30.28	1.07	6.6	0.145	1.38
RS-1687	10YR 3/2	5.90	1.94	3.69	10.82	6.54	28.90	16.80	54.30	0.48	7.1	0.490	1.22
RS-1688	10YR 4/3	5.62	10.54	10.41	15.85	17.82	60.24	32.37	7.39	1.63	7.5	0.149	1.06
RS-1689	10YR 3/2	4.48	1.32	0.84	1.52	1.74	9.89	35.17	54.94	0.56	8.2	0.556	0.76
RS-1690	10YR 3/3	1.10	0.91	2.56	8.04	8.37	20.98	23.51	55.51	0.61	8.0	0.265	0.63
RS-1691	10YR 3/2	11.65	13.75	14.27	14.11	11.09	64.87	20.40	14.73	1.46	7.5	0.205	0.73
RS-1692	7.5YR 3/3	3.57	6.24	6.37	8.71	9.15	34.04	35.59	30.37	0.62	6.9	0.301	2.12

LAB No.	MunsellColour (M)	Sand Fractions (%)					Total Sand (2-0.05 mm) (%)	Silt (0.05-0.002 mm) (%)	Clay (<0.002 mm) (%)	HC (cm hr^{-1})	pH	EC (dS.m^{-1})	OC (%)
		Very coarse (2-1 mm)	Coarse (1-0.5 mm)	Medium (0.5-0.25 mm)	Fine (0.25-0.05 mm)	Very fine (0.1-0.05)							
RS-1693	5YR 3/4	5.67	6.67	0.15	2.84	6.40	21.74	30.09	48.17	0.50	6.7	0.219	1.84
RS-1694	7.5YR 3/4	5.72	5.23	1.21	4.18	6.99	23.33	32.60	44.07	0.44	6.8	0.204	2.13
RS-1695	7.5YR 3/4	3.29	3.76	5.16	8.39	8.85	29.45	24.84	45.71	0.44	7.0	0.111	0.37
RS-1696	10YR 4/3	3.04	0.96	6.35	3.21	2.16	15.72	34.76	49.52	0.65	8.5	0.296	0.46
RS-1697	10YR 4/3	1.89	0.49	2.03	3.19	2.92	10.52	32.76	56.72	0.15	7.8	0.233	0.74
RS-1698	10YR 3/1	0.98	0.50	4.54	0.46	1.71	8.19	19.93	71.88	0.23	8.4	0.239	0.9
RS-1699	10YR 4/3	5.16	9.18	8.60	16.19	14.48	53.61	18.43	27.96	0.78	7.7	0.163	0.54
RS-1700	7.5YR 4/4	9.16	7.37	3.48	21.80	14.34	56.15	15.25	28.60	1.32	7.1	0.178	2.89
RS-1701	10YR 4/4	2.32	7.98	11.86	16.27	7.09	45.52	25.99	28.49	0.61	8.4	0.411	0.86
RS-1702	7.5YR 4/4	3.25	10.66	11.10	12.78	7.66	45.45	32.68	21.87	0.75	6.83	0.145	0.7
RS-1703	7.5YR 3/2	4.82	8.53	12.99	29.26	16.92	72.52	19.98	7.50	1.43	7.3	0.114	1.41
RS-1704	7.5YR 3/3	11.47	1.92	12.43	27.97	9.85	63.65	5.76	30.59	1.22	6.7	0.117	0.66
RS-1705	7.5YR 3/2	5.00	13.76	27.65	26.06	9.41	81.86	10.19	7.95	1.87	6.2	0.109	0.44
RS-1706	10YR 3/2	4.45	2.96	2.08	0.54	1.98	12.01	36.22	51.77	0.34	8.4	0.312	0.6
RS-1707	10YR 3/2	1.49	1.42	2.34	2.72	2.58	10.56	35.91	53.53	0.27	8.3	0.401	0.8
RS-1708	10YR 3/2	1.34	0.94	1.99	2.93	0.60	7.81	33.12	59.07	0.58	8.4	1.222	0.64
RS-1709	10YR 3/2	1.09	0.39	1.52	1.33	0.90	5.22	33.20	61.58	0.20	8.1	0.311	0.17
NGP- 5	10YR 3/2	10.86	4.17	4.33	25.90	7.20	52.46	11.36	36.18	0.73	7.2	0.476	1.21
NGP- 9	10YR 3/2	3.46	0.20	9.33	9.52	3.55	26.06	16.64	57.30	0.59	7.4	0.375	0.8
NGP- 23	5YR 3/3	3.09	8.21	19.50	20.33	6.11	57.25	16.32	26.43	1.33	6.6	0.058	0.88
NGP- 36	10YR 3/2	0.95	1.77	6.41	9.87	3.96	22.97	16.58	60.45	0.38	5.8	0.619	0.53
NGP -40	10YR 3/3	1.45	0.89	0.40	2.61	4.73	10.09	38.19	51.72	0.64	7.8	0.429	0.48
NGP -68	10YR 4/3	2.13	11.12	10.87	17.33	13.80	55.26	31.57	13.17	1.28	8.0	0.204	0.55
NGP -80	5Y 3/2	9.92	0.59	10.95	20.57	11.25	53.28	34.65	12.07	1.24	8.0	0.365	0.98
NGP-121	10YR 4/2	1.24	0.14	3.41	5.66	0.63	10.08	31.32	57.60	0.39	8.4	0.191	0.38

APPENDIX – IV

Appendix- IVa Climatic and soil-site suitability criteria for pigeonpea

Soil-site characteristics	DEGREE OF LIMITATION					
	0 (None)	1 (Slight)	2 (Moderate)	3 Severe	4 Very severe	
	S1		S2	S3	N1	N2
Climatic Characteristics						
Total rainfall (mm)	1200-1000	1000-850	850-700	700-550	<550	-
Rainfall growing season (mm)	1000-850	850-750	750-600	600-500	<500	-
Length of growing period (days)	>200	200-150	150-120	120-100	<100	-
Mean temp. growing season (°C)	28-26	26-24	24-22	22-20	<20	-
Mean max. temp. growing season (°C)	35-32	32-28	28-26	26-24	<24	-
Mean min. temp. (°C)	-	-	-	-	-	-
Mean R.H. in growing season	-	-	-	-	-	-
Length of dry spell (days) Frost occurrence	Quantification needed					
Site Characteristics						
Slope (%)	0-1	1-3	3-5	5-8	>8	-
Erosion	e0	e1	e2	e2-e3	e3	-
Drainage	Well	Mod. well	Imperfect	Poor & Excess	-	-
AWC (mm/m)	> 200	200-150	150-100	100-50	<50	-
Water logging (days)	< 1	1-2	2-3	>3	-	-
Stoniness (% surface)	<3	3-15	15-40	40-75	>75	-
Soil Characteristics						
Texture	l, Sicl, Sil, SC, SiC, F loamy, F silty	C,Sc Fine	V.Fine, Coarse loamy, Csl, Scl	Sandy-skeletal	-	-
Coarse fragments (Vol %)						
within 50 cm	< 5	5-15	15-40	40-75	>75	-
below 50 cm	5-15	15-40	45-75	>75	-	-
Depth (cm)	>125	125-100	100-50	50-30	< 30	-
Soil Fertility						
CEC (soil) cmol (p+) kg^{-1}	30-20	20-15	15-10	10-5	<5	-
B.S. (%)	> 80	80-50	50-35	<35	-	-
O.C. (%) (0-15 cm)	0.75	0.75-0.5	0.5-0.2	<0.2	-	-
ECe (dSm^{-1})	0.2	0.2-0.4	0.4-0.8	0.8-1.0	>1.0	-
pH (1:2.5)	6.5-7.5	7.5-8.5 <6.5	8.5-9.0 <5.5	>9.0	-	-
ESP	<2.5	2.5-5.0	5.0-7.5	7.5-10.0	>10.0	

Source :NBSS&LUP(1994)

Appendix – IVb Climatic and soil-site suitability criteria for Soybean

Soil-site characteristics	DEGREE OF LIMITATION					
	0	1	2	3	4	
	(None)	(Slight)	(Moderate)	Severe	Very severe	
	S1		S2	S3	N1	N2
Climatic Characteristics						
Total rainfall (mm)	1200-1500		800-1200	600-800	<600	-
Rainfall growing season (mm)	700-800		450-600	<450	-	-
Rainfall during critical period boll development	-		-	-	-	-
Length of growing period (days)	120-140		-	-	-	-
Mean temp. growing season (^oC)	27-30		-	-	-	-
Mean max. temp. growing season (^oC)						
Mean min. temp. (^oC)						
Mean R.H. in growing season	>80		70-80	50-70	<50	-
Length of dry spell (days)	Flowering to pod filling is critical					
Site Characteristics						
Slope (%)	<3		3-5	5-8	>8	-
Erosion	-	-	-	-	-	-
Drainage	Well to moderate		Imperfect	Poor/ excessive	-	-
Water logging (days) (early stage)	Well				> 5	-
AWC (mm/m)	>200		150-200	100-150	50-100	<50
Surface stoniness	<5		5-10	10-25	>25	-
Soil Characteristics						
Texture	cl, sil& l		sl,c (st)	c (w.st) ls	s/ls	-
Coarse fragments (%)						
within 50 cm	-	-	-	-	-	-
below 50 cm	-	-	-	-	-	-
Depth (cm)	>75		60-75	40-60	<40	-
$CaCO_3$ % within 50cm	-	-	-	-	-	-
Gypsum (%)	-	-	-	-	-	-
Soil Fertility						
CEC (soil) cmol (p+) kg^{-1}	-	-	-	-	-	-
B.S.	-	-	-	-	-	-
O.M. (%) (0-15 cm)	-	-	-	-	-	-
ECe (dSm^{-1})	<2		2-4	4-8	>8	-
pH (1:2.5)	6.0-7.5		7.5-8.5	>8.5	-	-
ESP	<5		5-10	10-15	>15	-

Source :NBSS&LUP(1994)

Appendix- IVc Climatic and soil-site suitability criteria for sorghum

Soil-site characteristics	DEGREE OF LIMITATION					
	0 (None)	1 (Slight)	2 (Moderate)	3 Severe	4 Very severe	
	S1		S2	S3	N1	N2
Climatic Characteristics						
Total rainfall (mm)	1200-1000	1000-850	850-700	700-550	<550	-
Rainfall growing season (mm)	1000-850	850-750	750-600	600-500	<500	-
Length of growing period (days)	200-150	120-150	120-90	150-120	<90	-
Mean temp. growing season (ºC)	28-26	26-24	24-22	22-20	<20	-
Mean max. temp. growing season (ºC)	35-32	32-28	28-26	26-24	<24	-
Mean min. temp. (ºC)	25-22	22-18	18-15	<15	-	-
Mean R.H. in growing season	100-70	50-70	50-40	<40	-	-
Site Characteristics						
Slope (%)	0-1	2-3	3-8	8-15	>15	-
Drainage	Well	Mod. well	Imperfect	Poor & Excess	Very Poor	-
AWC (mm/m)	> 200	200-150	150-100	100-50	<50	-
Water logging (days)	< 1	1-2	2-3	>3	-	-
Stoniness (% surface)	<3	5-15	15-30	30-65	>60	-
Soil Characteristics						
Texture	c, cl, sicl, sc	c, cl, sicl, sc	l, sil, sic	sl, ls	s, skeletal	-
Coarse fragments (Vol %)						
within 50 cm	< 5	5-15	15-40	40-75	>75	-
below 50 cm	5-15	15-40	45-75	>75	-	-
Depth (cm)	>100	100-75	50-75	30-50	< 30	-
Soil Fertility						
CEC (soil) cmol (p+) kg^{-1}	30-20	20-10	15-10	10-5	<5	-
B.S. (%)	> 80	80-50	50-35	<35	-	-
O.C. (%) (0-15 cm)	0.75	0.75-0.50	0.50-0.20	<0.20	-	-
ECe (dSm^{-1})	0.2	0.2-0.4	0.4-0.8	0.8-1.0	>1.0	-
pH (1:2.5)	6.0-8.0	6.0-8.0	5.5-5.9 8.1-8.5	<5.5 8.6-9.0	>9.0	-
ESP	<5	5-8	8.0-10	10-15	>15	-

Source :NBSS&LUP(1994)

Appendix- lVd Climatic and soil-site suitability criteria for wheat

Soil-site characteristics			Rating			
		unit	Highly suitable SI	sui table Moderately S2	suitable Marginally S3	Not Suitable N
Climatic regime	Mean temperature in growing season	°C	20-25	26-28 18-19	29- 34 14- 17	<14 >34
Land quality	Land characteristics					
Moisture availability	Length of growing Days	Days	>150	120-150	*90-120*	<90
	AWC	mm/m	>200	200-170	<170	
Oxygen availability to roots	Soil drainage	Class	Well drained to moderately; well drained	Imperfectly drained	Poorly drained	Very Poorly drained, excessively drained
Nutrient availability	Texture	Class	I, cl, sil, sil,	Sc, sic, c, ls, sicl, sl	C+(45-60%)	S, c++(>60%)
	pH	1:2.5	6.5	7.6-8.5, 5.5-6.4	8.6-10; 4.5-5.4	<4.5; >10
	OC	%	0.6-0 .7	0.5-0.6	0.3-0.5	<0.3
Rooting conditions	Effective soil depth	cm	65-100	65-50	50-25	<25
	Stonnines	%	<15	15- 35	>35	
Soil toxicity	Salinity (EC saturation extract)	*dS/m*	<4.0	0 4.0-6.0	>6.0	
	Sodicity (ESP)	%	<15	15- 30	30-40	>40
Erosion	Slope	%	<3	3-<5	5- 10	>10

Source :NBSS&LUP(1994)

Appendix - IVd Climatic and soil-site suitability criteria for Gram

Soil-site characteristics			Rating			
		unit	Highly suitable SI	sui table Moderately S2	suitable Marginally S3	Not Suitable N
Climatic regime	Mean temperature in growing season	°C	20-25	15-19	5-15 26-30	<5 >30
	Total rainfall	mm	800· 1000	600-800	400-600	<400
Land quality	Land characteristics					
Moisture availability	Length of growing Days for short duration varieties	Days	>100	90-100	70-90	<70
	Length of growing days period for long duration varieties	Days	>150	120- 150	90-120	<90
Oxygen availability to roots	Soil drainage	Class	Well drained	Moderately well drained; Imperfectly drained	Poorly drained; excessively drined	Very Poorly drained,
Nutrient availability	Texture	Class	I, cl, sil, scl,	Sic, c, sicl,	Sl, c>60%	
	pH	1:2.5	6.0-7.5	7.6-8.0; 5.5-5.7	8.1-9; 4.5-5.4	<9.0
Rooting conditions	Effective soil depth	cm	>75	51-75	25-50	<25
	Stonnines	%	<15	15- 35	>35	
Soil toxicity	Salinity (EC saturation extract)	*dS/m*	<1.0	1.0-2.0	>2.0	
	Sodicity (ESP)	%	<10	10-15	>10	
Erosion	Slope	%	<3	3-5	5- 10	>60

Source :NBSS&LUP(1994)