Chapter 20
Remote Sensing and GIS in Mapping and Monitoring of Land Degradation

G. P. Obi Reddy, Nirmal Kumar, and S. K. Singh

Abstract The information on the extent and spatial distribution of various kinds of degraded lands is essential for strategic planning and development of degraded lands. Processes of land degradation can be broadly grouped into physical, chemical, and vegetal (biological) degradation. The physical processes include land degradation mainly due to water and wind erosion, compaction, crusting, and waterlogging. The chemical process includes salinization, alkalization, acidification, pollution, and nutrient depletion. The vegetal or biological processes on the other hand are reduction of organic matter content in the soils and degradation of vegetation. The use of remote sensing and geographic information system (GIS) techniques makes land degradation estimation and its spatial distribution feasible with reasonable costs and better accuracy in larger areas. The use of spaceborne multispectral data shown its potential in deriving information on the nature, extent, spatial distribution, and magnitude of various kinds of degraded lands. Assessment and monitoring of land degradation through remote sensing offer a series of advantages such as consistency of data, fairly near real-time reporting, and a source for having spatially explicit data. The integration of high-resolution remote sensing data and digital elevation models derived from satellites data like Cartosat-1 and Cartosat-2 and Light Detection and Ranging (LiDAR) with ground data has immense potential in assessment and monitoring of land degradation in local scales. In this chapter, application of remote sensing and GIS in assessment and mapping of physical, chemical, and vegetal degradation has been discussed. The study indicates that integrated remote sensing and GIS applications have immense potential in assessment, mapping and monitoring of land degradation with reasonable cost and better accuracy in larger areas that would otherwise require large inputs of human and material resources.

Keywords Remote sensing · Geographic information system · Land degradation · Physical degradation · Chemical degradation · Vegetal degradation

---

G. P. O. Reddy (✉) · N. Kumar · S. K. Singh
ICAR-National Bureau of Soil Survey & Land Use Planning, Nagpur, India

G. P. O. Reddy, S. K. Singh (eds.), *Geospatial Technologies in Land Resources Mapping, Monitoring and Management*, Geotechnologies and the Environment 21,
https://doi.org/10.1007/978-3-319-78711-4_20

20.1 Introduction

Land degradation remains a challenge in the twenty-first century for many developing countries across the globe because of its effect on the sustainability of agricultural production and impacts on livelihoods among the marginal and rural poor. Bai et al. (2008) reported that more than 20% of all cultivated areas, 30% of forests, and 10% of grasslands in the world undergo various categories of land degradation. About a quarter of world population is threatened by the effects of degradation (Eswaran et al. 2001), which affect nearly 84% of agricultural lands (FAO 2008a). Land degradation means reduction or loss of the biological or economic productivity and complexity of rainfed cropland, irrigated cropland, or range, pasture, forest, and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns. Land degradation is the temporary or permanent lowering of the productive capacity of land. UNEP define it as a rate of adverse changes in soil quality resulting in decline in productivity of lands (UNEP 1992). It thus covers the various forms of soil degradation, adverse human impacts on water resources, deforestation, and lowering of the productive capacity of rangelands. Land degradation includes soil erosion due to wind and/or water; deterioration of the physical, chemical and biological, or economic properties of soil; and long-term loss of natural vegetation. Land degradation is an obstacle to sustainable development due to its impact on the environment, food security, agroecosystem services, and people’s livelihoods (UNCCD 2015). Metternicht (2006) considers that land degradation is the “reduction in the capability of the land” to produce benefits from a particular land use under a specified form of land management. In some cases, the cause for land degradation could be solely natural or purely human, but often both human and natural causes combine to land degradation. On-site effects of land degradation are the lowering of the productive capacity of the land, causing either reduced outputs (crop yields, livestock yields) or the need for increased inputs. Off-site effects of water erosion occur through changes in the water regime, including decline in river water quality and sedimentation of riverbeds and reservoirs.

There is a large variation in estimations of extent and rate of land degradation at global scale due to variation in definitions and methodologies adopted. It varied from 3.6 billion ha (Dregne and Chou 1994) to 1.9 billion ha (Oldeman 1994). Many methods have been applied to assess land degradation through different approaches, which use either qualitative or quantitative measures or both. GLASOD (Global Assessment of Soil Degradation) approach mapped the status of global soil degradation at a scale of 1:10 million by indicating type, extent, degree, rate, and main causes of degradation (Oldeman et al. 1991). LADA (Land Degradation Assessment in Drylands) developed an integrated assessment methodology for land degradation to understand the degradation processes at different scales (global, national, and local) by identifying the status and trends of land degradation, root causes, effects, and consequences (LADA 2009). In India, the earliest assessment of the area affected by the land degradation was made by the National Commission on Agriculture at 148 Mha (NCA 1976). The National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) estimated an area of 187 Mha (Sehgal and Abrol 1994) under various categories of degraded lands by using GLASOD methodology (Oldeman 1988). Nearly 175 Mha hectares of land in India is subject to one or other kind of degradational process (Das 1985). About 150 Mha of land are suffering from different types of erosion, out of which 69 Mha are in severe deterioration phase (Anonymous 1976). The salt-affected soils and waterlogged areas are reported as 7 Mha and 6 Mha, respectively (Bali 1985). The National Wasteland Development Board (NWDB 1985) estimated an area of 123 Mha under wastelands. National Remote Sensing Centre (NRSC) (formerly known as NRSA) followed the remote sensing data-based assessment in preparation of wasteland maps with adequate field checks on 1:50,000 scale and reported that 63.85 Mha area in India is under various categories of wastelands (NRSA 2005). These estimations are due to the use of varying definitions of land degradation, data sources, classification systems, methodologies, and scales (Gautam and Narayan 1988). Maji et al. (2010) harmonized the land degradation and wasteland datasets of India by adopting systematic approach in GIS environment and reported that about 120.72 Mha area is suffering from various kinds of land degradation. It includes 82.57 Mha area affected by water erosion, 12.4 Mha by wind erosion, 6.74 Mha by salinity/alkalinity, and 17.94 Mha by soil acidity, and 1.07 Mha is under other complex problems (Table 20.1).

Remotely sensed data was effectively used in identifying and mapping of land degradation risks (Lu et al. 2007; Reddy et al. 2002). Satellite sensor data provide spatially continuous, replicable, and homogenous information on the condition,

Table 20.1 Extent of degraded and wastelands in India

Degradation type	Area (in Mha)	Open forest (<40% canopy) (Mha)
Water erosion	73.27	9.30
Wind erosion	12.40	–
Chemical degradation soils		
Exclusively salt-affected soils	5.44	–
Salt-affected and water-eroded soils	1.20	0.10
Exclusively acidic soils (pH < 5.5)	5.09	–
Acidic and water-eroded soils	5.72	7.13
Physical degradation		
Mining and industrial waste	0.19	–
Waterlogging	0.88	–
Total	104.19	16.53
Grand Total	120.72	

Source: Maji et al. (2010)

distribution, and dynamics of vegetation status and land degradation in a cost-effective manner and over large areas. Remote sensing applications are often considered as cost-effective and time-efficient procedures for the collection of data over large areas that would otherwise require a very large input of human and material resources. The integrated remote sensing and GIS technologies helps immensely to spatially analyze and improve the understanding of causative factors in land degradation assessment. Qualitative assessment, delineation, and mapping of eroded lands were attempted using Landsat, MSS/TM, SPOT-PLA/MLA, and IRS LISS-I/II data (Dwivedi et al. 1997a, b). Landsat MSS data have been used for predicting soil loss in the rangelands of Western Australia (Pickup and Chewings 1986). Landsat MSS/TM data have been used for mapping ravines (Karale et al. 1987; Singh and Dwivedi 1989). Raina et al. (1991) have used Landsat TM data to map the type, extent, and degree of degradation. NDVI derived from temporal satellite data has been widely used in studies of land degradation from the field scale to the global scale (Wessels et al. 2004; Singh et al. 2006). Many studies used Landsat TM and ETM+ data in assessment of soil erosion, soil salinity, and crusting in drylands (Metternicht et al. 2009; Vrieling et al. 2008; Vågen et al. 2013; Nawar et al. 2014). Pandey et al. (2013) have used spectral indices such as CI (Crust Index), NDSDI (Normalized Difference Sand Dune Index), and GSI (Topsoil Grain Size Index) and compared with NDVI (normalized difference vegetation index) to assess land degradation and sand encroachment in Western India.

20.2 Methods in Assessment of Land Degradation

There are many methods used to assess land degradation, viz., expert opinions, land users' opinions, field monitoring, observations and measurement, modeling, estimates of productivity changes, and remote sensing (Kapalanga 2008). The important methods like expert opinions, field monitoring, observations, and remote sensing have been discussed below in detail.

20.2.1 Expert Opinion

Early land degradation assessments were essentially based on expert opinion/judgment, as in the case of the GLASOD. The expert-based GLASOD (Oldeman et al. 1991) approach maps the status of global soil degradation at a scale of 1:10 million by indicating type, extent, degree, rate, and main causes of degradation based on responses to a questionnaire, which was sent to recognized experts in countries around the world. GLASOD survey provides basic data on distribution and intensity of erosional, chemical, and physical types of degradation at global scale (Bridges and Oldeman 1999). A total of 1965 Mha land of the world was found to be degraded and out of which water erosion affecting 1094 Mha of the land. Sehgal and Abrol

(1992) following the criteria and guidelines of the GLASOD methodology estimated an area of 187 Mha under various categories of degraded lands in India. Another example of an expert approach is the soil erosion risk map of Western Europe (De Ploey 1989). Kessler and Stroosnijder (2006) utilized historical data and farmers' knowledge to identify eroded lands and severity of erosion in the Bolivian mountain valleys based on indicators of soil, productivity, and vegetation cover loss. Soil degradation in South and Southeast Asia (ASSOD) is another approach in which the degree of soil degradation is expressed by degradation subtypes using qualitative terms such as impact on productivity (Van Lynden and Oldeman 1997). LADA considers both biophysical factors and socioeconomic driving forces for assessing the land degradation (FAO 2008b). Koohafkan et al. (2003) developed the guidelines for a methodological approach for assessing land degradation under LADA project to assess the causes, status, and impact of land degradation and possible responses. The approaches based on experts and users' opinion are subjective and qualitative (Bai et al. 2008) and have proven inconsistent and hardly reproducible (Sonneveld and Dent 2009).

20.2.2 Field Monitoring and Observation

The assessment of land degradation requires reliable analyses based on field monitoring and observations. It is thus necessary to accurately describe the different types of degradation and quantify the degree and extent of each type of degradation using relevant indicators for targeted applications through using geospatial technologies like satellite imaging, GIS, and global positioning system (GPS) at different scales. A systematic field survey is necessary to determine the extent of a given type of land degradation. During the field surveys, surveyor can pinpoint the areas in the field affected by the type of degradation, transferring the observations on a large-scale map, and then calculate the degraded area in GIS to determine its extent. The visual observations can be supplemented by legacy data and available high-resolution satellite images. GPS can be used in the field to accurately locate the observations. The collected field samples can be analyzed in the laboratory to determine various chemical properties of soils relevant to land degradation. These types of field surveys can also be supplemented by surveys of farmers/inhabitants to determine the cropping practices and history of the crops cultivated. Through such field surveys and observations, various subtypes of chemical and biological degradation can be assessed and mapped. In India, based on soil resource mapping on 1:250,000 scale, it was reported that strongly acidic soils (pH <4.5) and moderately acidic soils (pH 4.5–5.5) cover 1.9% and 7.4% of TGA of India, respectively (Maji et al. 2012). In the recent times, high-resolution satellite images are being widely used in mapping of land degradation through field surveys and observations.

20.2.3 Remote Sensing

Land degradation monitoring through remote sensing could be achieved through two approaches through the comparative analysis of independently produced classification for different dates and the simultaneous analysis of multi-temporal satellite data. Different change detection techniques include univariate image differencing, vegetation index differencing, image regression, image ratioing, principal component analysis, post-classification comparison, direct multi-date comparison, change vector analysis, and background subtraction which could be used to assess the land degradation. Many authors adopted various approaches such as visual interpretation, unsupervised and supervised classification, and remote sensing-derived indices for mapping of land degradation (Gupta et al. 1998; Saini et al. 1999; Jafari et al. 2008). Though researchers devised best techniques to derive the results, these techniques seem to yield different levels of results for different environmental features and applications. Image fusion techniques such as image sharpening, improvement of registration accuracy, creation of stereo data sets, feature enhancement, improved classification, temporal aspect for change detection, and overcoming data gaps due to clouds could improve and yield more information than a single sensor data can provide (Pohl and Van Genderen 1998). Metternicht and Zinck (1998) investigated synergistic use of JERS-1 and Landsat TM for mapping water-induced surface erosion features. Metternicht and Zinck (1997) found out the highest separability between erosion classes upon integration of seven bands of the Landsat TM and JERS-1 SAR with an overall classification accuracy of 87%. Dwivedi et al. (1997a, b) revealed that fusion of Landsat TM and SPOT MSS data provided an overall accuracy of 92% for erosion mapping.

20.3 Remote Sensing and GIS in Mapping and Monitoring of Land Degradation

Various processes of land degradation have been broadly grouped into physical, chemical, and vegetal degradation. Remote sensing and GIS technologies have immense potential in mapping and monitoring of land degradation with adequate field surveys.

20.3.1 Physical Degradation

Physical degradation covers land degradation due to water erosion, wind erosion, waterlogging, lowering of the water table, mining and quarrying, and urban and industrial waste. Global water erosion and wind erosion affect 1094 and 549 Mha, respectively (Lal 2003).

20.3.1.1 Water Erosion

The information on extent and spatial distribution of soil erosion is essential for formulating effective mitigation strategies and implementing appropriate conservation measures (Vrieling 2006; Panagos et al. 2015). Water erosion covers all forms of soil erosion by water, including sheet and rill and gully erosion. Soil erosion by water involves the processes of detachment and transportation by impact of raindrop and flowing water (Wischmeier and Smith 1978). Soil erosion is a natural process that removes soil particles and deposit as sediment in some other location. Out of total 1965 Mha of degraded lands in the world, 1094 Mha is under soil erosion due to water, and it accounts for 55% and causing up to a 17% reduction in crop productivity (Oldeman et al. 1990). Dhruvanarayana and Ram Babu (1983) reported that in Indian conditions about 16.4 t ha^{-1} year.^{-1} of top soil, of which 29% is lost permanently into the sea, 10% gets deposited in the reservoirs reducing their capacity by 1–2% every year, and the remaining 61% gets displaced from one place to another. Mandal and Sharda (2011) reported that soil erosion caused by water is a major factor contributing to land degradation in India and many other countries, as it exceeds the natural soil formation rates.

Remote sensing and GIS techniques make soil erosion estimation and its spatial distribution feasible with reasonable costs and better accuracy in larger areas (Millward and Mersey 1999; Wang et al. 2003). Integrated remote sensing, GIS, and RUSLE provide the potential to estimate soil erosion loss on a cell-by-cell basis (Millward and Mersey 1999). Wang et al. (2003) demonstrated that integration of ground dataset, Thematic Mapper (TM), and digital elevation model (DEM) data through geostatistical methods provides significantly better results than using traditional methods in predicting soil erosion loss. Remote sensing data has immense potential to develop the cover management factor through land cover classifications (Reusing et al. 2000; Ma et al. 2003), whereas GIS tools could be effectively used to integrate the USLE factors in calculation of soil erosion (Bartsch et al. 2002; Wang et al. 2003). The utility of GIS capabilities increased when they coupled with empirical and predictive models in assessment of soil loss (Reddy et al. 2004, 2013, 2016; Srinivas et al. 2002). Wilson and Lorang (2000) reviewed the applications of GIS in estimating soil erosion, discussed the limitations of previous approaches, and identified that GIS provided tremendous potential for improving soil erosion estimation.

Many researchers used soil erosion models such as the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978) and its subsequent Revised Universal Soil Loss Equation (RUSLE) (Renard et al. 1997) and GIS techniques to make soil erosion estimation and its spatial distribution (Wang et al. 2003; Fu et al. 2005). In practice, the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978) and later the Revised Universal Soil Loss Equation (RUSLE) (Renard et al. 1997) has been the most widely used model in predicting soil erosion loss. 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

(Millward and Mersey 1999; Wang et al. 2003). The integrated use of GIS and erosion models, such as USLE/RUSLE, has been proved to be an effective approach for estimating the extent, magnitude, and spatial distribution of erosion (Mitasova et al. 1996; Molnar and Julien 1998; Millward and Mersey 1999; Fernandez et al. 2003). Availability of spatial databases in GIS, digital elevation models (DEMs), and temporal satellite imageries have immense potential to predict erosion potential on a cell by cell (Reusing et al. 2000).

In both models, the average soil erosion per year is computed from the product of six factors, namely, rainfall erosivity (R), soil erodibility (K), slope length (L), slope steepness (S), vegetation cover (C), and support practice factor (P). In the RUSLE, the mean annual soil loss is expressed as a function of six erosion factors:

$$A = R \times K \times L \times S \times C \times P \tag{1}$$

where A is the computed amount of the average soil loss in tons per hectare per year, R the rainfall erosivity factor in megajoules per millimeter per hectare per hour per year, K the soil erodibility factor in tons per hour per megajoules per millimeter, L the slope length (meters), S the slope steepness (%), C the crop management factor, and P the erosion control practice factor. Factors C and P are dimensionless. R factor, in the USLE and RUSLE models, is an index of rainfall erosivity, which is the potential ability of the rain to cause erosion. The soil erodibility factor (K) represents both susceptibility of soil to erosion and the amount and rate of runoff, as measured under standard plot conditions. The cover factor (C) is an index which reflects, on the basis of the land use, the effect of cropping practices on the soil erosion rate. After computation of R, K, LS, C, and P maps as data layers, they can be multiplied in the GIS to assess spatial distribution of soil loss. Other than the USLE and RUSLE, other erosion models such as the Morgan and Finney method (Morgan et al. 1984), ANSWERS (Beasley et al. 1980), WEPP (NSERL 1995), and PCARES (Paningbatan 2001) were also used to predict soil erosion.

20.3.1.2 Wind Erosion

It refers to loss of soil by wind, occurring primarily in dry regions. Wind erosion process is often found to be one of the major causes of land degradation in arid and semiarid regions. In wind-induced land degradation mapping, sand dunes, wind streaks, paleo-aeolian features, desert pavements, sand encroachments, blowouts, and changes in the vegetation cover are indicators commonly to be considered. Wind erosion is controlled by several factors such as wind velocity, rainfall pattern, stability of the surface on which wind is acting upon, vegetation cover, and also socioeconomic condition of the region. Wind erosion not only impacts just the land but also the whole ecosystem and adversely affects socioeconomic conditions of the population. The focus of wind erosion has gradually been shifted from qualitative studies to semiquantitative and quantitative wind tunnel studies (Steffens et al. 2009). Over the past decades, the significance of the wind erosion problem is increased because of the changing agricultural practices (Riksen et al. 2003), and further increase can be expected due to the projected climate change (IPCC 2014). Therefore, it is important to precisely map the extent and spatial distribution of wind erosion.

Many authors used remote sensing techniques to monitor trends of land degradation as well as to identify and characterize sand dunes and their temporal dynamism (Chen et al. 1998; Tucker et al. 1994). Some of the other techniques applied for extracting data on wind erosion indicators are image transformation techniques (Carneiro and Zinck 1994), digital image classification using neural networks (Collado 2000), spectral mixture analysis (Collado 2000), and supervised maximum likelihood classification (Carneiro and Zinck 1994; del Valle et al. 2008). The satellite data based derived products subsequently used as input in GIS analysis to estimate sand mobilization rates and sand dune migration (del Valle et al. 2008). Image segmentation and object-oriented classifications of Terra-ASTER and textural details derived from RADARSAT were applied to discriminate desert pavements, active and stabilized dunes, and shrub encroachment (Blanco et al. 2009). Ajai et al. (2007, 2009) demonstrated applications of remote sensing data and GIS in land degradation and desertification mapping and reported about 105.48 Mha of India is undergoing the process of land degradation. The causative factors for desertification include overgrazing, cultivation on marginal lands and high slopes, non-sustainable land use practices, wrong agricultural management, mining, urbanization, and other activities that disturb the natural ecosystem. In addition to these factors, frequent droughts, extreme weather conditions, climate change, etc. are natural causes of land degradation and desertification. The socioeconomic condition of the local population also contributes to the land degradation/desertification process. The unstabilized longitudinal sand dunes in part of Jaisalmer district of Rajasthan mapped through analysis of sentinel 2 data (10 m) of February 10, 2016, is shown in Fig. 20.1.

20.3.1.3 Waterlogging

Waterlogging and subsequent salinization and/or alkalization are the major land degradation processes in irrigated agricultural lands of arid and semiarid regions. Waterlogging is the rise of the water table into the root zone of the soil profile, such that plant growth is adversely affected by deficiency of oxygen. Waterlogging lowers the land productivity through the rise in groundwater close to the soil surface. It also included surface ponding, where the water table rises above the surface. Waterlogging is linked with salinization, both being brought about by incorrect irrigation management. Waterlogging should be distinguished from naturally occurring poorly drained areas and also from the different problems of flooding. In the GLASOD estimate, waterlogging affects 4.6 Mha, largely in the irrigated areas of India and Pakistan. It is closely linked with salinization. In India, Ahmad and Kutcher (1992) monitored the progressive rise in the water table beneath the Indo-Gangetic plains since the commencement of large-scale irrigation schemes in the 1930s.

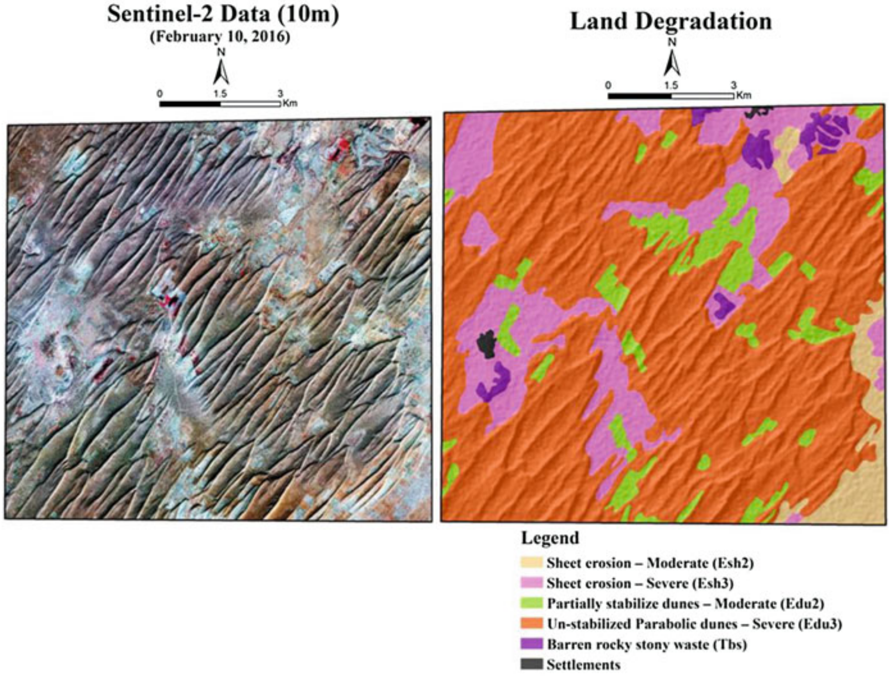

Fig. 20.1 Unstabilized longitudinal sand dunes in part of Jaisalmer district of Rajasthan mapped through analysis of sentinel 2 satellite data of February 10, 2016

Choubey (1997) used temporal IRS-IA-LISS-I, land use, and drainage data to delineate waterlogged areas and area sensitive to waterlogging in the Tawa command, and results were validated with water table data. He demonstrated that since the water table cannot be detected directly from satellite observations, the best integrative indicator can be the crop stress due to high-water table. Choubey (1998) made an attempt to identify waterlogged areas in Sriram Sagar command area by using remote sensing data. Barret and Curtis (1976) indicated that stream channel development and network, stream length, and the location of ponds and lakes can be mapped from Landsat-MSS data and it can be integrated in GIS to assess the waterlogging and drainage problems by identifying the drainage network and its characteristics in a basin besides the information on presence of high-water table, high morphology, soil color, plant stress, and drainage water collection in lower spots. The permanent waterlogged areas in the part of Sultanpur district of Uttar Pradesh, India, as appeared in Resourcesat-2 LISS-IV (5.8 m) of October 2016 are shown in Fig. 20.2.

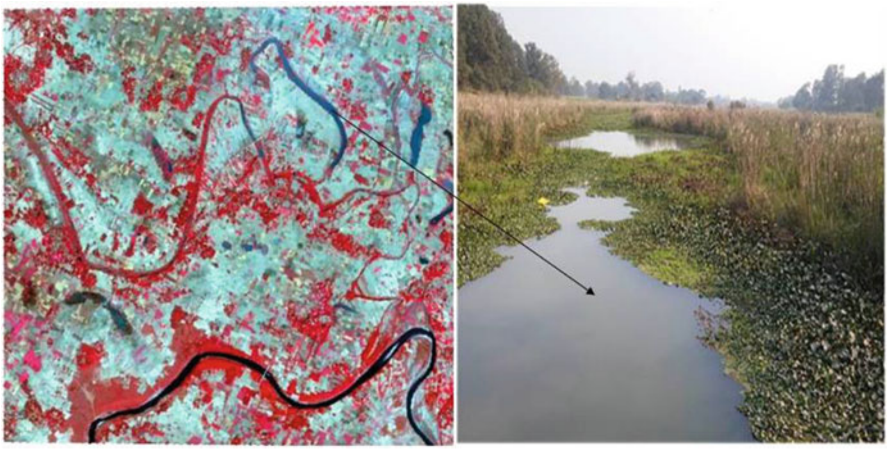

Fig. 20.2 Permanent waterlogged areas in the part of Sultanpur district of Uttar Pradesh as appeared in Resourcesat-2 LISS-IV (5.8 m) of October 2016

20.3.1.4 Lowering of the Water Table

It is a self-explanatory form of land degradation, brought about through tube well pumping of groundwater for irrigation exceeding the natural recharge capacity. In areas of deep alluvial deposits and where the groundwater has not become saline, tube well irrigation has become widespread and has led to substantial increases in crop production. In many parts of Northwestern India, due to overextraction of groundwater, its level has been progressively lowered. Singh (1992) reported that in parts of the Punjab, the water table has fallen by between 0.5 and 4.0 m in the 8 year period (1978–1986) and is receding at 0.3–0.5 m per year. Joshi and Tyagi (1991a, b) indicated that in the Sudhar block of Ludhiana district, groundwater has fallen from 3 m to 11 m during 1965 and 1989 and in Haryana from 4.8 m to 7.7 m during 1974 and 1989. Rodell et al. (2009) used GRACE (Gravity Recovery and Climate Experiment) data to monitor groundwater storage changes for long term in high plains aquifer in the Central United States. Noomen (2007) also presented the groundwater monitoring techniques using both GRACE and ERS satellite images in continental or global scale. Suphan et al. (2004) also proposed a method for estimation of spatial variation of subsurface water level change caused by crop growth from Landsat TM data and its relationship with groundwater level in an irrigation project in Thailand.

20.3.1.5 Mining and Industrial Waste

A major problem across the globe is the loss of prime agricultural land for housing, industry, roads, and other nonagricultural purposes. As urban centers expand, good quality land is converted, usually permanently, to other uses. To compensate for this, farmers are forced on to poorer land – frequently steeply sloping ground with shallow, poor soils, which can quickly erode and lead to land degradation, flooding, siltation of dams and waterways, and an accompanying cycle of poverty. During the mining operations, removal of vegetation cover results in soil degradation due to accelerated water erosion, soil compaction, and soil crusting, which affects the land productivity. Mining activities also disturb large tract of land due to overburden dumps, which change the natural topography and drainage pattern of the area (Dhar et al. 1991). Remote sensing and GIS have been widely used in mapping land use/land cover changes and environmental degradation caused by mining activities. Remote sensing provides multi-temporal data, which gives valuable temporal information about the process and pattern of land use/land cover change, and it may be analyzed and mapped in GIS to find the impact of mining and industrial activities on land degradation.

20.3.2 Chemical Degradation

20.3.2.1 Salt Affected Soils

Salinization is defined as the presence of excessive salts on the top layer of the soil, resulting in deterioration of its chemical and physical properties. Soil salinization not only causes the destruction of land and plant resources and immense decline of agricultural productivity, but also threatens the ecosystem of the region. It often occurs in areas where soil's evaporation is very intense, and the water table is high and contains high dissolubility salt. Soil salinization is a serious issue, particularly in Argentina, Egypt, India, Iraq, Pakistan, Syria, and Iran (Rhoades 1990). Soil salinity is a prevalent environmental hazard in arid and semiarid regions of the world (Hillel 2000). Koohafkan and Stewart (2012) reported that saline soils covered 397 Mha of the total land area of the world. Ghassemi et al. (1995) estimated approximately one billion hectares of the earth's continental extent is affected soil salinity. Landsat data have been extensively used for separating different levels of soil salinity/sodicity in the United States (Wiersma and Horton 1976), India (Venkatratnam 1983), Iraq (Al Mahawili 1983), and Canada (Sommerfeldt et al. 1985). Most of the authors are able to distinguish only 2–3 classes (strong and medium) of salinity levels with errors between moderately saline and normal soils. Rao and Venkataratnam (1991) studied the spectral behavior of salt-affected soils of Indo-Gangetic alluvial plain and concluded that salt-affected soils as compared to normal cultivated soils showed relatively higher spectral response in visible and near-infrared regions. Further, strongly saline-sodic soils were found to have higher spectral response as compared to moderately saline-sodic soils. Joshi and Sahai (1993) compared the accuracy of TM, MSS, and SPOT and found TM to be the superior multispectral radiometer for soil salinity mapping. Metternicht and Zinck (1996) mapped salt- and sodium-affected surface by combining digital image classification with field observations of soil degradation features and laboratory determination.

Remote sensing technology, with its unique characteristics of systematic, synoptic, rapid, and repetitive coverage, has emerged as a cost-effective and time-efficient approach for studying and mapping salt-affected soils and other degraded lands in space and time domains (Navalgund et al. 2007; Metternicht and Zinck 2008). Johnston and Barson (1993) reported that the use of satellite data in discriminating the saline areas was the most successful approach during the peak vegetation growth. Goossens and Van Ranst (1996) demonstrated that the combination of remote sensing with GIS is very promising, especially for the monitoring of soil salinization. Goossens and Van Ranst (1998) reported that single image may be suitable for detecting severely salinized soils, but more gradations can be determined by using temporal images. Goossens and Van Ranst (1998) monitored and predicted soil salinity in the Nile Delta, Egypt, using GIS and remote sensing techniques. Khan et al. (2001) used IRS-LISS-II digital data and different remote sensing-derived indices such as salinity index (SI), normalized difference salinity index (NDSI), brightness index (BI), and normalized difference vegetation index (NDVI) for mapping salt-affected soils in Punjab, Pakistan. Koshal (2010) used wetness index (WI), soil brightness index (SBI), and soil-adjusted vegetation index (SAVI) for degraded land characterization and delineation with emphasis on salinity and sodicity problems.

In Indian conditions, Seghal et al. (1988) applied Landsat MSS data for mapping salt-affected soils in the frame of the reconnaissance soil map of India. Dwivedi (1992) used Landsat MSS and TM data for more detailed mapping and monitoring of the salt-affected soils in the Indo-Gangetic alluvial plains of India. Many authors reported that the delineation of saline soils using remote sensing data and GIS techniques has been proved efficient (Dwivedi 1992; Dwivedi and Sreenivas 1998; Rao et al. 1991; Sharma et al. 1988). Verma et al. (1994) demonstrated that the addition of the thermal band of Landsat TM to the visible NIR bands helped overcome spectral similarity issues with saline soils. Dwivedi et al. (2008) reported that fusion of IKONOS imagery with IRS-ID LISS-III sensor data significantly improves the overall accuracy in soil salinity mapping and detection. The first systematic mapping of salt-affected soils of the country has been carried out in 1996 with various project partners including NRSA, CSSRI, NBSS&LUP, all India soil and land use survey, state soil survey departments, and state/regional remote sensing application centers (NRSA 1996, 2008). To address the problem of diverging national estimates by remote sensing for arriving at an acceptable figure, CSSRI, NRSA, and NBSS&LUP held a series of consultations and have developed a GIS-based approach to reconcile the national estimates as 6.73 Mha (CSSRI 2007; Maji 2007). Maji et al. (2010) harmonized land degradation datasets of India and reported that exclusively salt affected soils and salt affected soils with water covers 5.44 and 1.30 Mha, respectively. The planners and decision-makers are using this information for planning reclamation programs. Salt-affected soils in the part of Sultanpur district of Uttar Pradesh as detected on Resourcesat-2 LISS-IV (5.8 m) on May 27, 2016, are shown in Fig. 20.3.

Fig. 20.3 Salt-affected soils in the part of Sultanpur district of Uttar Pradesh as detected on Resourcesat-2 LISS-IV (5.8 m) on May 27, 2016

20.3.2.2 Soil Fertility Decline

It is used as a short term to refer to what is more precisely described as deterioration in soil physical, chemical, and biological properties. While decline in fertility is indeed a major effect of erosion, the term is used here of cover effects of processes other than erosion. The main processes involved in soil fertility decline are lowering of soil organic matter, with associated decline in soil biological activity; degradation of soil physical properties, as brought about by reduced organic matter; and adverse changes in soil nutrient resources, including reduction in availability of the major nutrients, onset of micronutrient deficiencies, development of nutrient imbalances and buildup of toxicities, primarily acidification through incorrect fertilizer use.

GLASOD defines this form of degradation as “loss of nutrients and/or organic matter”. The GLASOD assessment shows 65% of agricultural land in Bangladesh and 61% in Sri Lanka affected by this type of degradation. In Bangladesh, the average organic matter (presumably of topsoils) is said to have declined by 50%, from 2 to 1%, over the past 20 years (Bangladesh 1992). For the Indian state of Haryana, soil test reports over 15 years show a decrease in soil carbon (Chaudhary and Aneja 1991). Decreased organic matter leads to degradation of soil physical properties, including water holding capacity, reduced nutrient retention capacity, and longer release of nutrients, including micronutrients, from mineralization of organic matter. Negative soil nutrient balances have been reported for all three major nutrients in Bangladesh and Nepal, for phosphorus and potassium in Sri Lanka, and a large deficit for potassium in Pakistan (FAO 1986). Nutrient depletion has been reported for each of the 15 agroclimatic regions of India (Biswas and Tewatia 1991; Tandon 1992). For India, a deficiency between nutrient removal and addition of 60 kg/ha per year, or 9 Mt for the whole country, has been estimated (Tandon 1992). As per secondary and micronutrient deficiencies are concern, sulfur deficiency has been reported for India, Pakistan, and Sri Lanka and zinc deficiency for

India and Pakistan (FAO/RAPA 1992; Bowonder 1981; Chaudhary and Aneja 1991; Abrol 1990). For Bangladesh, 3.9 Mha are reported deficient in sulfur and 1.75 Mha in zinc, including areas of continuous swamp rice cultivation (Bangladesh 1992). Pakistan, because of its generally alkaline soils, is particularly liable to micronutrient deficiencies, which are being increasingly reported (Twyford 1994).

20.3.3 Vegetal Degradation

Vegetal degradation basically covers deforestation, overgrazing, and shifting cultivation.

20.3.3.1 Deforestation

Deforestation is one of causes of land degradation, firstly, when the land that is cleared is steeply sloping or has shallow or easily erodible soils and, secondly, when the clearance is not followed by good management. Deforestation and forest degradation lead to water erosion in steeply sloping humid environments. It is also a contributory cause of wind erosion, soil fertility decline, and salinization. The drivers and intensity of forest degradation vary by region (Kissinger et al. 2012), but the severity and impact of forest loss and degradation can be observed at all scales, from global climate change to declining economic value of forest resources and biodiversity and threatened local livelihoods. The impact of forest degradation varies from fine-scale structural changes in canopy cover and height (Franke et al. 2012; Hirschmugl et al. 2014), or subtle disruptions to ecosystem services, to broad-scale loss of biomass (Miettinen et al. 2014). These changes can occur over a range of spatial and temporal scales, which can be mapped and monitor through temporal satellite data. Many authors used satellite data to analyze the spatial and temporal patterns of deforestation and the identification of key variables related to deforestation and identify the driving forces behind changes to forest cover (Jha et al. 2000, Gautam et al. 2003; Panta et al. 2008).

20.3.3.2 Overgrazing

Overgrazing is the status of grazing of natural pastures as stocking intensifies above the livestock carrying capacity. Overgrazing adversely affects soil properties, which result in reduced infiltration, accelerated runoff, and soil erosion. Oldeman et al. (1991) reported that overgrazing is considered to be the major cause of soil degradation worldwide especially widespread in Australia and Africa, where it accounts for 80.6% and 49.2%, respectively, of all soil degradation (Warren and Khogali 1992). Degradation of vegetation cover and erosion leads to decline of soil organic matter and physical properties. Overgrazing especially in arid regions reduced infiltration and accelerated runoff and soil erosion. Results of several studies conducted in Argentina and India indicate that at the macro- and mesoscales, soil erosion can increase dramatically due to overgrazing, causing increases of 5–41 times over the control at the mesoscale and 3–18 times at the macroscale (Sharma, 1997).

20.3.3.3 Shifting Cultivation

In the past, shifting cultivation was a sustainable form of land use, at a time when low population densities allowed forest fallow periods of sufficient length to restore soil properties. Population increase and enforced shortening of fallow periods have led to it becoming non-sustainable. Shifting cultivation is found in the hill areas of Northeast India, where it is a cause of water erosion and soil fertility decline. In Northeast India, out of the total forest cover, 1.5 Mha is currently managed by shifting cultivation (Roy et al. 2012). Shifting cultivation in Northeast India not only degrades land productivity but also causes excess runoff and accelerates soil erosion in steep slope regions and deposit sediments on the riverbed in the adjoining basins and lowlands.

20.4 Management of Degraded Lands

GIS based reliable data on extent and spatial distribution on nature and degree of degraded lands; it includes soils, climate, vegetation, and topography which are needed to develop land management strategies and sound land use plans. This information can provide the background to the policies and strategies that are required by planners and policy makers to develop policies and programs in management of land degradation hazards. Subsidies, incentives, and taxes can all have an effect on what crops are grown, where, and whether or not the land is well managed. The best way to protect soil from erosion is through a dense cover of living or dead vegetation. Healthy, densely growing crops not only produce high yields but they also provide good ground cover and protection from erosion. Any conservation program should therefore promote good crop management. There is considerable potential for increasing the use of green manures in order to improve soil fertility and improve levels of organic matter in the soil.

Land degradation has been fairly high in Northeastern states of India like Nagaland, Sikkim, and Meghalaya and in some cases, it accounts for 50% of the total geographical areas. So development, reclamation, and management of degraded lands should be prioritized through proper land conservation programmes with an aim to encourage land users, at the level of the farm unit, to adopt land use systems and management practices that will lead to conservation. In order to impart essential knowledge and skills in conservation program, practical training on conservation program needs to be conducted. Overexploitation of groundwater has reached danger levels in Punjab, Haryana, and Tamil Nadu. For sustained agriculture and livelihood security in the future, rational planning and utilization of groundwater resources are essential. Salinized soils can be restored to productive use, although at a high cost, through salinity control and reclamation projects. In other cases, the land can only be restored by taking it out of productive use for some years, as in reclamation forestry. The cost of reclamation, or restoration to productive use, of degraded soils is invariably less than the cost of preventing degradation before it occurs.

20.5 Conclusions

In order to acquire more accurate data, it is necessary to define the type and degrees of land degradation in terms that offer practical means of observation, monitoring, and mapping. The study indicates that remote sensing technology, with its unique characteristics of systematic, synoptic, rapid, and repetitive coverage, has emerged as a cost-effective and time-efficient approach for studying and mapping land degradation in time and space domains. Remote sensing and GIS techniques have immense potential to map and monitor various types of physical degradations due to water erosion, wind erosion, waterlogging, mining and quarrying, and urban and industrial waste. 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. The temporal remote sensing data has immense potential to monitor and characterize sand dunes and their temporal dynamism. Integrated remote sensing and GIS could be effectively used to map and monitor the waterlogged- and salt-affected soils. The spatiotemporal patterns of deforestation and identification of key driving forces behind changes in forest cover could be effectively mapped and monitored.

Reclamation and management of degraded lands should be a priority through proper land conservation program with the aim to adopt suitable land use systems and management practices. The information generated through integrated remote sensing and GIS on extent and spatial distribution of degraded lands could be effectively used in watershed management programmes for soil and water conservation, reclamation of salt-affected soils, afforestation towards sustainable management of land resources and improvement of the status of soil organic matter. In general, lightly degraded soils can be improved by crop rotation, minimum tillage techniques, and other on-farm practices. Moderately damaged land takes more resources to restore the land resources. More severely degraded soils could be used for afforestation and mechanical measures. In developing countries like India, the program of reclamation and management of degraded lands could be effectively linked with government-run employment guarantee schemes to provide employment to the landless and rural poor for effective management of land resources toward sustainable agriculture and livelihood security.

References

Abrol IP (1990) Problem soils in India. In: Problem soils of Asia and the Pacific. FAO/RAPA, Bangkok, pp 153–165

Ahmad M, Kutcher GP (1992) Irrigation planning with environmental considerations: a case study of Pakistan's Indus basin. World Bank Technical Paper 166. World Bank, Washington DC, 196 pp

Ajai RR, Arya AS, Dhinwa PS et al (2007) Desertification/land degradation atlas of India. Space Applications Centre, Ahmedabad. ISBN No. 978-81-909978-2-9

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

Al Mahawili SMH (1983) Satellite interpretation and laboratory spectral reflectance measurements of saline and gypsiferous soils of West Baghdad, Iraq. M.S. Thesis, Purdue University, West Lafayatte, Indian, USA

Anonymous (1976) Report of National Commission on Agriculture, part V, IX and abridged report, Ministry of Agriculture and Irrigation, Govt. of India, New Delhi

Bai ZG, Dent DL, Olsson L, Schaepman ME (2008) Proxy global assessment of land degradation. Soil Use Manag 24:223–234

Bali JS (1985) Problems of gullied and ravinous area -Policy, programmes and progress. In: Proceedings national seminar on soil conservation and watershed management, New Delhi, 17–18 September 1985

Bangladesh (1992) Land degradation. Paper presented to FAO 21st regional conference for Asia and the Pacific, New Delhi

Barrett EC, Curtis LF (1976) Introduction to environmental remote sensing. Chapman and Hall, London, p 336

Bartsch KP, van Miegroet H, Boettinger J, Dobrwolski JP (2002) Using empirical erosion models and GIS to determine erosion risk at Camp Williams. J Soil Water Conserv 57:29–37

Beasley DB, Huggins LF, Monke EJ (1980) ANSWERS: a model for watershed planning. Trans Am Soc Agric Eng 23(4):938–944

Biswas A, Tewatia RK (1991) Nutrient balance in agro-climatic regions of India – an overview. Fert News 36(6):13–18

Blanco PD, Metternicht GI, del Valle HF (2009) Improving the discrimination of vegetation and landforms patterns in sandy rangelands: a synergistic approach. Int J Remote Sens 30:2579–2605

Bowonder B (1981) The myth and reality of high yield varieties in Indian agriculture. Dev Chang 12(2):293–313

Bridges EM, Oldeman LR (1999) Global assessment of human-induced soil degradation. J Arid Soil and Rehabil 13(4):319–325

Carneiro FA, Zinck JA (1994) Mapping paleo-aeolian sand cover formations in the northern Amazon basin from TM images. ITC J 3:270–282

Chaudhary MK, Aneja DR (1991) Impact of green revolution on long-term sustainability of land and water resources in Haryana. Indian J Agric Econ 45:428–432

Chen Z, Elvidge CD, Groenveld DP (1998) Monitoring of seasonal dynamics of arid land vegetation using AVIRIS data. Remote Sens Environ 65:255–266

Choubey VK (1997) Detection and delineation of waterlogging by remote sensing techniques. J Indian Soc Remote Sens 25(2):123–135

Choubey VK (1998) Assessment of waterlogging in Sriram Sagar command area, India, by remote sensing. Water Resour Manag 12(5):343–357

Collado AD (2000) Spatio-temporal dynamics of dune patterns in semiarid Argentina: a neural network analysis. Edaphomatics Bull. no. 20. AICET-INTA, Buenos Aires, Argentina

CSSRI (2007) Annual report 2006–07. Central Soil Salinity Research Institute, Karnal, India

Das DC (1985) Problem of soil erosion and land degradation in India. Proceedings of the national seminar on the soil conservation and watershed management held on 17–18 September New Delhi

De Ploey J (1989) A soil erosion map for Western Europe. Catena Verlag

del Valle HF, Rostagno CM, Coronato FR, Bouza PJ, Blanco PD (2008) Sand dune activity in north-eastern Patagonia. J Arid Environ 72:411–422

Dhar BB, Jamal A, Ratan S (1991) Air pollution problem in an Indian open cast coal mining complex: a case study. Int J Surf Min Reclam Environ 5(2):83–88

Dhuruvanarayana VV, Ram Babu NP (1983) Estimation of soil erosion in India. J Irrig Drain Eng 109:419–434

Dregne HE, Chou NT (1994) Global desertification dimensions and costs. In: Dregne HE (ed) Degradation and restoration of arid lands. Texas Technical University, Lubbock

Dwivedi R (1992) Monitoring and the study of the effects of image scale on delineation of salt-affected soils in the Indo-Gangetic plains. Int J Remote Sens 13(8):1527–1536

Dwivedi RS, Sreenivas K (1998) Delineation of salt-affected soils and waterlogged areas in the indo-Gangetic plains using IRS-1C LISS-III data. Int J Remote Sens 19:2739–2751

Dwivedi RS, Kumar AB, Tewari AN (1997a) The utility of multi-sensor data for mapping eroded lands. Int J Remote Sens 18:2303–2318

Dwivedi RS, Ravi Sankar T, Venkataratnam L, Karale RL, Gawande SP, Rao KVS, Senchuandhary S, Bhaumik KR, Mukherjee KK (1997b) The inventory and monitoring of eroded lands using remote sensing data. Int J Remote Sens 18:107–119

Dwivedi RS, Kothapalli RV, Singh AN (2008) Generation of farm-level information on salt-affected soils using IKONOS-II multispectral data. In: Metternicht G, Zinck J (eds) Remote sensing of soil salinization: impact on land management. CRC Press, Boca Raton

Eswaran H, Lal R, Reich PF (2001) Land degradation: an overview. In: Bridges EM, Hannam ID, Oldeman LR, Pening de Vries FWT, Scherr SJ, Sompatpanit S (eds) Responses to land degradation. Proceedings of. 2nd international conference on land degradation and desertification, Khon Kaen, Thailand. Oxford Press, New Delhi

FAO (1986) Status report on plant nutrition in fertilizer programmes countries in Asia and Pacific region. AGL/MISC/86/7. FAO, Rome

FAO (2008a) Land degradation on the rise – one fourth of the world's population affected says new study. Report by Food and Agricultural Organization. http://www.fao.org/newsroom/en/news/2008/1000874/index.html

FAO (2008b) LADA project documents FAO, internet website: http://www.fao.org/ ag/agl/agll/lada/ladaprojectdoc.pdf. Accessed 10 July 2017

FAO/RAPA (1992) Environmental issues in land and water development. FAO/RAPA, Bangkok. 488 pp (Includes country papers on Bangladesh, India, Nepal, Pakistan and Sri Lanka)

Fernandez C, Wu JQ, McCool DK, Stockle CO (2003) Estimating water erosion and sediment yield with GIS, RUSLE, and SEDD. J Soil Water Conserv 58:128–136

Franke J, Navratil P, Keuck V, Peterson K, Siegert F (2012) Monitoring fire and selective logging activities in tropical peat swamp forests. IEEE J Select Top Appl Earth Observ Remote Sens 5(6):1811–1820

Fu BJ, Zhao WW, Chen LD, Zhang QJ, Lu YH, Gulinck H, Poesen J (2005) Assessment of soil erosion at large watershed scale using RUSLE and GIS: a case study in the loess plateau of China. Land Degrad Dev 16:73–85

Gautam NC, Narayan LRA (1988) Wastelands in India. Pink Publishing House, Mathura, p 96

Gautam AP, Webb EL, Shivakoti GP, Zoebisch MA (2003) Land use dynamics and landscape change pattern in a mountain watershed in Nepal. Agric Ecosyst Environ 99:83–96

Ghassemi F, Jakeman AJ, Nix HA (1995) Salinisation of land and water resources: human causes, extent, management and case studies. CABI, Wallingford

Goossens R, Van Ranst E (1996) The use of remote sensing and GIS to detect gypsiferous soils in the Ismailia Province (Egypt). In the international conference on soils with gypsum, Lleida, Spain, 15–21. Accessed 15 Oct 2017

Goossens R, Van Ranst E (1998) The use of remote sensing to map gypsiferous soils in the Ismailia Province (Egypt). Geoderma 87(1–2):47–56

Gupta SK, Ahmed H, Hussain M, Pandey AS, Singh S, Saini KM, Das SN (1998) Inventory of degraded lands of Palamau district, Bihar: a remote sensing approach. J Indian Soc Remote Sens 26:161–168

Hillel D (2000) Salinity management for sustainable irrigation: integrating science, environment, and economics. World Bank Publications, Washington, DC

Hirschmugl M, Steinegger M, Gallaun H, Schardt M (2014) Mapping forest degradation due to selective logging by means of time series analysis: case studies in central Africa. Remote Sens 6:756–775

IPCC (2014) Synthesis report. Contribution of working groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change [Core Writing Team, Pachauri RK, Meyer LA (eds)]. IPCC, Geneva, Switzerland, 151 pp

Jafari R, Lewis MM, Ostendorf B (2008) An image-based diversity for assessing land degradation in an arid environment in South Australia. J Arid Environ 72:1282–1293

Jha CS, Dutt CBS, Bawa KS (2000) Deforestation and land use changes in Western Ghats, India. Curr Sci 79:231–238

Johnston RM, Barson MM (1993) Remote sensing of Australian wetlands: an evaluation of Landsat TM data for inventory and classification. Mar Freshw Res 44(2):235–252

Joshi MD, Sahai B (1993) Mapping of salt-affected land in Saurashtra coast using Landsat satellite data. Int J Remote Sens 14(10):1919–1929

Joshi PK, Tyagi NK (1991a) Sustainability of existing farming system in Punjab and Haryana – some issues in groundwater use. Indian J Agric Econ 46(3):412–421

Joshi PK, Tyagi NK (1991b) Sustainability of existing farming system in Punjab and Haryana some issues on groundwater use. Indian J Agric Econ 46:412–421

Kapalanga TS (2008) A review of land degradation assessment methods. Land restoration training programme Keldnaholt, 112 Reykjavík, Iceland, pp 17–68

Karale RL, Saini KM, Narula KK (1987) Mapping and monitoring ravines using remotely sensed data. J Soil Water Conserv (India) 32(1–2):75–82

Kessler CA, Stroosnijder L (2006) Land degradation assessment by farmers in Bolivian mountain valleys. Land Degrad Dev 17:235–248

Khan NM, Rastoskuev VV, Elrna VS, Yohei S (2001) Mapping salt affected soils using remote sensing indicators. In: 22nd Asian conference on remote sensing, Singapore, 5–9 November 2001

Kissinger G, Herold M, De Sy V (2012) Drivers of deforestation and forest degradation: a synthesis report for REDD+ policymakers. Lexeme Consult, Vancouver

Koofhafkan AP, Lantieri D, Nachtergaele F (2003) Land Degradation in Drylands (LADA): guidelines for a methodological approach. FAO, Rome

Koohafkan P, Stewart BA (2012) Water and cereals in drylands, the food and agriculture. Organization of the United Nations and Earthscan, Rome

Koshal AK (2010) Indices based salinity areas detection through remote sensing and GIS. In parts of south waste Punjab. In: 13th annual international conference and exhibition on geospatial information technology and applications, Gurgaon, India

LADA (2009) Guidelines for the identification, selection and description of nationally based indicators of land degradation and improvement, land degradation assessment in drylands. UNEP, Rome

Lal R (2003) Soil erosion and the global carbon budget. Environ Int 29:437–450

Lu D, Batistella M, Mausel P, Moran E (2007) Mapping and monitoring land degradation risks in the Western Brazilian Amazon using multitemporal Landsat TM/ETM+ images. Land Degrad Dev 18:41–54

Ma JW, Xue Y, Ma CF, Wang ZG (2003) A data fusion approach for soil erosion monitoring in the upper Yangtze river basin of China based on Universal Soil Loss Equation (USLE) model. Int J Remote Sens 24:4777–4789

Maji AK (2007) Assessment of degraded and wastelands of India. J Indian Soc Soil Sci 55:427–435

Maji AK, Reddy GPO, Sarkar D (2010) Degraded and wastelands of India, status and spatial distribution. ICAR and NAAS Publication, New Delhi, pp 1–158

Maji AK, Reddy GPO, Sarkar D (eds) (2012). Acid soils of India – their extent and spatial variability, NBSS Publ. No.145, NBSS&LUP, Nagpur, 147 p

Mandal D, Sharda VN (2011) Assessment of permissible soil loss in India employing a quantitative bio-physical model. Curr Sci 100(3):383–390

Metternicht G (2006) UN-Zambia-ESA regional workshop on the applications of GNSS in sub-Saharan Africa

Metternicht GI, Zinck JA (1996) Modelling salinity-sodicity classes for mapping salt affected top soils in the semi-arid valleys of Cochabamba (Bolivia). ITC J 11:125–135

Metternicht GI, Zinck JA (1997) Spatial discrimination of salt- and sodium-aff ected soil surfaces. Int J Remote Sens 18:2571–2586

Metternicht GI, Zinck JA (1998) Evaluating de information content of JERS-1 SAR and Landsat TM data for discrimination of soil erosion features. ISPRS J Photogramm Remote Sens 53:143–153

Metternicht GI, Zinck JA (eds) (2008) Remote sensing of soil salinization: impact on land management. CRC Press/Taylor & Francis, Boca Raton

Metternicht G, Zinck JA, Blanco PD, del Valle HF (2009) Remote sensing of land degradation: experiences from Latin America and the Caribbean. J Environ Qual 39:42–61

Miettinen J, Stibig H-J, Achard F (2014) Remote sensing of forest degradation in Southeast Asia-aiming for a regional view through 5–30 m satellite data. Glob Ecol Conserv 2:24–36

Millward AA, Mersey JE (1999) Adapting the RUSLE to model soil erosion potential in a mountainous tropical watershed. Catena 38:109–129

Mitasova H, Hofierka J, Zlocha M, Iverson LR (1996) Modelling topographic potential for erosion and deposition using GIS. Int J Geogr Inf Sci 10:629–641

Molnar DK, Julien PY (1998) Estimation of upland erosion using GIS. Comput Geosci 24:183–192

Morgan RPC, Morgan DDV, Finney HJ (1984) A predictive model for the assessment of soil erosion risk. J Agric Eng Res 30(1):245–253

National Commission on Agriculture (1976) Report of the National Commission on Agriculture: part V, IX and abridged. Ministry of Agriculture and Irrigation, New Delhi

Navalgund RR, Jayaraman V, Roy PS (2007) Remote sensing applications: an overview. Curr Sci 93:1747–1766

Nawar S, Buddenbaum H, Hill J, Kozak J (2014) Modeling and mapping of soil salinity with reflectance spectroscopy and Landsat data using two quantitative methods (PLSR and MARS). Remote Sens 6:10813–10834

Noomen M (2007) Groundwater monitoring using GRACE and ERS satellite image. In: Proceeding of the 28th Asian conference on remote sensing, Malaysia

NRSA. (1996). Mapping salt-affected soils of India on 1:250,000. NRSA, Hyderabad

NRSA (2005) Wasteland atlas of India. Ministry of Rural Development and NRSA Publ., NRSA, Hyderabad

NRSA (2008) National wide mapping of land degradation on 1:50,000 scale using multi-temporal satellite data. NRSA, Hyderabad

NSERL (1995) WEPP user summary. National Soil Erosion Research Laboratory, US Department of Agriculture. Accessed 10 September 2017

NWDB (1985) Description, classification, identification and monitoring of wastelands. National Wastelands Development Board, Ministry of Environment and Forests. Govt. of India, New Delhi

Oldeman LR (ed) (1988) Global Assessment of Soil Degradation (GLASOD). Guidelines for general assessment of status of human-induced soil degradation. ISRIC, Wageningen. Working paper and reprint no. 88 (4), pp 12

Oldeman LR (1994) The global extent of land degradation. In: Greenland DJ, Szabolcs I (eds) Land resilience and sustainable land use. CABI, Wallingford, pp 99–118

Oldeman RL, Hakkeling RTA, Sombroek WG (1990) World map of the status of human induced soil degradation. International soil reference and information Centre, Wageningen

Oldeman LR, Hakkeling RTA, Sombroek WG (1991) World map of the status of Human Induced soil degradation: an explanatory note. ISRIC (International Soil Reference and Information Center), Wageningen

Panagos P, Borrelli P, Poesen J, Ballabio C, Lugato E, Meusburger K, MOntanarella L, Alewell C (2015) The new assessment of soil loss by water erosion in Europe. Environ Sci Pol 54:438–447

Pandey PC, Rani M, Srivastava PK, Sharma LK, Nathawat MS (2013) Land degradation severity assessment with sand encroachment in an ecologically fragile arid environment: a geospatial perspective. Q Sci Connect 43:17

Paningbatan EP (2001) Geographic information system assisted dynamic modeling of soil erosion and hydrologic processes at a watershed scale. Philippine Agric Sci 84(4):388–393

Panta M, Kim K, Joshi C (2008) Temporal mapping of deforestation and forest degradation in Nepal: applications to forest conservation. For Ecol Manag 256:1587–1595

Pickup G, Chewings VH (1986) A grazing gradient approach to land degradation assessment in arid areas from remotely-sensed data. Int J Remote Sens 15:597–617

Pohl C, van Genderen JL (1998) Review article. Multisensor image fusion in remote sensing: concepts, methods and applications. Int J Remote Sens 19(5):823–854

Raina P, Joshi DC, Kolarkar AS (1991) Land degradation mapping by remote sensing in the arid region of India. Soil Use Manag 7(1):47–51

Rao BRM, Venkataratnam L (1991) Monitoring of salt-affected soils- a case study using aerial photographs, Salyut-7 space photographs and Landsat-TM data. Geocarto Int 6(1):5–11

Rao BRM, Dwivedi RS, Venkataratnam L, Ravishankar TSS, Bhargawa GP, Singh AN (1991) Mapping the magnitude of sodicity in part of the indo-Gangetic plains of Uttar Pradesh, northern India using Landsat-TM data. Int J Remote Sens 12(3):419–425

Reddy GPO, Maji AK, Srinivas CV, Velayutham M (2002) Geomorphological analysis for inventory of degraded lands in a river basin of basaltic terrain, using remote sensing data and geographical information systems. J Indian Soc Remote Sens 30(1&2):15–31

Reddy GPO, Maji AK, Chary GR, Srinivas CV, Tiwary P, Gajbhiye KS (2004) GIS and remote sensing applications in prioritization of river sub basins using morphometric and USLE parameters – a case study. Asian J Geoinform 4(4):35–49

Reddy GPO, Kurothe RS, Sena DR, Harindranath CS, Naidu LGK, Sarkar D, Sharda VN (2013). Soil erosion of Goa. NBSS Publ. 155. NBSS&LUP (ICAR), Nagpur, p 54

Reddy GPO, Kurothe RS, Sena DR, Harindranath CS, Niranjana KV, Naidu LGK, Singh SK, Sarkar D, Mishra PK, Sharda VN (2016) Assessment of soil erosion in tropical ecosystem of Goa, India using universal soil loss equation, geostatistics and GIS. Indian J Soil Conserv 44(1):1–7

Renard KG, Foster GR, Weesies GA et al (1997) Predicting soil erosion by water – a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE), Agricultural Handbook No. 703, US Government Printing Office, Washington, DC

Reusing M, Schneider T, Ammer U (2000) Modeling soil erosion rates in the Ethiopian highlands by integration of high resolution MOMS-02/D2-stereo-data in a GIS. Int J Remote Sens 21:1885–1896

Rhoades JD (1990) Soil salinity-causes and controls. In: Goudie AS (ed) Techniques for desert reclamation. Wiley, Chichester, pp 109–134

Riksen M, Brouwer F, De Graaf J (2003) Soil conservation policy measures to control wind erosion in north-western Europe. Catena 52:309–326

Rodell M, Velicogna I, Famiglietti JS (2009) Satellite-based estimates of groundwater depletion in India. Nature 460:999–1002

Roy PS, Kushwaha SPS, Murthy MSR, Roy A, Kushwaha D, Reddy CS, Behera MD, Mathur VB, Padalia H, Saran S, Singh S, Jha CS, Porwal MC (2012) Biodiversity characterization at landscape level: national assessment 2012. Indian Institute of Remote Sensing, Dehradun, India, p 140

Saini KM, Deb TK, Mitra PP, Ghatol SG (1999) Assessment of degraded lands of Puruliya district, West Bengal using remotely sensed data. J Indian Soc Remote Sens 27:23–30

Seghal JL, Saxena RK, Verma KS (1988) Soil resource inventory of India using image interpretation techniques, remote sensing is a tool for soil scientists. In the 5th symposium of the working group remote sensing ISSS, Budapest, pp 17–31

Sehgal J, Abrol IP (1992) Land degradation statue: India. Desertification Bull 21:24–31

Sehgal J, Abrol IP (1994) Soil degradation in India: status and impact. Oxford/IBH, New Delhi

Sharma RC, Bhargawa GP (1988) Landsat imagery for mapping saline soils and wetlands in north-west India. Int J Remote Sens 9:69–84

Sharma KD, Walling DE, Probst JL (1997) Assessing the impact of overgrazing on soil erosion in arid regions at a range of spatial scales. Human impact on erosion and sedimentation. Proceedings of an international symposium of the fifth scientific assembly of the International Association of Hydrological Sci. (IAHS), Rabat, Morocco, pp 119–123

Singh B (1992) Groundwater resources and agricultural development strategy: Punjab experience. Indian J Agric Econ 47:105–113

Singh AN, Dwivedi RS (1989) Delineation of salt affected soils through digital analysis of Landsat-MSS data. Int J Remote Sens 10:83–92

Singh D, Meirelles MSP, Costa GA, Herlin I, Berroir JP, Silva EF (2006) Environmental degradation analysis using NOAA/AVHRR data. Adv Space Res 37(4):720–727

Sommerfeldt TG, Thompson MD, Pront NA (1985) Delineation and mapping of soil-salinity in southern Alberta from Landsat data. Can J Remote Sens 10(104–1):18

Sonneveld BGJS, Dent DL (2009) How good is GLASOD? J Environ Manag 90:274–283

Srinivas CV, Maji AK, Reddy GPO, Chary GR (2002) Assessment of soil erosion using remote sensing and GIS in Nagpur district, Maharashtra, for prioritization and delineation of conservation units. J Indian Soc Remote Sens 30(4):197–211

Steffens M, Koebl A, Giese M, Kogel-Knabner I (2009) Spatial variability of top soils and vegetation in a grazed steppe ecosystem in inner Mongolia (PR China). J Plant Nutr Soil Sci 172:78–90

Suphan S, Honda K, Gupta AD, Eiumnoh A, Chen X (2004) Estimation of subsurface water level change from satellite data. In: Proceeding of 25th Asia conference remote sensing, Thailand, 1, pp 512–516

Tandon HLS (1992) Assessment of soil nutrient depletion. Paper presented to FADINAP seminar, Fertilization and the environment, Chiang Mai, Thailand

Tucker CJ, Newcomb WW, Dregne HE (1994) AVHRR data sets for determination of desert spatial extent. Int J Remote Sens 15:3547–3565

Twyford I (1994) Fertilizer use and crop yields. Paper presented to 4th National Congress of the Soil Science Society of Pakistan, Islamabad. 1992

UNCCD (2015) Land matters for climate reducing the gap and approaching the target. Available from: http://www.unccd.int/Lists/SiteDocumentLibrary/Publications/2015Nov_Land_matters_For_Climate_ENG.pdf 2015

UNEP (1992) Desertification, land degradation [definitions]. Desertification Control Bull 21

Vågen TG, Winowiecki LA, Abegaz A, Hadgu KM (2013) Landsat-based approaches for mapping of land degradation prevalence and soil functional properties in Ethiopia. Remote Sens Environ 134:266–275

Van Lynden GWJ, Oldeman LR (1997) The assessment of the status of human-induced soil degradation in south and South East Asia. UNEP/FAO and ISRIC, Wageningen

Venkatratnam L (1983) Monitoring of soil salinity in indo-Gangetic plain of NW India using multidate Landsat data. In: Proceedings of 17th international symposium on remote sensing of environment. Ann. Arbor, Michigan, USA 1, pp 369–377

Verma KS, Saxena RK, Barthwal AK, Deshmukh SN (1994) Remote sensing technique for mapping salt affected soils. Int J Remote Sens 15(9):1901–1914

Vrieling A (2006) Satellite remote sensing for water erosion assessment: a review. Catena 65:2–18

Vrieling A, de Jong SM, Sterk G, Rodrigues SC (2008) Timing of erosion and satellite data: a multi-resolution approach to soil erosion risk mapping. Int J Appl Earth Obs Geoinf 10:267–281

Wang G, Gertner G, Fang S, Anderson AB (2003) Mapping multiple variables for predicting soil loss by geostatistical methods with TM images and a slope map. Photogramm Eng Remote Sens 69:889–898

Warren A, Khogali M (1992) Assessment of desertification and drought in the Sudano-Sahelian region IW−/99/. United Nations Sudano-Sahelian Office

Wessels KJ, Prince SD, Frost PE, VanZyl D (2004) Assessing the effects of human-induced land degradation in the former homelands of northern South Africa with a 1 km AVHRR NDVI time-series. Remote Sens Environ 91:47–67

Wiersma JL, Horton M (1976) Remote sensing applications for detection of saline seep. Report no. OWRD-44, South Dakota State University, Brookings, South Dakota, USA

Wilson JP, Lorang MS (2000) Spatial models of soil erosion and GIS. In: Fotheringham AS, Wegener M (eds) Spatial models and GIS: new potential and new models. Taylor & Francis, Philadelphia, pp 83–108

Wischmeier WH, Smith DD (1978) Predicting rainfall erosion losses – a guide to conservation planning, USDA agricultural handbook no 587