



Inventory and Monitoring of Land Degradation Processes Using Space Data

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Abstract: Land degradation is one of the major environmental hazards, affecting the living conditions of millions of people all across the world. Inventory and monitoring of the land degradation status are the primary requirement in preparation of mitigation plan to combat land degradation. The present paper, therefore, aims at the creation of spatial inventory of land degradation processes using satellite data. Multi-season Landsat TM data of 30 m spatial resolution, pertaining to the years 1992, 2001 and 2016, have been analysed to prepare land degradation maps of Ballia district, Uttar Pradesh state in northern India. Monitoring and assessment of the desertification has been carried out for a period of 24 years. In this study, an attempt is made to monitor the changes in land degradation status during 1992 to 2016 by using multi-temporal satellite data. Water logging and sodicity in agricultural land are the major processes of land degradation active in Ballia district. Analysis of satellite data reveals that area under sodicity in agriculture land has increased from 23.04 km² in 1992 to 25.08 km² in 2016, while water logging in agricultural land has increased from 199.92 km² in 1992 to 210.25 km² in 2016.

Key words: Land degradation, monitoring, multi-temporal, satellite data.

Land degradation is one of the major environmental concerns all across the world. It is a complex geo-environmental hazard resulting from the interaction of physical, meteorological, biological, socio-economic and cultural factors leading to changes in soil, vegetation, water, climate and the socio economic conditions of the people. About 70% of dry lands are affected by land degradation, which support over 1 billion people in more than 110 countries. Land degradation occurs slowly and cumulatively and has long lasting impacts on rural people who become increasing vulnerable to this environmental problem (Muchena, 2008). Land degradation has many definitions which emphasize different aspects of reduction in quality of the land through degradation processes. Land degradation is a process that diminishes or destroys the agricultural-crop or live-stocks and forest production capacity of the land. It is induced by human activities or can be a natural phenomenon aggravated by the effects of human activities (Brabant, 2008, 2010). Land degradation is a process which reduces the current and or potential capacity of soils to produce (FAO, 1979). Millennium Ecosystem Assessment (MEA,

2005) defines land degradation (LD) as the reduction in the capacity of land to provide ecosystem goods and services. Definition of land degradation/desertification and the evolution of the desertification concept have been reviewed by many authors (Thomas and Middleton, 1994; Lal *et al.*, 1989; Puigdefabregas *et al.*, 2009; Eswaran *et al.*, 2001; Reynolds and Smith, 2002; Reynolds *et al.*, 2007; Reynolds *et al.*, 2011; Brabant, 2008; Brabant, 2010; Safriel, 2007; Ajai *et al.*, 2007; Ajai *et al.*, 2009). The new book (Squires and Ariapour, 2018) discusses the problems of definition and the confusion as well analyses the evolution of counter measures. As per UNCCD, "Land degradation" is defined as reduction or loss of the biological or economic productivity of land resulting from land uses or from a process or a combination of processes, including processes arising from human activities and habitation patterns, such as: i) soil erosion caused by fluvial and/or aeolian processes, ii) deterioration of physical (crusting, compaction, water logging), chemical (acidification, salinization) and biological or economic properties of soil and iii) loss or degradation of vegetation. Land degradation is a process which may finally turn a "productive land" in to 'degraded or waste land'

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Land degradation includes various types of processes such as physical (soil erosion by water and wind, water logging, soil compaction and crusting, frost shattering, frost heaving, mass wasting), chemical degradation (acidification, salinization, alkalisation) and biological degradation (vegetal degradation, change in species composition) (Lal, 1994; Eswaran *et al.*, 2001; Christian *et al.*, 2018).

Causes of land degradation can be either anthropogenic or natural. Anthropogenic reasons include the following: deforestation including shifting cultivation, over grazing, cultivation on marginal lands and high slopes, non-sustainable land use practices, wrong agricultural management, mining, road construction, urbanization and other activities that disturb the natural ecosystem. Socio-economic condition of the local people (poverty and illiteracy) is one of the major drivers of land degradation and desertification. Basically, it is the increasing population (human and cattle) pressure which is responsible for disturbing the fragile ecosystem and exerts undue pressure on natural resources which activates the process of land degradation. Natural causes of land degradation include, frequent droughts, extreme weather conditions, climate change etc. that causes land degradation. Human activities are the main factors triggering and/or accelerating the land degradation processes on vulnerable land. To sum-up, all the above manmade drivers of land degradation have two root causes: i) poverty, illiteracy and underdevelopment, ii) "modern" development.

Mapping and monitoring of land degradation extent, along with the information on the type and severity of degradation, are prerequisites in preparation of action plans to combat land degradation. There are mainly two types of methodologies which have been used for mapping and monitoring of desertification and land degradation: i) indicator based methods and ii) methods where land degradation processes are directly mapped. The indicators used include vegetation cover, vegetation biomass, net primary production, land use/land cover change etc. The major disadvantage of the indicator based method is that here the process or types of land degradations are not identified. Thus, mapping based on indicators is not useful in preparation of action plans for combating land degradation as the strategies

for combating are different for different types of land degradation. Satellite remote sensing and GIS have been extensively used for mapping and monitoring land degradation/desertification, mostly with multispectral sensors including Landsat and the Indian remote sensing (IRS) series of satellites (Dwivedi, 2001; Verma *et al.*, 1994; Chikhaouim *et al.*, 2005; Ajai *et al.*, 2007; Jong *et al.*, 2008; Ajai *et al.*, 2009; Shalaby and Tateishi 2007; Brabant 2010; Bai *et al.*, 2013; Lanfredi *et al.*, 2015; Dhinwa *et al.*, 2016; Kwanele and Njoya, 2017; Dube *et al.*, 2017; Christian *et al.*, 2018; Sepuru *et al.*, 2018).

Thus, in the present study, mapping, monitoring and assessment of land degradation processes has been carried out at 1:50,000 scale using multi-temporal Landsat satellite data for Ballia district of Uttar Pradesh in, northern India. Inventory and monitoring of land degradation status, has been carried out over a period of 24 years using multi-season Landsat TM/ETM+ and OLI data of 1992, 2001 and 2016. Unlike the indicator based inventory and monitoring, the present study provides the spatial inventory of the various types/processes of land degradation as well as their severity.

Study Area

Ballia district is the eastern most district of Uttar Pradesh bordering Bihar. It comprises of an irregularly shaped tract extending westwards from the confluence of the Ganga and Ghagra. The major rivers of the district are the Ganga, the Ghagra and the Sarju. The Ganga separates it from Bihar in the south and Ghagra from Deoria and Bihar in north and east respectively. The boundary between Ballia and Bihar is determined by deep streams of rivers Ganga and Ghagra. The district lies between the parallels of 25°33' and 26°11' N latitude and 83°38' and 84°39' E longitude (Fig. 1). It is bounded on the west by Mau, on the north by Deoria, on the north-east and south-east by Bihar and on the south-west by Ghazipur. Total population of Ballia district is 3,223,642 according to census 2011 and its total area is 3008 sq. km. The district is a level plain, intersected by numerous streams. Though there are no hills, the level surface is varied with the high banks of the rivers and depressions. The general slope is from the central watershed towards the Ganga, Ghagra and Sarju or Tons.

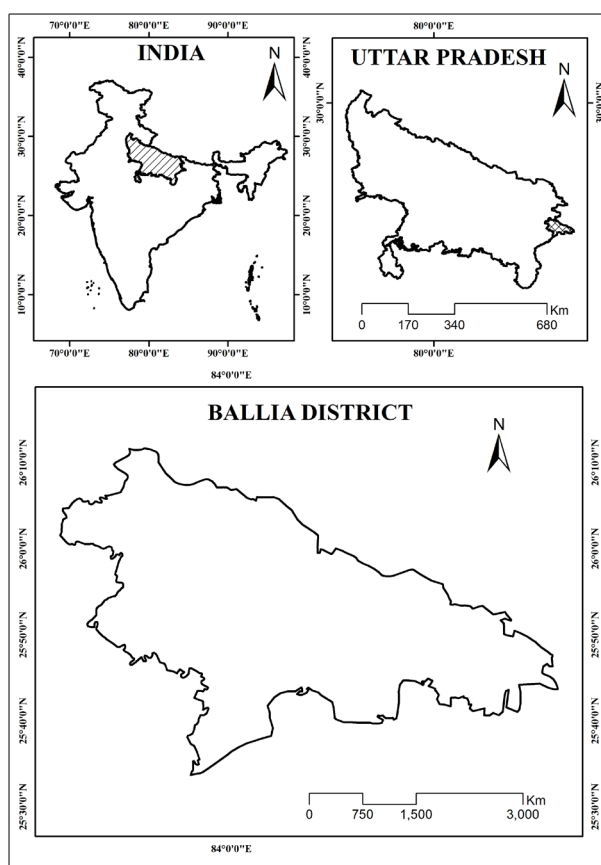


Fig. 1. Location map of Ballia district, Uttar Pradesh.

The *tongue* or water-rich tract of land lying between the Ghagra and the Ganga is called the *doab* (Bhatt, 1997).

The geology of the district does not reveal anything striking except ordinary Gangetic alluvium. The only minerals of importance are *kankar* and saline efflorescence known as *reh* found in the western part. The chief varieties of soils in the district are *bhur* or sand, *dormat* or loam and *matiar* or clay. *Bhur* is found along the high banks of the rivers, *matiar* occur in depressions, while *dormat* is found in the rest of the district. There is no forest in the district but *jhau* or *tamarisk* jungles occur along the rivers. A few patches of *dhak* jungles are also found in the interior of the district. The chief trees are *bargad* (*Ficus benghalensis*), *kathal* (*Artocarpus heterophyllus*), *mahua* (*Madhuca longifolia*), *neem* (*Azadirachta indica*), *shisham* (*Dalbergia sissoo*) and *fir* (*Abies* spp.). The Ghagra and the Ganga cause extensive floods in the district causing loss of life, property and standing crops. It is hot in summer with maximum day temperature between 25°C to 42°C.

Data Used

The Landsat (thematic mapper, TM) multi-temporal satellite data, ancillary information and collateral data has been used to prepare land degradation status maps for Ballia District, U.P. Details of the data used are provided in Table 1. Landsat OLI images of Ballia district for the year 2015-16 pertaining to Kharif, Rabi and summer seasons are shown in Fig. 2.

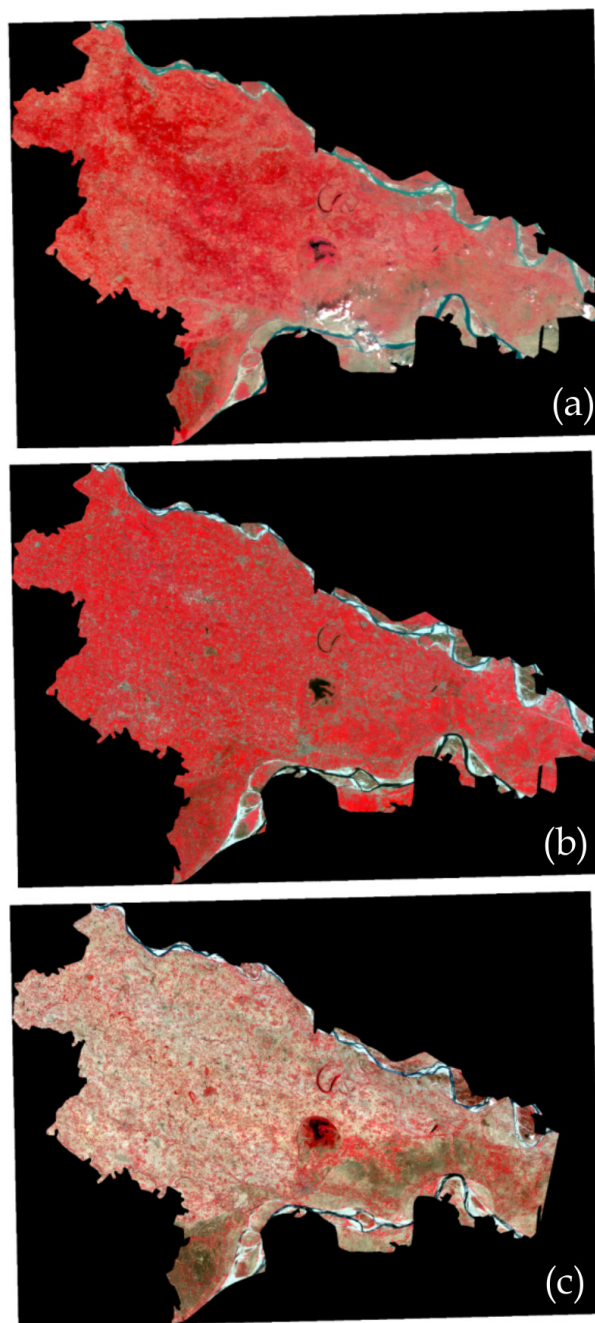


Fig. 2. Landsat TM/OLI-FCC image of Ballia district for (a) kharif, season (October 2015), (b) rabi season (February 2016) and (c) summer season (May 2016).

Table 1. Details of data used

Satellite Data	Data	Sensor ID	Date of Acquisition
	Landsat	TM	September 1991, February 1992
	Landsat	ETM+	February and October 2001
		OLI	October 2015, February and May 2016
Ancillary information	SOI Topographic maps 43 P/5, 6, 9 & 10 (1:50,000) Scale	-	Survey of India
Collateral data	1. Population 2. Climate 3. Geology 4. Soils etc.	-	Census

Table 2. Comprehensive classification system for land degradation status mapping (source Ajai *et al.*, 2009)**LEVEL 1 : Land use/Land cover**

The following categories have been identified as below:

Agriculture - Unirrigated	D
Agriculture - Irrigated	I
Forest/Plantation	F/P
Grassland/Grazing land	G
Land with scrub	S
Barren/Rocky area	B/R B(sc) indicating scree areas in cold deserts
Dune/Sandy area	E
Waterbody/Drainage	W
Glacial/Peri-glacial (In cold region)	C/L
Others (Urban, Man-made etc.)	T

- (Rocky areas within forest annotated as only FV3-R in the map)
- (Vegetal degradation in Land with Scrub around periphery of notified forests can be delineated as Sv_)
- (Encroachment in forest area especially agricultural practices, is Fv3)
- (Barren and Rocky areas to be delineated separately as B or R and shown in others category of the legend)
- (All settlements are hatched)

LEVEL 2. Processes of Degradation

Type of processes resulting in degradation:

Vegetation degradation	V
Water erosion	W
Wind erosion	E
Waterlogging	I
Salinization/ Alkalinization	s/a
Mass movement (in cold areas)	G
Frost heaving (in cold areas)	H
Frost shattering (in cold areas)	F
Man-made (Mining/Quarrying, Brick Kiln, Industrial Effluents, City Waste, Urban Agglomeration, etc.)	M

(Gully/ravines shown as Xw3, where X is the Land use/cover class of surrounding area).

(Salinization or Alkalinization should be shown as 's or 'a' separately. Where both occur, they shown together i.e. s_xa_y, where x and y are respective degree of severities)

LEVEL 3: Severity of Degradation

This level represents the degree and severity of the degradation.

Slight	1
Moderate	2
Severe	3

Methodology

Land degradation status maps are prepared through on screen interpretation digitization technique using multi-season Landsat satellite data pertaining to 1992 (TM), 2001 (ETM+) and 2016 (OLI). A preliminary desertification status map is prepared by using comprehensive classification system as given in Table 2 and following the methodology provided in Fig. 3. It is later on checked through ground truth and

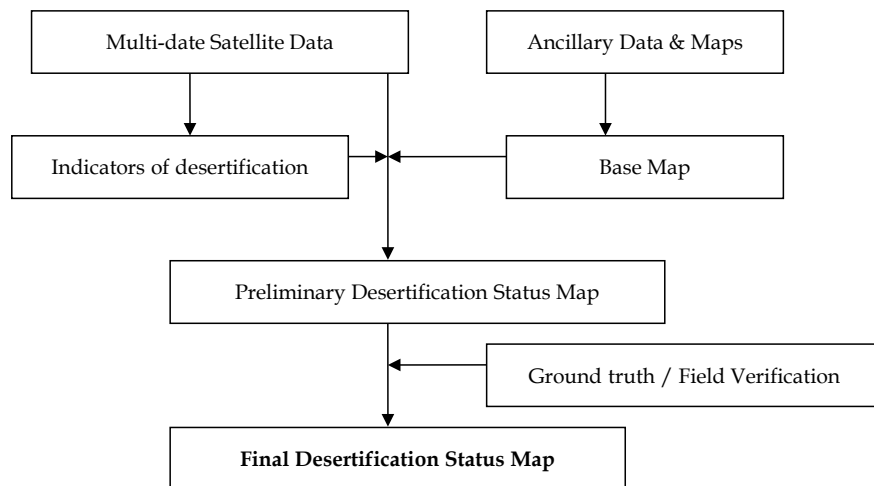


Fig. 3. Methodology flow chart for land degradation status mapping using Satellite data (Source: Ajai et al., 2009).

after field checks desertification status map is finalized (Fig. 3).

Survey of India (SOI) topographical maps (Table 1) corresponding to, Ballia district (Uttar Pradesh, India) at the scale of 1:50,000, were used to demarcate and delineate taluka (an administrative divisions of India denoting a sub-district, also referred as *Tehsil*) boundary and drainage as the basic inputs. Base map was prepared using relevant information on major water bodies, settlements, drainage network, major road and rail network from the SOI maps. SOI maps were also used to extract the Ground Control Points (GCPs) and then used for image geo-referencing and co-registration of multi-season/date Landsat data (TM, ETM+ and OLI).

Photographic elements such as tone, texture, size, shape, pattern, association were considered for delineating the land-use classes; land degradation processes (types) and severity. ERDAS imagine 2015 and Arc GIS 10.4 was used for digital image processing and GIS analysis, respectively.

Results and Discussions

Land degradation status maps prepared using the above methodology derived from multi-season Landsat satellite data pertaining to 1992 (TM), 2001 (ETM+) and 2016 (OLI) are given in Fig. 4. Details on the area under various land degradation processes active in the Ballia district, for the years 1992, 2001 and 2016 are given in Table 3. Comparisons of the area classified as degraded in 1992, 2001 and 2016 are given in Fig. 5.

Water logging and sodicity in agricultural land are the major land degradation processes found to occur in Ballia district. Analysis of satellite data reveals that the area under the sodicity in irrigated agriculture are 23.04, 24.58 and 25.08 km² during the years 1992, 2001 and 2016, respectively (Table 3). Thus there is an increase of 204 ha (2.04 km²) in the area under sodicity during the past 24 years. Area under the slight category of severity (Is_1) in sodicity has increased from 18.38 km² to 19.43 km² during the 24 years period. Area under sodicity-moderate category of severity (Is_2)

Table 3. Area under different land degradation processes in Ballia district during the years 1992, 2001 and 2016

Land degradation processes	1992	2001	2016
	Area in sq. km		
Agriculture irrigated, sodicity, Is_1	18.38	19.93	19.43
Agriculture irrigated, sodicity, Is_2	4.66	4.65	5.65
Agriculture irrigated, water logging, Il_1	115.91	118.90	121.94
Agriculture irrigated, water logging, Il_2	84.01	85.97	88.31
Land with scrub, vegetal degradation, Sv_1	0.18	0.18	0.17
Land with scrub, vegetal degradation, Sv_2	2.06	2.06	2.05
Land with scrub, vegetal degradation, Sv_3	0.66	0.67	0.66
Human settlements	85.80	117.17	134.87
Waterbody	528.77	339.72	330.41

Total area of Ballia district 3008.54 sq. km.

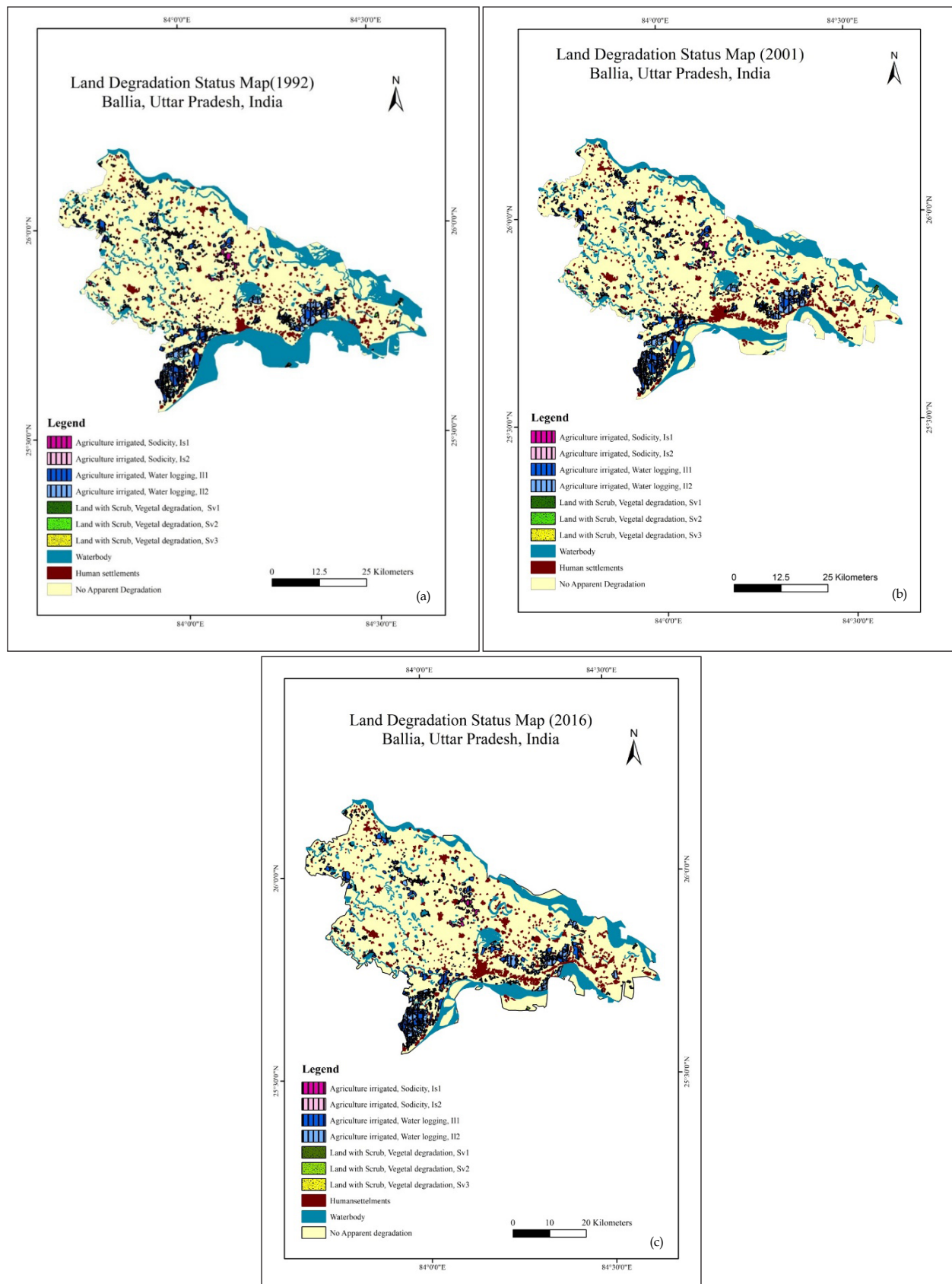


Fig. 4. Land degradation map of Ballia district for (a) 1992, (b) 2001 and (c) 2016.

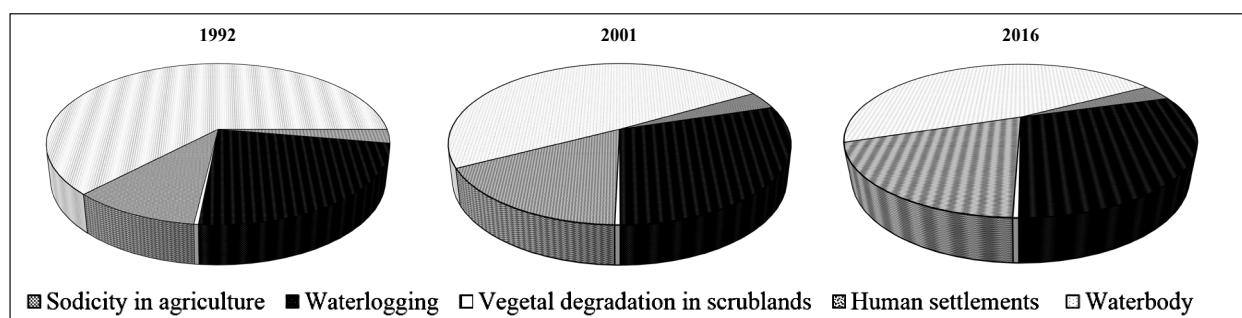


Fig. 5. Area under different land degradation processes during 1992, 2001 and 2016.

has increased from 4.66 km² to 5.65 km². Area under water-logging in agricultural land has increased from 199.92 km² in 1992 to 210.25 km² in the year 2016. The area under water logging is about seven per cent of the geographic area of the district. Thus there is an increase of 10.33 km² in the water logged area in the district, during the past 24 years. Area under vegetal degradation in scrubland are 290, 291 and 288 during 1992, 2001 and 2016, respectively. There is a large increase in the area under human settlement, it has increased from 85.80 km² in 1992 to 143.87 km² in 2016. Area of water bodies have decreased from 528.77 km² in 1992 to 330.41 km² in 2016.

Conclusions

Land degradation maps have been prepared at 1:50,000 scale using multi-season Landsat TM data, pertaining to the years 1992, 2001 and 2016, for Ballia district in Uttar Pradesh state of India. Unlike the land degradation inventory, normally prepared based on proxy indicators, the methodology presented here provides the information on the types of land degradation processes and their severity. Preparation of combating plans requires spatial information not only on the land degradation status but also on the types of the processes and their severity. Above maps have been used for monitoring and assessment of land degradation status in Ballia district over a period of 24 years (1992-2016). Waterlogging and sodicity in agricultural area, are the major land degradation processes active in this area. Area under water-logging in agricultural land has increased from 199.92 km² in 1992 to 210.25 km² in the year 2016 which is presently about seven percent of the geographic area of the district. There has been an increase of 204 ha (2.04 km²) in the area under sodicity during the past 24 years also.

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References

- Ajai *et al.*, 2007. Desertification Monitoring and Assessment using Remote Sensing and GIS: A Pilot Project under TPN-1 UNCCD SAC/RESIPA/MESG/DMA/2007/01.
- Ajai, Arya, A.S., Dhinwa, P.S., Pathan, S.K. and Ganesh Raj, K. 2009. Desertification/land degradation status mapping of India. *Current Science* 97(25): 1478-1483.
- Bai, X.Y., Wang, S.J. and Xiong, K.N. 2013. Assessing spatial-temporal evolution processes of Karst rocky desertification land: Indications for restoration strategies. *Land Degradation and Development* 24(1): 47-56.
- Bhatt, S.C. (Ed.) 1997. *The Encyclopaedic District Gazetteers of India*. Central Zone, Vol. 6, pp. 473-478, Ballia District, Uttar Pradesh, Gyan Publishing House, 5, Andheri Road, New Delhi.
- Brabant, P. 2008. Activités humaines et dégradation des terres, collection Atlas Cederom, Indicateurs et method. IRD Paris: Published under the International year of the Planet Earth (IYPE) *Planet Terre label* (cartographie.ird.fr/degra_PB.html).
- Brabant Pierre 2010. A land degradation assessment and mapping method. A standard guideline proposal. Les dossiers thématiques du CSFD. N°8. November 2010. CSFD/Agropolis International, Montpellier, France. 52 pp.
- Chikhaouim, M., Bonn, F., Bokoye, A. I. and Merzouk, K. 2005. A spectral index for land degradation mapping using ASTER data: Application to a semi-arid Mediterranean

- catchment. *International Journal of Applied Earth Observation and Geoinformation*, 7: 140-153.
- Christian, B., Dhinwa, P.S and Ajai 2018 Long term monitoring and assessment of desertification processes using medium and high resolution satellite data. *Applied Geography* 97: 10-24.
- Dhinwa, P.S., Dasgupta, A. and Ajai 2016. Monitoring and assessment of desertification using satellite remote sensing. *Journal of Geomatics* 10(2): 210-216.
- Dube, T., Mutanga, O., Sibanda, M., Seutloali, K. and Shoko, C. 2017, Use of Landsat series data to analyse the spatial and temporal variation of land degradation in dispersive soil environment: a case of King Sabata Dalindyebo local municipality in the Eastern Cape province, South Africa. *Physics and Chemistry of Earth* 100: 112-120. <https://doi/10.1016/j.pce.2017.01.23>.
- Dwivedi, R.S. 2001. Soil resources mapping: A remote sensing perspective. *Remote Sensing Reviews* 20(2): 89-122.
- Eswaran, H., Lal, R. and Reich, P.F. 2001 Land degradation: An overview. In *Response to Land Degradation* (Eds. E.M. Bridges, I.D. Hannam, L.R. Oldeman, F.W.T. Pening De Vries, S.J. Scherr and S. Sompatpanit), pp. 20-35. Science Publishers Inc, Enfield, NH.
- FAO 1979. *A Provisional Methodology for Soil Degradation Assessment*, Rome, FAO.
- Jong, R.D., Bruin, S.D., Schaepman, M. and Dent, D. 2008. Quantitative mapping of global land degradation using earth observations. *International Journal of Remote Sensing* 32(11): 6823-6853.
- Kwanele, P. and Njoya, S.N. 2017. Mapping soil erosion in Quaternary catchment in the Eastern Cape using GIS and remote sensing. *South African Journal of Geomatics* 6: 11-29.
- Lanfredi, M., Coppola, R., Simoniello, T., Coluzzi, R., D'Emilio, M., Imbrenda, V. and Macchiato, M. 2015. Early identification of land degradation hotspots in complex bio-geographic regions. *Remote Sensing* 7: 8154-8179.
- Lal, R. 1994. Tillage effects on soil degradation, soil resilience, soil quality and sustainability. *Soil and Tillage Research* 27: 1-8.
- Lal, R., Hall, G.F. and Miller, F.P. 1989. Soil degradation: 1. *Basic Processes Land Degradation and Rehabilitation* 1: 51-69.
- MEA 2005. Ecosystem and human wellbeing: Synthesis, World Resource Institute, Washington DC, Island Press.
- Muchena, F.N. 2008. Indicators for Sustainable Land Management in Kenya's Context. GEF Land Degradation Focal Area Indicators, ETC-East Africa. Nairobi, Kenya.
- Puigdefabregas, J., Gabriel del Barrio and Joachim, H. 2009. Advances in studies on desertification, contributions to the international conference in memory of Prof. John B. Thorms. Murcia: Universidad de Murcia, editum. *Ecosystemic Approaches to land Degradation* 77-87.
- Reynolds, J.F., Grainger, A., Stafford Smith, D.M., Bastin, G.L., Garcia-Barrios, R.J., Fernandez, M.A., Janssen, N., Jurgens, R.J., Scholes, A., Veldkamp, M.M., Verstraete, G. and Von Maltitz, Zdruli, P. 2011. Scientific concepts for an integrated analysis of desertification. *Land Degradation and Development* 22: 166-183.
- Reynolds, J.F., Stafford, D.M., Smith, E.F., Lambin II, B.L., Turner, M., Motimore, S., Batterbury, P.J., Downing, T.E., Dowlatabadi, H., Fernandez, R.J., Herrick, J.E., e. Huber-Sannwald, H., Jiang, R., Leemans, T., Lynam, F.T., Maestre, M., Ayarza and Walker, B. 2007. Global desertification: Building a science for dryland development. *Science* 316: 847-851.
- Reynolds, J.F. and Stafford Smith, D.M. 2002. *Global Desertification: Do Humans Cause Deserts?* University Press, Berlin.
- Safriel, U. 2007. The assessment of global trends in land degradation. *Climate and Land Degradation*. Berlin, Heidelberg: Springer.
- Sepuru, T.K. and Dube, T. 2018. Remote Sensing Applications: Society and environment an appraisal on the progress of remote sensing applications in soil erosion mapping and monitoring. *Remote Sensing Applications: Society and Environment* 9: 1-9.
- Shalaby, A. and Tateishi, R. 2007. Remote Sensing and GIS for mapping and monitoring land cover and land use changes in the Northwestern coastal zone of Egypt. *Applied Geography* 27: 28-41.
- Squires, V.R. and Ariapour, A. 2018. *Desertification: Past, Present and Future Trends*. NOVA Science Publishers, NY.
- Thomas, D.S.G. and Middleton, N.J. 1994. *Desertification: Exploding the Myth*. Chichester, John Wiley & Sons Ltd., UK.
- Verma, K.S., Saxena, R.K., Barthwal, A.K. and Deshmukh, S.N. 1994. Remote sensing techniques for mapping salt affected soils. *International Journal of Remote Sensing* 15(9): 1901-1914.