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Desertification and land degradation vulnerability assessment using integrated geospatial techniques

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ABSTRACT

Desertification and land degradation (DLD) are the most serious forms of environmental threat in India. Identification of areas that are more vulnerable to DLD is important for devising strategies to arrest land degradation and desertification. The present study aimed to map the most sensitive areas of DLD in Andhra Pradesh using climate, soil, land use and socio-economic factors. The map of DLD vulnerability index was prepared and divided into five DLD vulnerability classes namely very low, low, medium, high and very high. The results indicated that 13% of the areas were very highly vulnerable to DLD and 15% of areas were highly vulnerable. The very high vulnerability to the desertification threat was identified in Kurnool, Anantapur and Cuddappa districts. This map helps to prioritise the lands for taking up combating plan and measures to arrest the DLD.

1. INTRODUCTION

Desertification is a land degradation process occurring in arid, semi-arid and dry sub-humid areas primarily due to climatic variations and improper human activities. According to United Nations Convention to Combat Desertification (UNCCD), it is defined as reduction or loss in biological and economic productivity of land (UNCCD, 1994).The most challenging task of desertification is to assess its magnitude and the spatial distribution of areas which are prone to desertification (Symeonakis *et al*., 2016; Kapović *et al*., 2018). Since desertification is a multifarious land degradation process involving natural and human factors, it is necessary to understand causes, impacts and linkages among the most likely contributing natural factors such as climate, soil, water, land and socio-economic conditions of people living in vulnerable areas for evolving efficient environment policy in order to combat the process (Basso *et al.,* 2000; Imbrenda *et al*., 2014; Dharumarajan *et al.,* 2017; Keesstra *et al*., 2018).

This would need a systemic approach capable of deriving individual as well as integrated composite vulnerability indices of natural and human induced factors, and these indices need to be transformed on to space for identifying the lands which are vulnerable to desertification. The present study was attempted to evolve distinctive methodological framework to derive the desertification vulnerability index and its spatial transformation with the objective to identify the spatial extent and distribution of the problematic areas in Andhra Pradesh state, India.

In previous studies, research related to desertification process has been addressed for both conceptual and methodological issues, and as well as identification of the indicators for assessment of desertification process and its pattern (Dasgupta *et al*., 2013; Kosmas *et al*., 2014). Further, several methodologies have been suggested for evaluating desertification process such as direct observation and measurement, mathematical models and parametric equations and estimates, remote sensing and satellite images by using different sets of indicators or indices (Kosmas *et al*., 1999; Salvati and Zitti, 2008; Bakr *et al*., 2012). During the process, the most prominent indicators identified for assessing desertification process are soil, climate, vegetation, terrain, and socio-economic factors. The environmental sensitivity index (ESI) was calculated in the MEDALUS methodology by analyzing the climate quality index, soil quality index, vegetation quality index and management quality index (Kosmas *et al*., 1999). Based on biophysical and socio-economical factors, Salvati and Zitti (2008) proposed desertification vulnerability index which gave results that were comparable with those of MEDALUS. Petta *et al*.

(2005) identified different levels of susceptibility to desertification such as very high, high, moderate, low and very low using time series data from TM sensors of the LANDSAT-5 and LANDSAT-7. Dharumarajan *et al*. (2018a) developed the desertification vulnerability index utilized in Anantapur district based on climate, land use, soil, and socio-economic parameters, and identified 10.2% lands as a very highly vulnerable. These data base help in delineation and prioritization of desertification and land degradation (DLD) risk areas for effective planning and execution of soil conservation programs (Mishra *et al*., 2018; Dharumarajan *et al*., 2018a).These reviews have significantly revealed that the methodology for identification of desertification vulnerability area is either location specific or situation specific in nature. Hence, the present study in Andhra Pradesh state, India has been designed and organized comprehensively to identify DLD vulnerability area by using digital data base and information system with the objective to evolve the desertification and land degradation vulnerability index (DLVI) on the basis of multivariate analysis in GIS framework by using the indicators such as socio-economic, climate, soil and land use parameters.

2. MATERIALS AND METHODS

Socio-economic Component

Amenities index

Amenities are important indicator of social development. Unavailability or availability of these basic amenities at a particular location has direct or indirect linkage with productive potential and sustainability of land. Amenities index was calculated based on availability of different amenities present in particular settlement. Four amenities *viz.,* medical, education, communication and transport were selected for calculation of the amenities index. The presence or absence of each parameters used for calculating different amenity index was extracted from the national census for Andhra Pradesh state, India (Census, 2011). List of amenities used for calculation of cumulative amenities index (CAI) are given in Table 1.

The amenities index was calculated based on following formula:

$$I_a = \frac{\Sigma\,(A_i \times W_i)}{\Sigma\, W_i} \quad \text{where } i = 1 \text{ to } n \qquad ...(1)$$

Where, I_a is index for amenities of particular settlement; n is the number of amenities in a category; A_i is 1 or 2 (1 = Available, 2 = Not available); W_i is the weight of the amenity within category/class of facility and it is defined as:

$$W_i = \frac{\Sigma\,(N - f_i)}{N} \times 100 \qquad ...(2)$$

Where, N is the total number of settlements; f_i is the number of settlements having amenity i. CAI was calculated based on:

$$\text{CAI} = \Sigma\, I_a, \text{ where } a \text{ is 1 to } m; \qquad ...(3)$$

Table: 1
Different amenities used for calculation of cumulative amenities index (CAI)

Education Index	Health Index	Communication Index	Transportation index
Govt Pre-Primary School (Nursery/LKG/UKG)	Community Health Centre	Post Office	Public Bus Service
Govt Primary School	Primary Health Centre	Sub Post Office	Railway Station
Govt Middle School	Primary Health Sub-centre	Post and Telegraph Office	Auto/Modified Autos
Govt Secondary School	Maternity and Child Welfare Centre	Village Pin Code	Taxi
Govt Senior Secondary School	TB Clinic	Telephone (Landlines)	Vans
Govt Arts and Science Degree College	Hospital Allopathic	Public Call Office /Mobile (PCO)	Tractors
Govt Engineering College	Hospital Alternative Medicine	Mobile Phone Coverage	Cycle-pulled Rickshaws (Manual Driven)
Govt Medicine College	Dispensary	Internet Cafes/Common Service Centre (CSC)	Cycle-Pulled Rickshaws (Machine Driven)
Govt Management Institute	Veterinary Hospital	Private Courier Facility	Carts Driven by Animals
Govt Polytechnic	Mobile Health Clinic		Sea/River/Ferry Service
Govt Vocational Training School/ITI	Family Welfare Centre		National Highway
Government Non-formal Training Centre	Non-Government Medical Facilities Charitable		State Highway
	Non-Government Medical Facilities Medical Practitioner with MBBS Degree		Major District Road
	Non-Government Medical Facilities Medical Practitioner with Other Degree		Black Topped (Pucca) Road
	Non-Government Medical Facilities Medical Practitioner with No Degree		Gravel (Kuchha) Roads
	Non-Government Medical Facilities Traditional Practitioner and Faith Healer		Water Bounded Macadam
	Non-Government Medical Facilities Medicine Shop		Navigable Waterways (River/Canal)
	Non-Government Medical Facilities Others		

m is the number of amenity categories (medical, educational, transport, communication).

Economic development index (EDI)

Economic development is one of the major drivers for DLD (Salvati *et al*., 2011). Normally economic development of a particular settlement is related to the population and its employment of the settlement. Population density of a settlement and proportion of its employed population to total population was used for calculation of an economic development index.

$$EDI = \sqrt{D.W(W-A)} \qquad ...(4)$$

Where, EDI is economic development index; D is population density; W is the proportion of employed population; A is the proportion of unskilled workers (*i.e.* unemployed + agricultural laborers + marginal workers / total population). The CAI and economic development index were classified into five classes based on Jenks natural breaks. The Jenks natural breaks are based on data clustering method to determine the best display of values into different classes (Becerril-Piña *et al*., 2016).This classification method identifies the cut-off points between different categories using Jenks optimization algorithm. The algorithm groups the data according to the inherent natural breaks in the data (Lamqadem *et al*., 2018). The socio-economic index (SEI) was calculated based on CAI and EDI, and classified into five classes (very low, low, moderate, high, and very high) in GIS environment.

Natural Resource Component

Land utilization index (LUI)

LUI was derived based on land use/land cover and land capability class. Land capability classification (LCC) is based on the inherent potential of land, external land features, and limitations that determine the capacity of the land to support various uses. LCC was derived based on slope and soil characteristics. The limitations increase progressively from class I to class VIII. Lands falling under classes I-IV can be used for cultivation whereas lands under classes V-VIII cannot be used for cultivation without risking serious damage to the land and environment. LUI gives better picture on how the lands are allotted to different land uses. LCC and land use are integrated in GIS environment and classified into three classes, *viz.,* 'underutilized', 'optimally utilized' and 'over utilized'. For example, land capability class of more than IV with agricultural land use was assigned over utilization, whereas LCC of I or II with scrub lands were assigned with under utilization.

Soil quality index (SQI) and climate quality index (CQI)

SQI was derived by integrating variables such as soil depth, texture, drainage, gravelliness, and available water content (NBSS&LUP, 1996) under GIS environment (Table 2). Scores for each parameter were assigned based on the range of data and its impact on DLD (Kosmas *et al*., 1999). SQI was arrived based on eq. 5. SQI was further divided into five unique soil quality classes: very good, good, moderate, poor and very poor. Climate quality index was derived using CGIAR-CSTM database of aridity index. The aridity index in Andhra Pradesh ranges from 0.17 to 1.08 (Zomer *et al*., 2008).

Table: 2
Assigned scores of soil quality indices for calculation of DLVI

Class	Score	Class	Score
Soil depth		**Soil texture**	
Deep (>100 cm)	4	SL, SCL, CL	3
Moderately deep (75-100 cm)	3	Sandy clay, Clay	2
Moderately shallow (50-75 cm)	2	Sand, Loamy sand	1
Shallow (<50 cm)	1	**Drainage**	
Gravelliness		Well drained	4
Slightly gravelly (<15%)	3	Mod. well drained	3
Moderate (15-35%)	2	Imperfectly drained	2
Strong (>35%)	1	Poor	1
AWC		**Soil Quality Indices**	
Very high (>200 mm m^{-1})	3	Very low	1-1.25
High (150-200 mm m^{-1})	2.5	Low	1.25-1.5
Medium (100-150 mm m^{-1})	2	Moderate	1.50-1.75
Low (50-100 mm m^{-1})	1.5	High	1.75-2.0
Very low (<50 mm m^{-1})	1	Very high	>2.0

AWC-water holding capacity; SL-sandy loam; SCL-sandy clay lam; CL-clay loam

SQI = (soil depth * drainage * soil texture * AWC * gravelliness)$^{1/5}$ ...(5)

Derivation of desertification and land degradation vulnerability index (DLVI)

An inter-disciplinary framework of analysis was evolved using both natural resources and socio-economic components for identification and assessment of desertification prone areas in the study region. Scores were allotted to climate quality, soil quality and LUI between 1 to 2, and bio-physical sensitive index (BSI) was calculated based on geometric mean. Assigned scores for different classes of climate, soil and LUI are given Table 3.

BSI = (land utilization index * soil quality index * climate quality index)$^{1/3}$ ...(6)

DLVI was calculated based on BSI and SEI. Scores assigned for BSI and SEI are given in Table 4.

DLVI = (BSI * SEI)^{½} ...(7)

The spatial patterns of different levels of vulnerability to desertification were delineated on the basis of natural break intervals of values and different classes of vulnerability (Table 5).

3. RESULTS AND DISCUSSION

Socio-Economic Index (SEI)

Statistics of amenities index are presented in Table 6. The area statistics revealed that 6.7% of the area classified

Table: 3
Assigned Scores of different indices for calculation of BSI

CQI	Score	SQI	Score	LUI	Score
Very low	2.0	Very low	2.0	Over	2.0
Low	1.75	Low	1.75	Optimum	1.5
Moderate	1.50	Moderate	1.5	Under	1.0
High	1.25	High	1.25		
Very high	1.0	Very high	1.0		

CQI: Climate quality index; SQI: Soil quality index; LUI: Land utilization index

Table: 4
Assigned scores of different indices for calculation of DLVI

BSI	Score	SEI	Score
Very low	1.0	Very low	2.0
Low	1.25	Low	1.75
Moderate	1.50	Moderate	1.5
High	1.75	High	1.25
Very high	2.0	Very high	1.0

BSI: Biophysical sensitive index; SEI: Socio-economic index

Table: 5
Desertification and land degradation vulnerability index (DLVI) class and its description

DLVI class	Description
Very high	Critical areas to desertification and subjected to very high erosion rates due to intensive cultivation, overgrazing, frequent fires; or subject to very high salinization risk or very high vegetal degradation
High	Critical areas to desertification and subjected to high erosion rates due to intensive cultivation, over-grazing, frequent fires; or subject to high salinization risk or high vegetal degradation
Medium	Fragile areas to desertification subjected to moderate erosion rates due to intensive cultivation or over-grazing or frequent fires; or subjected to moderate salinization risk or moderate vegetal degradation
Low	Potential areas to desertification subjected to low erosion rates or low salinization risk or low vegetal degradation
Very low	Slight or non-threatened areas to desertification subjected to very low or no erosion with no or slight salinization risk

Table: 6
Statistics of amenities index

Index	Education	Health	Communication	Transport	CAI
Mean	0.05	0.09	0.19	0.219	0.13
Minimum	0.00	0.00	0.00	0.00	0.00
Maximum	0.42	0.64	1.00	0.72	0.70
Std.dev	0.05	0.08	0.16	0.13	0.09
Kurtosis	6.22	4.23	7.45	0.34	4.51
Skewness	1.89	1.80	2.24	0.89	1.72

under very high CAI category and 24 % of area under high CAI. Economic development describes the well-being of society as a whole. The positive correlation between land vulnerability and low-income regions has been reported by many researchers across the world (Gerber *et al*., 2014; Barbier and Hochard, 2016). The main reason behind that is lack of financial resources, and alternatives can lead to increasing intensification and over utilization of natural resources (Lalitha *et al*., 2016). The population density of Andhra Pradesh state is 308 km^{-2}. Population growth in most of the cases has direct impact on land degradation, especially in rural areas. Economic development index was calculated based on population density and proportion of employed population of the settlement, and it ranged from 0 to 3.37 with the mean and standard deviation of 1.33 and 0.95, respectively. Area statistics showed that 21.7% of area was classified as very high economic development and 19.3% of area under high economic development. Very low category occupied about 21% of study area.

CAI and economic development index were integrated in the GIS environment, and the output was classified into five classes based on expert knowledge. Very high CAI and very high economic development resulted in very low degree of desertification and *vice-versa* (Kelly *et al*., 2015). Hence, well developed economic, social, institutional, and cultural domains are crucial for communities being resilient against desertification vulnerability. The socio-economic analysis (Fig.1) showed that 18% of the area has very low socio-economic development and 14% of area has very high SEI.

Natural Resource Component

Soil quality index (SQI)

Soil is an important factor for evaluating the environmental vulnerability of any eco-system. Soil properties are highly related to DLD by affecting water retention capacity and erosion resistance. The results of SQI (Fig. 2) revealed that 23.6% of area was classified as very high category and 22.5% lands were having moderate quality soils. Only 7.1% of lands have very low-quality soils.

Climatic quality index (CQI)

The rainfall uncertainty increased dry period; over-exploitation of groundwater caused water shortage, and consequently lead to degradation and desertification of lands. The climate constraints influence the availability of water for the vegetation growth. With the absence of vegeta-

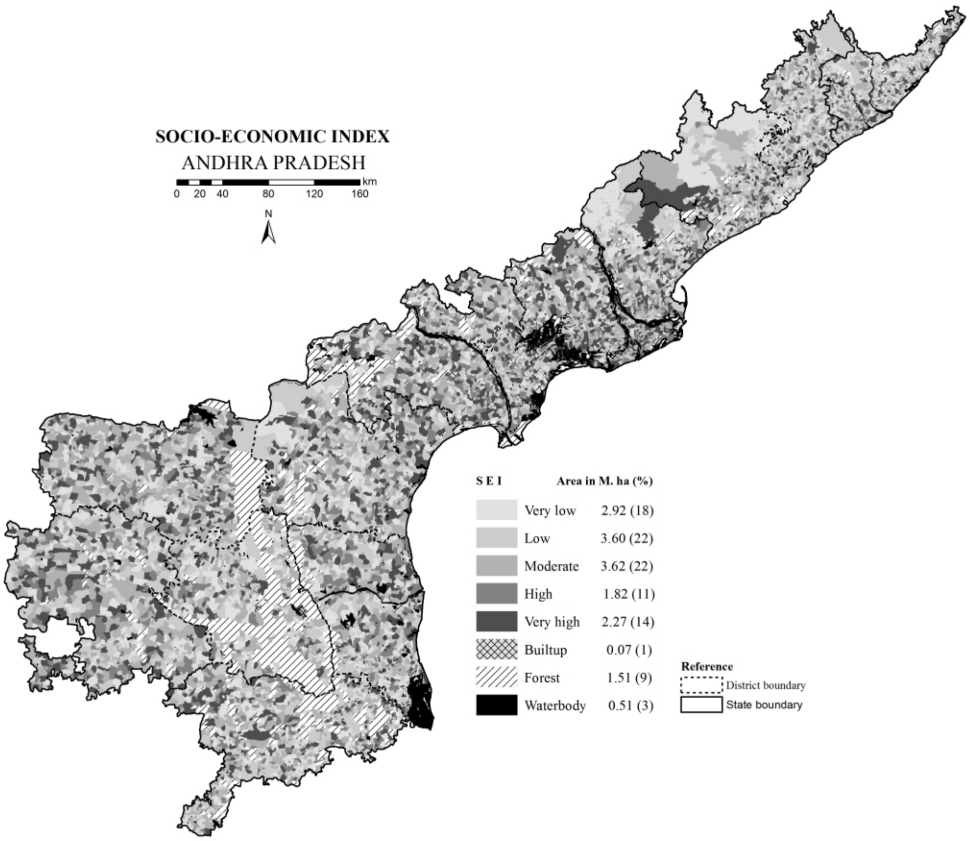

Fig. 1. Socio-economic index map in Andhra Pradesh

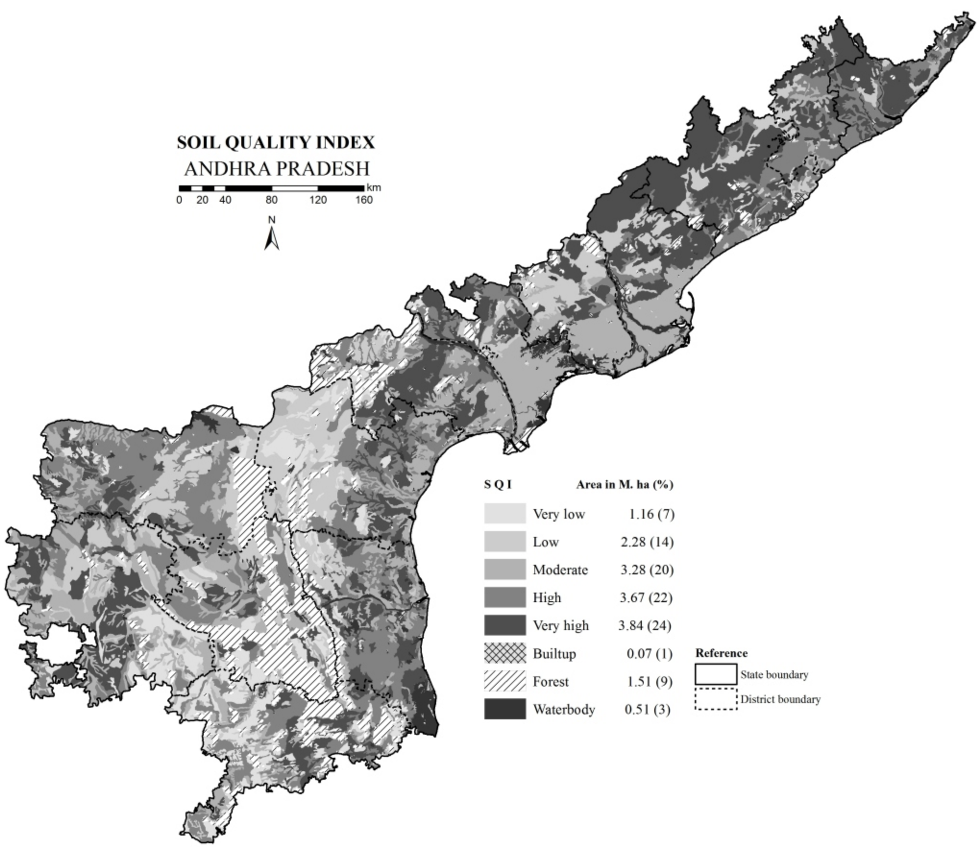

Fig. 2. Soil quality index map of Andhra Pradesh

tion coverage, the lands are exposed to water and wind erosion. Climate quality index was calculated based on aridity of the study area. The results revealed that 18.8% of total area of very poor climate qualities are highly vulnerable to desertification (Fig. 3). High and very high climate quality areas are occurring in Northern and coastal parts of Andhra Pradesh, and occupy 37% of total area.

Land utilization index (LUI)

For assessment of desertification vulnerability, LUI was used in place of land management quality index as adopted in MEDALUS model (Kosmas *et al*., 1999). LUI was calculated based on LCC and land use and classified into three LUI classes, namely, under-utilization, over-utilization, and optimal-utilization. The results (Fig. 4) revealed that 36.3% of lands were underutilized and10.3% of lands were over utilized.

Desertification and Land Degradation Vulnerability Index

The desertification and land degradation vulnerability index results (Fig. 5 and Table7) showed that 13.4% lands were classified as having a very high index. These lands are major priority lands that need immediate action to combat the desertification. About 15.1% of lands were classified as high, and 20.1% of lands were classified as moderate lands for DLD vulnerability.

The most vulnerable zones (very high vulnerability) to the desertification threat are located in southern part of the study area especially in Kurnool (4.03%), Anantapur (3.04%) and Cuddappa districts (1.22%). These areas are characterized by very low rainfall, high evapotranspiration and sandy soil. Dharumarajan *et al*. (2018b) reported that the area under desertification was higher in Anantapur district followed by Kurnool district based on desertification status mapping using high resolution satellite data. Kurnool experienced high forest vegetal degradation (5.1%) and Anantapur district has high water erosion (7.3%). DLD vulnerability index was also validated using desertification status atlas developed by ICAR-NBSS&LUP in collaboration with Space Application centre, Ahmadabad using Resource-Sat 2 AWiFS data (SAC, 2016). Desertification / land degradation process, severe category of water erosion, vegetal degradation and wind erosion classes were integrated with DLVI maps and the results revealed that the model performed well in identifying vulnerable areas in the state.

4. CONCLUSIONS

DLD vulnerability index map was prepared using multivariate analysis and classified into five DLD vulnerability classes. The results indicated that 13% of the Andhra Pradesh lands were very highly vulnerable to DLD and 15% of areas were highly vulnerable. The desertification vulnerability map preliminarily supports and helps local and national authorities who work for the protection of fragile landscapes. This map will facilitate the protection of valuable land resource by prioritising the region that needs intervention. This approach can be transferred for other semi-arid, arid, and sub-humid regions of the country to achieve the UNCCD goal of land degradation neutrality.

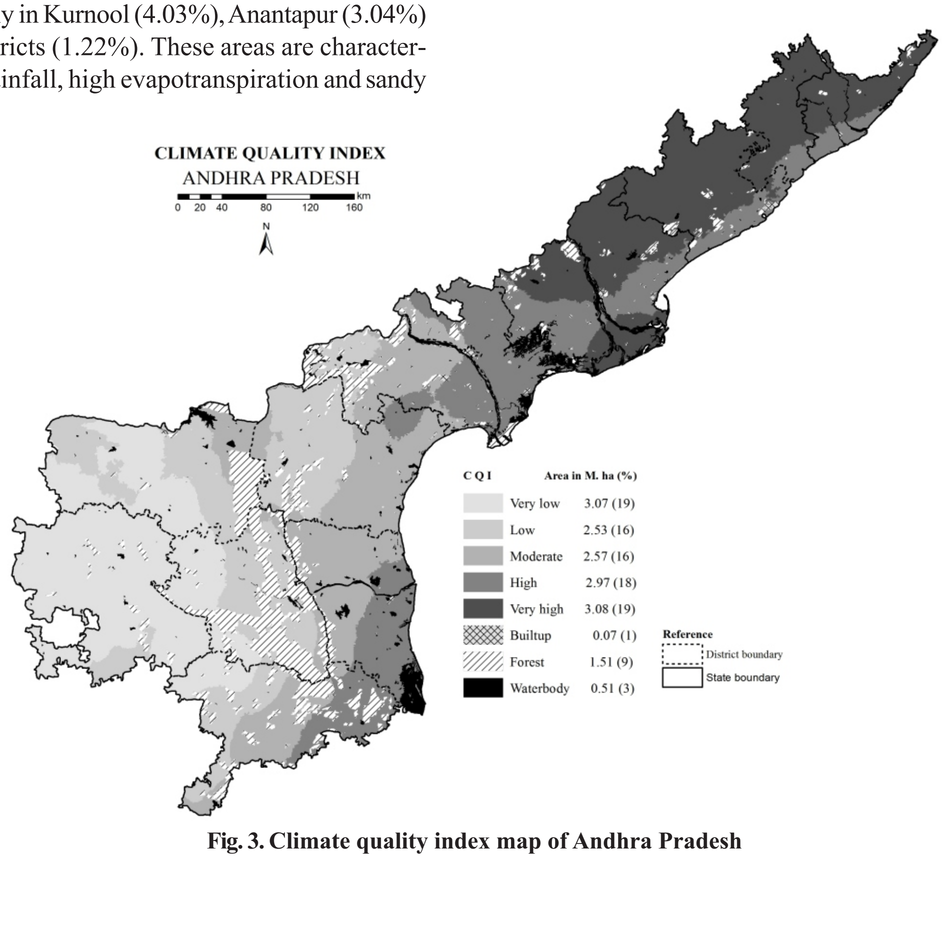

Fig. 3. Climate quality index map of Andhra Pradesh

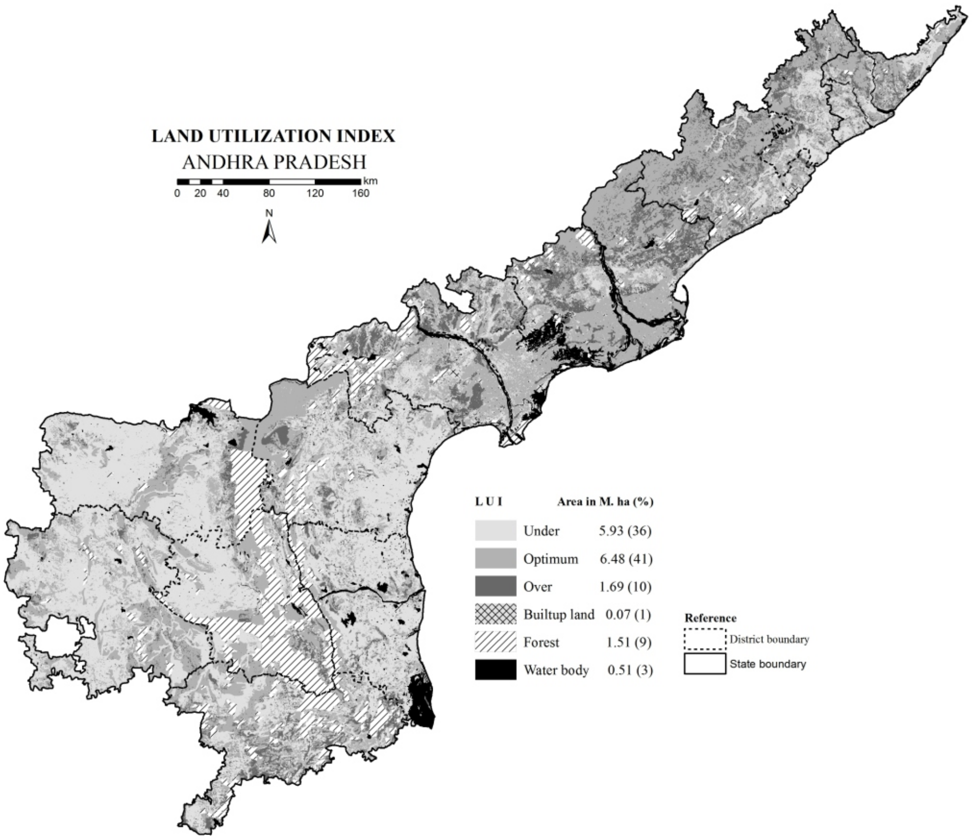

Fig. 4. Land utilization index map of Andhra Pradesh

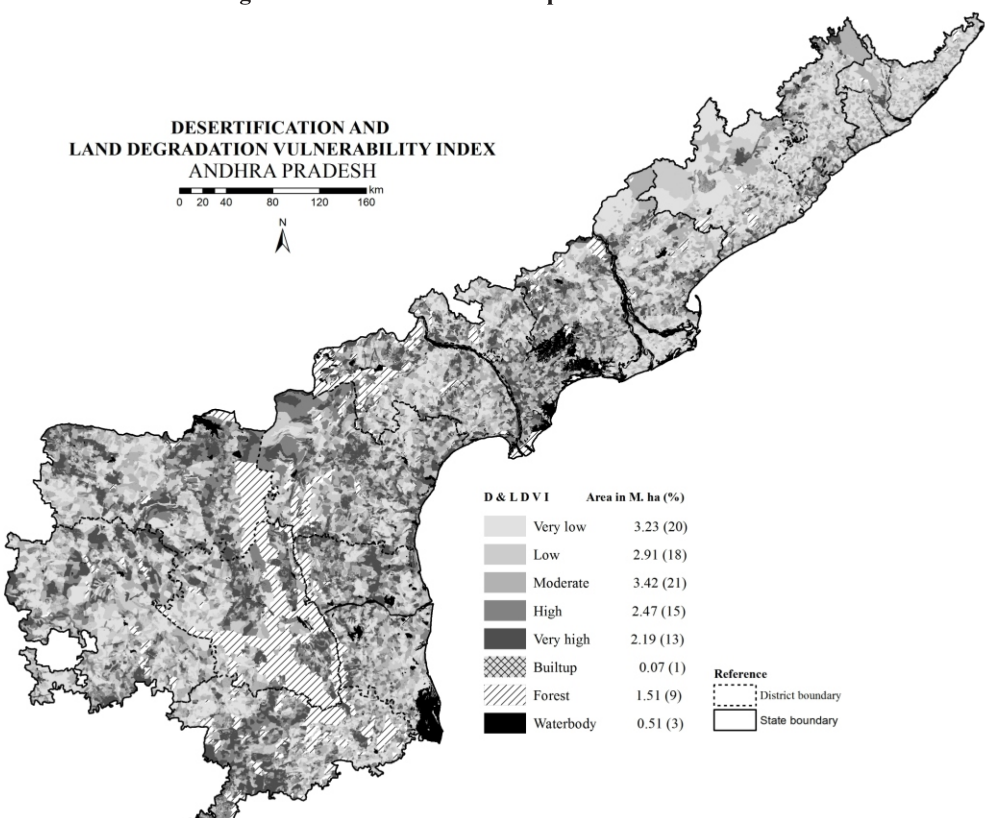

Fig. 5. Desertification and land degradation vulnerability index map of Andhra Pradesh

Table: 7
Areas under different severity of DLD vulnerability in Andhra Pradesh State, India

S.No.	Severity of DLD vulnerability	Area (M ha)	Area (%)
1.	Very low	3.23	19.7
2.	Low	2.91	17.8
3.	Moderate	3.42	20.0
4.	High	2.47	15.1
5.	Very high	2.19	13.4

REFERENCES

Bakr, N., Weindorf, D.C., Bahnassy M.H. and El-Badawi, M.M. 2012. Multi temporal assessment of land sensitivity to desertification in a fragile agro-ecosystem: Environmental indicators. *Ecol. Indi.,* 15: 271–280.

Barbier, E.B. and Hochard, J.P. 2016. Does Land Degradation Increase Poverty in Developing Countries?.*PloS One*, 11(5): e0152973, doi:10.1371/journal.pone.0152973.

Basso, F., Bove, E., Dumontet, S., Ferrara, A., Pisante, M., Quaranta, G. and Taberner, M. 2000. Evaluating environmental sensitivity at the basin scale through the use of geographic information systems and remote sensed data: an example covering the Agri basin (Southern Italy). *Catena,* 40(1):19–35.

Becerril-Piña, R., Díaz-Delgadoa, C., Mastachi-Loza, C.A. and González-Sosa, E. 2016. Integration of remote sensing techniques for monitoring desertification in Mexico. *Hum. Ecol. Risk. Assess*., 22(6): 1323–1340.

Census, 2011. House listing and housing census schedule. Government of India, Andhra Pradesh.

Dasgupta, A., Sastry, K.L.N., Dhinwa, P.S., Rathore, V.S. and Nathawat, M.S. 2013. Identifying desertification risk areas using fuzzy membership and geospatial technique –A case study, Kota district, Rajasthan. *J. Earth. Syst. Sci.,* 122: 1107–1124.

Dharumarajan, S., Lalitha, M., Natarajan, A., Naidu, L.G.K., Balasubramanian, R., Hegde, R., Vasundhara, R., Anil Kumar, K.S. and Singh, S.K. 2017. Biophysical and socio-economic causes for increasing fallow land in Tamil Nadu. *Soil Use Manage.*, 33: 487-498, doi: 10.1111/ sum.12361.

Dharumarajan, S., Bishop, T.F.A., Hegde, R. and Singh, S.K. 2018a. Desertification vulnerability index - an effective approach to assess desertification processes: A case study in Anantapur district, Andhra Pradesh, India. *Land. Degrad. Dev*., 29: 150-161, doi.org/10.1002/ ldr.2850.

Dharumarajan, S., Lalitha, M., Rajendra, Hegde, Janani, N., Rajavat, A.S., Sastry, K.L.N. and Singh, S.K. 2018b. Status of desertification in South India - Assessment, Mapping and Change detection analysis. *Curr. Sci*., 115: 331-338, doi: 10.18520/cs/v115/i2/331-338.

Gerber, N., Nkonya, E. and Von Braun, J. 2014. Land Degradation, Poverty and Marginality. In: von Braun J., Gatzweiler F. (eds.) Marginality. Springer, Dordrecht.

Imbrenda, V., D'Emilio, M., Lanfredi, M., Macchiato, M., Ragosta, M. and Simoniello, T. 2014. Indicators for the estimation of vulnerability to land degradation derived from soil compaction and vegetation cover. *Eur. J. Soil. Sci.,* 65: 907–923.

Kapović Solomun, M., Barger, N., Cerda, A., Keesstra, S. and Marković, M. 2018. Assessing land condition as a first step to achieving land degradation neutrality: A case study of the Republic of Srpska. *Environ. Sci. Pol.*, 90: 19-27, doi.org/10.1016/j.envsci.2018.09.014.

Keesstra, S., Mol, G., de Leeuw, J., Okx, J., de Cleen, M. and Visser, S. 2018. Soil-related sustainable development goals: four concepts to make land degradation neutrality and restoration work. *Land*, 7: 133.

Kelly, C., Ferrara, A., Wilson, G.A., Ripullone, F., Nolè, A., Harmer, N. and Salvati, L. 2015. Community resilience and land degradation in forest and shrub land socio-ecological systems: Evidence in Gorgoglione, Basilicata, Italy. *Land Use Policy*, 46: 11–20, doi.org/10.1016/j. landusepol.2015.01.026.

Kosmas, C., Ferrara, A., Briasouli, H. and Imeson, A. 1999. Methodology for mapping Environmentally Sensitive Areas (ESAs) to Desertification. In: C. Kosmas, M. Kirkby, N. Geeson (eds.), the MEDALUS project: Mediterranean desertification and land use Manual on key indicators of desertification and mapping environmentally sensitive areas to desertification, Brussels: European Union 18882, pp 31–47. ISBN: 92-828-6349-2.

Kosmas, C., Kairis, O., Karavitis, C. *et al.* 2014. Evaluation and Selection of Indicators for Land Degradation and Desertification Monitoring: Methodological Approach. Environ. *Manage.*, 54: 951, doi.org/10. 1007/s00267-013-0109-6.

Lalitha, M., Dharumarajan, S., Natarajan, A., Niranjana, K.V., Srinivas, S., Naidu, L.G.K. and Sarkar, D. 2016. Need for site specific land resource database for integrated watershed management. *Ind. J. Soil Cons.,* 44: 168-176.

Lamqadem, A.A., Saber, H. and Pradhan, B. 2018. Quantitative assessment of desertification in an arid oasis using remote sensing data and spectral index techniques. *Remote Sens*., 10: 1862, doi.org/10.3390/ rs10121862.

Mishra, P.K., Mandal, D., Math, S.K.N. and Sharda, V.N. 2018. Delineation of erosion risk areas in Andhra Pradesh and Telangana States of India. *Ind. J. Soil Cons.,* 46: 139-145.

NBSS&LUP. 1996. Soils of Andhra Pradesh for Optimising Land Use, NBSS Publ.69b, NBSS&LUP, Nagpur, India. ISBN:81-85460-36-1.

Petta, R.A., Ohara, T. and Medeiros, C.N. 2005. Desertification studies in the brazilian north-eastern areas with GIS database. In: Anais XII Simposio Brasilleiro de Sensoriamento Remoto, Florianopolis, Brasil, abril, 16–21, INPE, pp1053–1061.

SAC. 2016. Desertification and land degradation atlas of India (based on IRS AWiFS data of 2011-13 and 2003-05), Space Applications Centre, ISRO, Ahmedabad, India.

Salvati, L., Mancini, A., Roberta Gemmiti, B.S. and Carlucci, M. 2011. Socio-economic development and vulnerability to land degradation in Italy. *Reg. Environ. Change.,* 11: 767, doi.org/10.1007/s10113-011-0209-x.

Salvati, L. and Zitti M. 2008. Assessing the impact of ecological and economic factors on land degradation vulnerability through multiway analysis. *Ecol. Indi.,* 9: 357–363.

Symeonakis, E., Karathanasis, N., Koukoulas, S. and Panagopoulos, G. 2016. Monitoring sensitivity to land degradation and Desertification with the environmentally sensitive area index: the case of lesvos island. *Land. Degrad. Dev*., 27: 1562–1573, doi: 10.1002/ldr.2285.

UNCCD. 1994. United Nations Convention to Combat Desertification 1994-Elaboration of an international convention to combat desertification in countries experiencing serious drought and/ordesertification, particularly in Africa. U.N.Doc A/AC/241/27, 33I.L.M 1328.

Zomer, R.J, Trabucco, A., Bossio, D.A., van Straaten, O., Verchot, L.V. 2008. Climate Change Mitigation: A Spatial Analysis of Global Land Suitability for Clean Development Mechanism Afforestation and Reforestation. *Agric. Ecosyst. Environ.,* 126: 67-80.