LAND DEGRADATION VULNERABILITY ASSESSMENT

Concept, Methodology & Demonstration for Selected Areas in India using Geospatial Analysis

Space Applications Centre
Indian Space Research Organisation
Department of Space, Government of India

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Cover page: Front - Filed photo showing landscape of Arid region, in parts of Jaisalmer district, Rajasthan

Back - Agriculture practices on sand dunes, in parts of Bikaner district, Rajasthan

मंत्री
पर्यावरण, वन एवं जलवायु परिवर्तन
भारत सरकार

सत्यमेव जयते

भूपेन्द्र यादव
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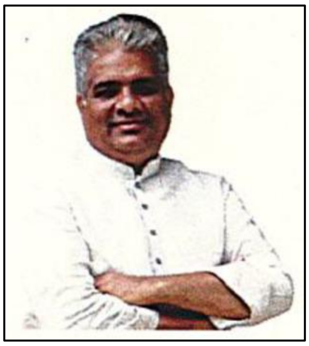
MESSAGE



Desertification, along with climate change and the loss of biodiversity are identified as the greatest challenges to sustainable development. Desertification threatens not only the productivity of land but also disturb the ecosystem, water quality, human health and the economy. Inappropriate land use and agricultural practices, deforestation, poor, indiscriminate mining, increasing urbanization are some of the major causes leading to loss of fertile agricultural and forest covered land. There is an urgent need for sustainable land management along with preparation and implementation of suitable action plans for restoration of land.

Ministry of Environment, Forest & Climate Change (MoEF&CC) is representing India in United Nations Convention on Combating Desertification (UNCCD) and is actively coordinating with all concerned Central and State Government Departments engaged in various scientific and technical issues related to combating desertification and land degradation. I am sure that these efforts shall help us in achieving country's land restoration targets.

I am happy to note that Space Applications Centre, ISRO has executed a project on Land Degradation Vulnerability Assessment, with development of methods and demonstration for selected districts across the country. The outcome is presented in the form of atlas titled "Land Degradation Vulnerability Assessment (Concept, Methodology & Demonstration for Selected Areas in India using Geospatial Analysis)". This is very comprehensive study and will be useful in understanding the dynamics of desertification and land degradation, especially for the people involved in land restoration activities and the policy makers.

I appreciate the efforts project team of Space Applications Centre, ISRO and all partner Central/State Government Departments and Academic Institutes in bringing out this Atlas. I am sure that it shall be extremely useful to planers involved in land restoration activities.

(Bhupender Yadav)

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सत्यमेव जयते

भारत सरकार
Government of India
अन्तरिक्ष विभाग
Department of Space

MESSAGE

Harnessing space technology for national development has always been the major focus of Indian Space Programme. Applications of space technology in monitoring and management of natural resources as well as for early warning assessment of natural disasters have been successfully demonstrated in our country in past few decades.

Desertification and land degradation is one of the major environmental concerns affecting earth ecosystem economy and lives. Accurate assessment of land degradation and understanding of its dynamics is very crucial for combating and prioritizing areas for restoration. Space Applications Centre (SAC) had been involved in various land degradation related studies including monitoring, vulnerability assessment and change analysis.

This atlas is an important reference for assessment of land degradation vulnerability considering variety of drivers and indicators of land degradation including climatic and human linked factors. I am sure that the geospatial database and the atlas will be of immense help to the Ministry of Environment, Forest & Climate Change (MoEF&CC) for India's reporting to United Nations Convention to Combat Desertification (UNCCD) and also to achieve country's commitment of land degradation neutrality and land restoration program.

I applaud the efforts of the project team comprising of SAC scientists and members from various collaborating agencies spread all across the country. I appreciate their remarkable contribution in bringing out this national atlas as a ready reference for policy makers, planners and researchers.

November 12, 2024 ***एस. सोमनाथ / S. Somanath***

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सत्यमेव जयते

PREFACE

India is endowed with a variety of landscape, soils, climate, bio-diversity and ecological regions. About 69 percent of the geographical area are dry lands (arid, semi-arid and dry sub-humid). With 2.4% of global land area, India is homeland to around 18% of global human population, 15% livestock population and supports more than 8% of world's agriculture. These conditions make large parts of the country vulnerable to desertification and land degradation and thus, a large part of our country's land is truly undergoing the process of desertification. There is an urgent need to arrest the process of desertification and restore land.

The roles of earth observation satellites data and geospatial technology are well recognized in various natural resource management applications, including land degradation. Space Applications Centre (SAC), ISRO, Ahmedabad, has been working on the land degradation related studies for more than two decades. I am happy to share with the readers that the outcome of a previously completed work was used as baseline data for India's land restoration program by Ministry of Environment, Forest and Climate Change (MoEF&CC) and was also reported to the United Nations Convention to Combat Desertification (UNCCD).

The present atlas showcases the use of remote sensing and geospatial techniques for Land Degradation Vulnerability Assessment, taking into account variety of drivers and factors affecting land degradation, viz. climatic & demographic factors, and biophysical parameters. This outcome will be extremely useful for identifying and prioritizing areas for land restoration. This atlas will also serve as a good reference for researchers and policy makers.

I appreciate the efforts made by the national project team members and congratulate them for their valuable contributions. I am sure that the project team will further work towards the utilization of newer and advanced technologies viz. Artificial Intelligence (AI) and Machine Learning (ML) in their near future studies.

11/11/2024

Place: Ahmedabad
Date: November 11, 2024

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Desertification is one of the major environmental concerns of today, affecting the living conditions of hundreds of millions of people across the world. This phenomenon is not confined to the desert areas or to the arid region alone, but also affects land and people beyond the boundary of desert and arid zones.

Space Applications Centre (SAC), in collaboration with partner organisations/institutions has carried out Land Degradation Vulnerability Assessment work using remote sensing data and geospatial analysis. The outcome is being published in the form of this atlas and is vety useful in understanding the conpexity of land degradation.

We would like to place on record our deep sense of gratitude to Shri S. Somanath, Secretary DOS and Chairman ISRO and Shri Nilesh Desai, Director, SAC for their encouragement and guidance in carrying out this national level project. The entire project team expresses deep gratitude for their full support and guidance.

We are grateful to officials of Ministry of Environment, Forest & Climate Change (MoEF&CC) for showing keen interest in this project.

I specially express my full appreciation for the contribution made by Shri Manish Parmar, Scientist, SAC in the development of the methodology, analysis of the results and preparation of this atlas. We extend our gratitude to all the collaborating agencies/institutes for their support in executing this project.

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EXECUTIVE SUMMARY

Land degradation is decline in productivity of land in terms of bio-diversity and economy, resulting from various reasons including climate and human dominance, leading to loss of ecosystem. It is an issue of global concern and threatens productivity of land, water, biodiversity, ecology, economy, and people. India, with 2.4% of global land area is homeland for around 18% of global human population and supporting more than 8% of world's agriculture with more than 69% area falling under drylands. The blend of high population, high agriculture production and diverse agro-climatic conditions result in excessive pressure on resources. This report presents Land Degradation Vulnerability Assessment (LDVA) by geospatial analysis of demographic, climate, soil, terrain data and satellite derived information. The parameters either effecting land degradation (directly or indirectly) or associated with the process of degradation of land are analysed independently to derive vulnerability index maps of individual parameters and further integrated together for the derivation of land degradation vulnerability map. IRS LISS3 satellite data was used to generating land use land cover and land degradation status maps. Three different methods viz. Indexing based method, Hierarchy based indexing method and Weighted hierarchy based indexing method are used to derive LDVA. Multi-level intermediate index maps are prepared by multivariate analysis and geospatial integration of input datasets. These methodologies are further demonstrated on selected 30 districts, covering all the states in the country. The outcome of each case is an indexed map, categorised into five classes of vulnerability, viz. Very high, High, Moderate, Low and Very low. The analysis and statistics indicate that districts falling into arid and semi-arid regions are showing large part of their area falling into high and moderate vulnerability index, viz. 95% area of Kachchh, Gujarat and 84% of Pali, Rajasthan. On the other hand for the districts falling into non dryland region, the large part of the area falls into low-very low vulnerability category viz. 84% area of Hailakandi, Assam and 66% area of North Goa, Goa. This outcome is useful for stakeholders in understanding the issues and for preparing action plans for combating land degradation.

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1. INTRODUCTION

Land can be referred to as terrestrial bio-productive system and Land Degradation means reduction or loss of biological or economic productivity of land. The term desertification is subset of land degradation, and referred as land degradation occurring in dryland regions (UNEP, 1992). The United Nations Convention to Combat Desertification (UNCCD) identifies desertification as one of the most challenging environmental concerns (UNCCD, 1994; UNCCD, 2002). Degradation may affect variety of land usage including cropland (rain-fed and irrigated), rangeland, pastureland, forest and woodlands. The degradation of land may result from factors including climatic variations or the chain of processes arising from human activities. Land degradation/desertification is an issue of increasing global concern and threatens productivity of land, water quality, biodiversity, ecology, economy, and living status of the people (UNCCD, 2017). Land degradation is temporary or permanent reduction in the efficiency of the land and its associated systems, which may result due to natural events and/or by anthropogenic activities (Parmar et al., 2021). There is an urgent need to stop and reverse the process of land degradation, and efforts at national and international levels are emerging to combat desertification and land degradation. Sustainable management of soil, water and human society are required for protecting the land from further degradation, which is an inherent and most important part of the ecology.

Drylands are the environmentally stressed areas with less rainfall and higher temperature variations and degradation of land in drylands is crucial, as majority of world's population and livestock is directly dependent on drylands. Drylands constitute 41.3% of the world landmass, 35% of the global population, 50% of world's livestock, 42% of the Earth's tropical and subtropical open or closed forests, house world's largest diversity of mammals and yet gross domestic production is 50% lower than in non-drylands (UNCCD, 2017). India, with 2.4% of global land area is homeland for around 18% of global human population (Census of India, 2011) and 30.4% livestock population and supports more than 8% of world's agriculture (FAO, 2019). More than 69% of the country's area falls under drylands. The blend of high population, high agriculture production and diverse agro-climatic conditions create a scenario of excessive pressure on land and raise the risk factor for degradation of land in India. Hence, monitoring of land degradation, understanding its dynamics and making efforts to control land degradation is very crucial for an agricultural driven economy like India. As per the atlas published by Space Applications Centre, Indian Space Research Organisation, 29.77% (96.85 Mha) area of the India was undergoing land degradation during 2018-19, and a cumulative increase of 1.45 Mha area is reported from 2011-13, which constitutes 0.44% area of country (SAC, 2021; SAC, 2016).

Land Degradation Vulnerability Assessment (LDVA) is essentially identification and quantification of pressure on land due to various parameters or factors affecting the quality of land system. The proximate causes of land degradation are demographic, climatic and biophysical parameters. There exist a complex relationship between land degradation, socio-economic development; changes in biophysical parameters and climatic variations (Sur & Chauhan, 2019). Thus, monitoring and assessment of land degradation requires a multilayered, multi-disciplinary approach along with the integration of datasets from multiple sources and methodologies. Identification of vulnerable areas along with associated issues are useful for policy makers for preparing strategies to arrest and combat land degradation (Dharumarajan, et al., 2017). Researchers have been using many approaches for assessment of land degradation and its vulnerability. MEDALUS methodology is one amongst commonly used methods for integration of various parameters affecting land degradation (Kosmas et al., 1999; Jafari & Bakhshandehmehr, 2013; Lahlaoi et al., 2017; Rabah & Aida, 2018). An indicator based approach had also been used taking into account the soil erosion, soil salinization, forest fire, water stress, overgrazing, etc., to understand the present state as well as the past trend for the assessment of land degradation (Kosmas et al, 2014). Multiway analysis and synthetic index based methods have also been used (Salvati & Zitti, 2009a; Salvati & Zitti, 2009b). Lamqadem et al., 2018 had used index based method to derive desertification sensitivity based on the quality indexing of Soil, Climate, Vegetation, and Management parameters. These methods have the drawbacks of equal levels and ranking, and researches have further used methods for defining hierarchy (Parmar et al., 2021) and weightages (Jafari & Bakhshandehmehr, 2013). Wu et al., 2018 used fuzzy analytical method and analytic hierarchy process to derive ecological vulnerability assessment in yellow river delta, China.

Further for combating land degradation, it is essential to recognize the linkages among climate, soil, water, land and socio-economic factors. The determinants such as agricultural development and urban sprawl plays prominent role but are still ambiguous and thus needs further studies. Based on the findings, it is possible to make strong policy responses to mitigate land degradation and thus reducing desertification risk (Salvati et al., 2009).

This report presents assessment of land degradation vulnerability by geospatial analysis of demographic, climate, soil, terrain data and satellite derived information. The parameters either effecting land degradation (directly or indirectly) or associated with the process of degradation of land are analysed independently to derive vulnerability index maps of individual parameters and further integrated together for the derivation of land degradation vulnerability map. Three different methods viz. Indexing based method, Hierarchy based indexing method and Weighted hierarchy based indexing method are used to derive LDVA. Multi-level intermediate index maps are prepared by multivariate analysis and geospatial integration of input datasets.

2. STUDY AREA

The study area for this work is selected 30 districts in India, as shown in figure-1.

India is the second most populated country in the world with 1.21 billion population and area wise is the seventh largest covering 328.72 million ha (Census of India, 2011). The country is also at first place with 512 million livestock population (Census Livestock, 2012). India is a developing country and stands as fifth largest economy by nominal gross domestic production.

Globally, India is the second largest producer of food and agricultural, with world’s largest cattle population, India ranks first in milk, jute and pulse production (FAO, 2019). India has the second-largest arable land area covering 1.53 billion hectare. As compared to United States or China, India’s geographical area is around one-third of these countries. However, the area of cultivable land in India is almost equal to that of the United States and China (World Bank, 2011).

India is covered with variety of land use and land covers; from evergreen forest to barren areas, cold/hot deserts to highly productive agriculture lands, glaciers to sand dunes, etc. Climate wise, there are areas witnessing very intense rainfall as well as areas with scarcity of rainfall, temperature in some of the area touches 50^0C in summer season and at some places the temperature is observed as low as -30^0C (IMD, 2019). The country also covers more than

8400 km long shoreline along the coast of Arabian sea on the west side and Bay of Bengal on the east side (Rajawat et al., 2015).

Considering the variation in climatic parameters, LULC, demography etc., a number of districts are chosen for demonstration of LDVA. The list of selected districts is shown in figure-1. These selected are well distributed across the country, falling into different agro-climatic zones, cover all the states in the country.

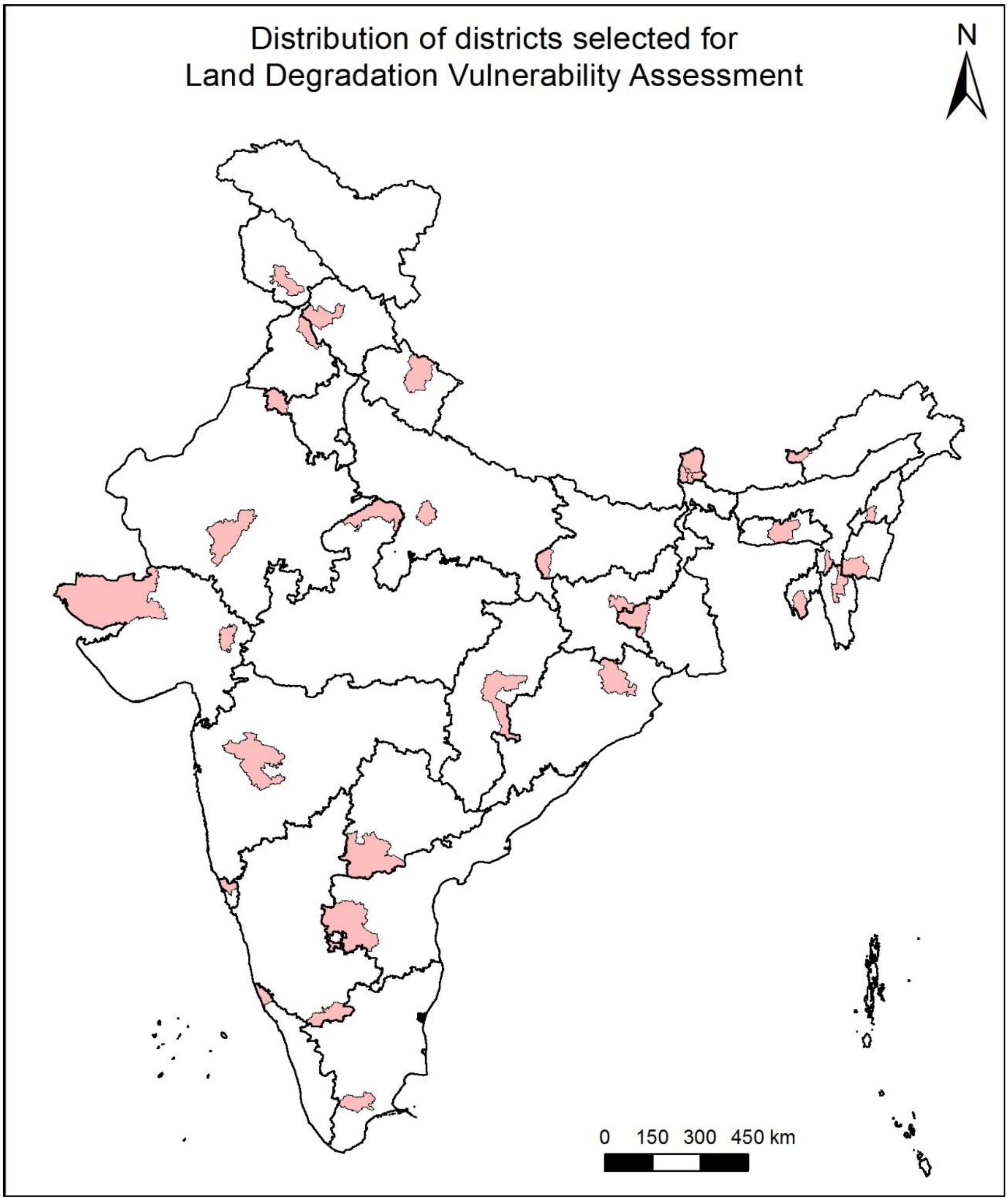


Figure-1: Study Area - distribution of study districts for LDVA

3. Data Used

The land degradation is a process linked with number of human related activities as well as climatic factors. The data and information from different sources have been collated as inputs to the analysis for LDVA and validation. Table-1 gives the list of data used in the study and their sources:

Table-1: Data used and their sources

S. No.	Data Used	Source
1	Demographic data, 2011	Census of India, 2011
2	Village shape file (1:50K scale), as per Census of India, 2011	• NRDB database, Space Applications Centre, ISRO, Ahmedabad (modified with respect to 2011 census village maps) • From respective collaborating agencies
3	Climate data – gridded rainfall ($0.25^{0)}$ and temperature (1^{0}) of period 1969-2013	Indian Meteorological Department
4	Land use land cover (2018-19) at 1:50K scale	prepared using IRS LISS3 data of timeframe 2018-19 and three seasons (kharif, rabi and summer)
5	Land degradation status map (2018-19) at 1:50K scale	prepared using IRS LISS3 data of timeframe 2018-19 and three seasons (kharif, rabi and summer) and other ancillary datasets
6	Soil map at 1:50k scale	From respective state center/ collaborating agencies

4. METHODOLOGY AND DATA ANALYSIS

Vulnerability assessment for land degradation is essentially identification and quantification of pressure on land due to various parameters or factors affecting the quality of land. The proximate causes of land degradation are demographic, climatic, biophysical and geological parameters. In this study, Land Degradation Vulnerability Assessment is attempted taking into account the input datasets, as listed under table-1, and further analysed to derive intermediate datasets and the final land degradation vulnerability map of respective district. The broad methodology is as given in figure-2.

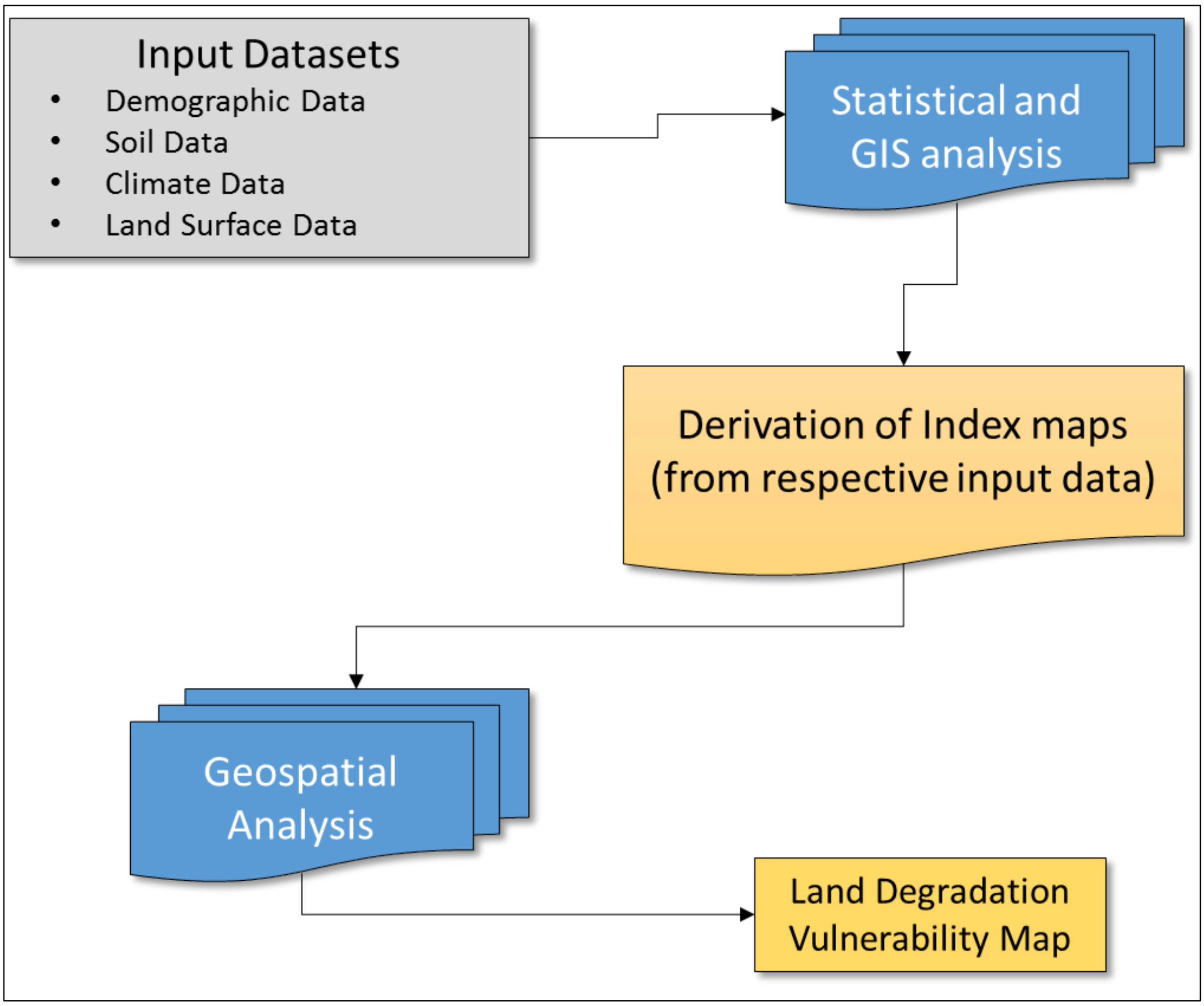


Figure -2: Broad methodology of land degradation vulnerability assessment

The scale/ resolution of input vector and raster datasets are different; however, the geospatial integration is carried out to get all the outputs uniformly at 1:50K scale. Year 2018-19 is considered as the timeframe for this analysis.

In the following sub-sections, the methodology of analysis of individual input datasets is explained for derivation of index maps. Further, the methodologies adopted for derivation of Land Degradation Vulnerability Assessment is discussed and explained. Three different methodologies for LDVA are explained in this report, viz. Indexing based method, Hierarchy based indexing method and Weighted hierarchy based indexing method. These methods are adopted and demonstrated for derivation of LDAV for 30 districts, covering all states of the country.

4.1. Analysis of demographic data:

It will be factual statement that one of the most significant contributors to the land degradation is anthropogenic activities, which can broadly be defined as the utilisation of natural resources for various purposes. Hence, the analysis of demographic data is pivotal for land degradation assessment. The category of demographic variables, which are likely to influence the land degradation processes, can be broadly classified into a) population, b) economy, and c) development. Each of these broad categories comprises of a set of well-defined variables, which influence land degradation processes in a unique manner.

Village level primary and secondary census-2011 data of selected district were downloaded from Census of India site www.censusindia.gov.in (Census of India, 2011). Corresponding vector layer of all the villages of the district was also prepared. The primary census data mainly contains the details of population distribution (total population, male/female distribution) and the distribution of workers (main workers, marginal workers, agriculture worker, and non-working). The secondary census data consist information about the availability of various developmental facilities and amenities, viz. education, medical, infrastructure, etc.

Three broad categories are set for analysis of demographic data and the set of variables selected under each category are listed in table-2. Table-3 depicts the hypothesis about the variable and its impact on Land degradation.

Table-2: Demographic data categories and variable

	Demographic Data Category		
	Population	**Economy**	**Development**
Variable	Population density	Working population	Education
	Literacy	Marginal worker	Medical
		Agricultural laborers	Transportation
		Non-working population	Communication

Table-3: Hypotheses about the variable and its impact of Land degradation/ desertification

Variable	Hypothesis
Population	High population growth/ density area are more vulnerable
Literacy	Low literacy areas are more vulnerable
Non-working population	High population of non-workers are more vulnerable
Availability of amenities (education Medical, etc.)	Areas with availability of good education, medical facilities and infrastructure tends to low vulnerability.

Using the primary and secondary census datasets, four maps were produced using statistical methods, i.e. Population density Index Map, Population literacy Index Map, Economic Index Map and Social Development Index Map.

4.1.1. Population Density Index (PDI) Map:

The Population Density Index (PDI) map was derived using population density (PD) (person / sq km) of all villages and further indexed in five classes of vulnerability, as per the details given in table-4.

Table-4: Population Density and corresponding vulnerability class

S. No.	Population Density (persons/ sqkm)	Vulnerability Class
1	< 100	Very Low
2	101-250	Low
3	251-500	Moderate
4	501-1000	High
5	>1000	Very High

4.1.2. Population Literacy Index (PLI) Map:

The percentage population for each village was calculated from literacy data given in primary census data and further the indexing of the vulnerability was carried out in five classes, as per the details given in table-5.

Table-5: Population literacy and corresponding vulnerability class

S. No.	Population Literacy (%)	Vulnerability Class
1	80 - 100	Very Low
2	60 - 80	Low
3	40 - 60	Moderate
4	20 - 40	High
5	0 - 20	Very High

4.1.3. Economic Development Index (EDI) map

Economic development and linked activities are one of the major drivers for land degradation (Salvati et al., 2011). The economic development of human settlement is directly linked with the employment status of the population; hence, the workmanship population distribution as available in primary census data was used and EDI was derived using equation-1:

$$EDI = \sqrt[2]{PD * W * (1 - A)} \quad \text{......(1)}$$

Where PD is population density, W is proportion of employed population (working population/ total population) and A is the proportion of unskilled workers ((unemployed + agricultural laborers + marginal workers) / total population). Further, the indexing of the outcome is done using mean (μ) and standard deviation (σ), as shown in table-6.

Table-6: Indexing method for vulnerability

Class Range	Vulnerability Index
< (μ - 2σ)	Very low
(μ - 2σ) to (μ - σ)	Low
(μ - σ) to (μ + σ)	Moderate
(μ + σ) to (μ + 2σ)	High
> (μ + 2σ)	Very High

4.1.4. Social Development Index (SDI) Map

The Social development index was derived following the probability of occurrence of the individual services (viz. education, medical, infrastructure) and later adding them to arrive at the composite Social Development Index. The multi-variate weighted Index based statistical method was used. Three steps involved in the derivation of SDI a) Normalization of the variables b) Calculation of indices for each sub-variable and finally c) composite SDI. Following are the list of variables and corresponding sub-variable used for analysis:

a. Education – pre-primary, primary, secondary, college, etc.
b. Medical – community health center, primary health center, hospitals, dispensary, etc.
c. Transportation –bus services, rail services, road connectivity, rail connectivity, etc.
d. Communication – post office, telephone, mobile, internet, etc.

Normalization of variable: Normalization of the data is carried out for all the sub-variables based on the availability; 1 (facility available) and 0 (facility not available)

Calculation of index for sub-variable:

$$\mathrm{Ic} = \sum_{i=0}^{n}(\mathrm{Ai} * \mathrm{Wi}) \,/\, \Sigma\mathrm{Wi} \quad \text{.....(2)}$$

Where i = 1 to n, n = number of categories under facility, Ic = Index for a particular sub-variable, Ai = 0 or 1 (0 = facility not available, 1 = facility available); Wi = Weight of the sub-variable within a category and is defined as

$$\mathrm{Wi} = (\mathrm{N}-\mathrm{Fi})/\mathrm{N}*100 \quad \text{.....(3)}$$

Where, N = Total number of villages; Fi = Number of villages without the particular facility

Social Development Index:

$$\mathrm{SDI} = \sum_{c=1}^{m} Ic \quad \text{.....(4)}$$

Further, the indexing of the outcome of the SDI is done following the criteria given in table-4.

4.1.5. Socio-Economic Index (SEI) Map:

The Socio-Economic Index (SEI) map was generated by spatial integration of PDI, PLI, EDI and SDI maps in GIS environment and the index value was derived by the averaging of index values of PDI, PLI, EDI and SDI maps.

4.2. Analysis of Climate data:

The terrestrial conditions (vegetation, water, soil, etc.) of an area indirectly indicate the climatic conditions and vice-versa. Hence, analysis of long term climate data would be an informative input for assessment of land degradation. Thus, in this study time-series rainfall and temperature datasets from Indian Meteorological Department (IMD) were used for analysis. The gridded rainfall dataset at a spatial resolution 0.25° × 0.25° (Pai et al., 2015) and gridded temperature data at 1° × 1° (Srivastava et al., 2009) of period 1969 to 2011 analysed to generate Aridity Index (AI) Map of the study area. The aridity Index was derived using De Martonne method (Martonne, 1920; Coscarelli et al., 2004).

$$AI = P / (T+10) \quad (5)$$

Where P is the total annual rainfall (cm) and T is average annual temperature (°C)

The output, Climate Index (CI) map is further classified into five categories of climatic zones (Croitoru et al., 2012; Pellicone et al., 2019) as given in table-7 and it was further assigned with vulnerability index, considering the fact that dryer areas are more vulnerable to land degradation.

Table-7: Classification for climate index map.

Aridity Index Class	Range of Aridity Index	Vulnerability Index
Arid	AI <10.0	Very High
Semi-arid	10.0≤ AI <20.0	High
Mediterranean	20.0≤ AI <24.0	Moderate
Semi-humid – Humid	24.0≤ AI <35.0	Low
Very - Extremely humid	AI >35.0	Very low

4.3. Analysis of satellite data:

Satellite data of three agricultural seasons (Kharif, Rabi and Zaid) were used for preparation of Land Use Land Cover (LULC) map and Land Degradation Status (LDS) Map by onscreen visual interpretation using ArcGIS. Both the maps were prepared at an output scale of 1:50,000, with WGS-84 datum and WGS_1984_Lambert_Conformal_Conic projection. Figure-3 below shows the Kanpur Dehat district of Uttar Pradesh, on three season coverage with IRS LISS3 satellite data. As seen in the image, coverage in multiple season helps in identifying various classes of LULC and LDS maps.

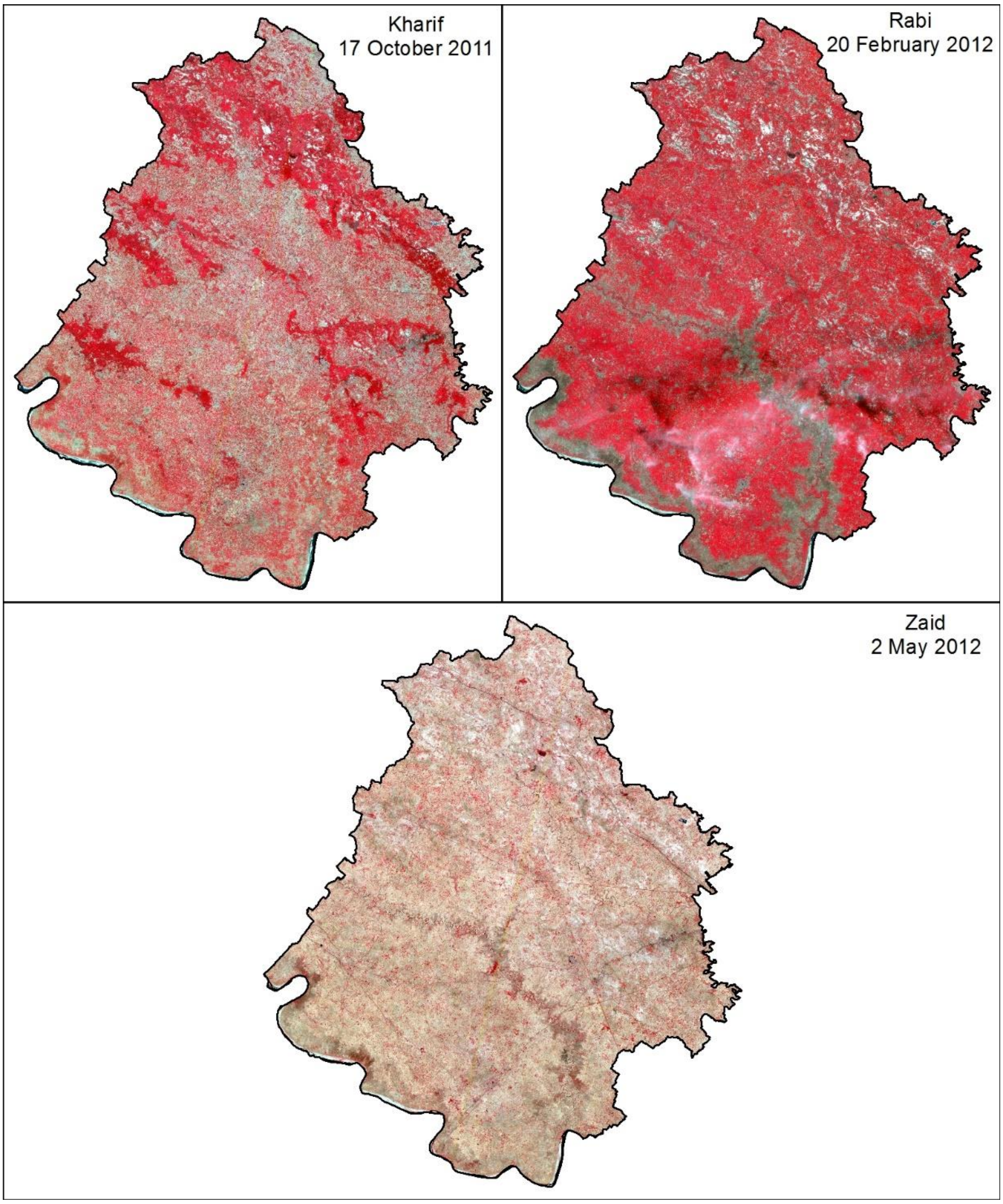


Figure-3 – Kanpur Dehat district, Uttar Pradesh as seen on multiple season IRS LISS3 data

4.3.1. Land Use Land Cover Map:

The study areas were classified in Land Use Land Cover (LULC) classes using level-1 classification system. Forest, Agriculture land, Scrub land, Waste land, Built-up and Water bodies are the classes delineated. Moreover, the forest and agriculture areas were further classified at Level-3 classification system, covering Dense Forest, Open Forest, Scrub forest, double/triple crop, single crop, fallow land classes. The output was further utilised for deriving land use index map and the land utilisation map. The land utilisation map was derived by geospatial integration of LULC map and Land Capability Map. Land capability is available in soil map as one of the attributes information.

4.3.2. Land Degradation Status Map:

Along with satellite datasets, the other information viz. terrain, climate, soil, LULC were also used/considered in the background for preparing Land Degradation Status (LDS) map. The classification system used for preparation of LDS map is given in table-8 (Ajai et al. 2009; SAC 2016; SAC 2018a; SAC 2018b).

Table-8: Classification system for land degradation status mapping

Level-1: Land Use		**Level-2: Process of Desertification**		**Level-3: Severity**	
Agriculture irrigated	I	**vegetation degradation**	**v**	Slight	1
Agriculture unirrigated	D	water erosion	w	Moderate	2
Forest / Plantation	**F**	wind erosion	e	**Severe**	**3**
Grassland / Grazing land	G	salinity / alkalinity	s/a		
Land with scrub	S	water logging	l		
Barren	B	mass movement	g		
Rocky area	R	frost heaving	h		
Dune / Sandy area	E	frost shattering	f		
Glacial	C	man made	m		
Periglacial	L				
Others	T				

Based on the combination of land use, process of land degradation and severity level, the final map output was indexed into five classes of vulnerability, viz. Very low, Low, Moderate, High and Very High. Indexing is done on the basis of the of land use/cover and vulnerability towards land degradation; Process of land degradation along with the severity level. Expert opinion was taken into consideration while indexing the map.

4.4. Analysis of Soil data:

Soil is again one of the major factors of land degradation and the composition of soil determines various dependent parameters and processes such as vegetation, Erosivity, land capability, etc. In this study, various soil properties, viz. Soil Depth, pH, Soil Erosion, Soil Drainage and Soil Texture, are taken into consideration and further indexed with respect to vulnerability towards land degradation. The table-9 gives the details about the indexing of soil properties.

Table-9: Indexing of soil properties with respect to vulnerability to land degradation

Soil Property	Classes within Soil Property	Range/ Category	Vulnerability Class
Soil depth (cm)	Very Shallow	<25	Very High
	Shallow	25-50	High
	Slightly Shallow	50-75	Moderate
	Moderately Deep	75-100	Low
	Deep	>100	Very Low
pH	Extremely Acidic	<4.5	Very High
	Very Strongly Acidic	4.5-5.0	Very High
	Strongly Alkaline	>8.5	Very High
	Strongly acidic	5.1-5.5	High
	Moderately acidic	5.6-6.0	Moderate
	Slightly acidic	6.1-6.5	Low
	Neutral	6.6-7.5	Very Low
	Slightly Alkaline	7.6-8.4	Very Low
Soil Erosion	Slight	e1	Very Low
	Moderate	e2	Low
	Severe	e2-e3	Moderate
	Very Severe	e3	High
	Extremely severe	e4	Very High
Soil drainage	Well	Very Good	Very Low
	Moderately Well	Good	Low
	Well to Excessive	Moderate	Low
	Excessive	Poor	Moderate
	Imperfectly well	Poor	Moderate
	Poorly Drained	Very Poor	High
	Very Poorly Drained	Very Poor	Very High
Texture	Clay Loam, Loam, Loam to Silty Loam, Loam to Clay Loam, Sandy Clay Loam to Clay Loam, Loam, Fine Silty, Fine Loamy	Very Good	Very Low
	Sandy Clay Loam to Clay, Sandy Loam to Sandy Clay Loam ,fine, coarse loamy	Good	Low

Soil Property	Classes within Soil Property	Range/ Category	Vulnerability Class
	Sandy Loam to Clay, Sandy Clay, clayey skeletal, Clayey, Coarse silty	Moderate	Moderate
	Sandy Loam, Gravelly Clay Loam, Gravelly Loam	Poor	High
	Gravelly, Loamy Sand to Gravelly Loamy Sand, Loamy Very Fine Sand to Sand, Loamy Sand, Sand, Loamy Sand to Sandy Loam, Gravelly Sandy Loam, sandy skeletal	Very Poor	Very High

4.5. Vegetation Index Map:

The land cover is a critical component to arrest or support land degradation. The type of vegetation cover is an important factor for protection against erosion, resistance to drought, etc. Following this, the land use land cover classes are classified into five categories with respect to their vulnerability against land degradation, as shown in below table:

Table-10: Criteria for Land Use Index Map

S. No.	LULC	Vulnerability
1	Dense forest, double/triple crop	1
2	Open forest, single crop, grass land, plantation	2
3	Fallow land, scrub forest	3
4	scrub land	4
5	Barren land, waste land, sandy dune area	5

4.6. Land Utilisation Map:

Land capability is the ability of land to support a particular type of use without causing permanent damage (Wells, 1989). Land capability indirectly represents the health of the soil/land taking into account the physical parameters as well as the chemical properties of the soil. Capability classes range from Class I soils, which have very few limitations for agriculture, to Class VIII soils, which are unsuitable for agriculture practices. Land utilization indicates the load the land with reference to the current LULC practices and its capability.

In this study, Land Utilisation Index (LUI) is derived by comparing the Land Capability Class (LCC) and corresponding LULC practice, following the details given in table-11 (NWASCO, 1979). LCC is available as one of the attributes information in soil map. The LUI map is derived through the geospatial integration of land capability map and LULC map of the study area. The output was classified into three land utilisation indices, viz. under-utilized, optimally-utilized and over-utilized. The under-utilized lands have low vulnerability to degradation and have potential to increase the vegetation biomass over the land by means of afforestation or increasing frequency of agriculture. Whereas, optimal and over utilised land are already under pressure and possess high degree of vulnerability to land degradation.

Table-11: Land Capability Class and corresponding cropping and land use suitability (adapted from NWASCO, 1979)

Land Capability Class	Cropping Suitability	Land Use Options
I	High	Many (Agriculture, forest, grazing land)
II		
III		
IV	Medium	
V	Low	Limited (forest, grazing land)
VI	Not Suitable	
VII		Extremely Limited (forest)
VIII		

4.7. Land Degradation Vulnerability map

The land degradation vulnerability map was derived by geospatial integration of Socio-economic Index maps, Climate Index map, Soil Index map, Desertification Index map, Land Utilisation index map, etc.

Three different types of methodologies have been used for the integration of aforementioned index maps and derivation of LDVA map. The selection of methodology depends upon the availability of input datasets and complexity of the study area.

The final output is a map classified into five vulnerability classes, viz. Very low, Low, Moderate, High, Very High vulnerable. The following subsections provide details about the methodologies used for LDVA.

4.7.1. Indexing based method

The indexing based method is based on simple geo-spatial integration of all the input layers. All inputs layers are prepared following the procedure explained in sections 4.1 to 4.6. In case of non-availability of one or more input datasets, the integration still can be carried out with limited available datasets in this method. However, the more and detailed availability of input datasets increases the accuracy of outcome. The LDV map is derived by averaging the index values of all input layers. The methodology is as shown in figure-4.

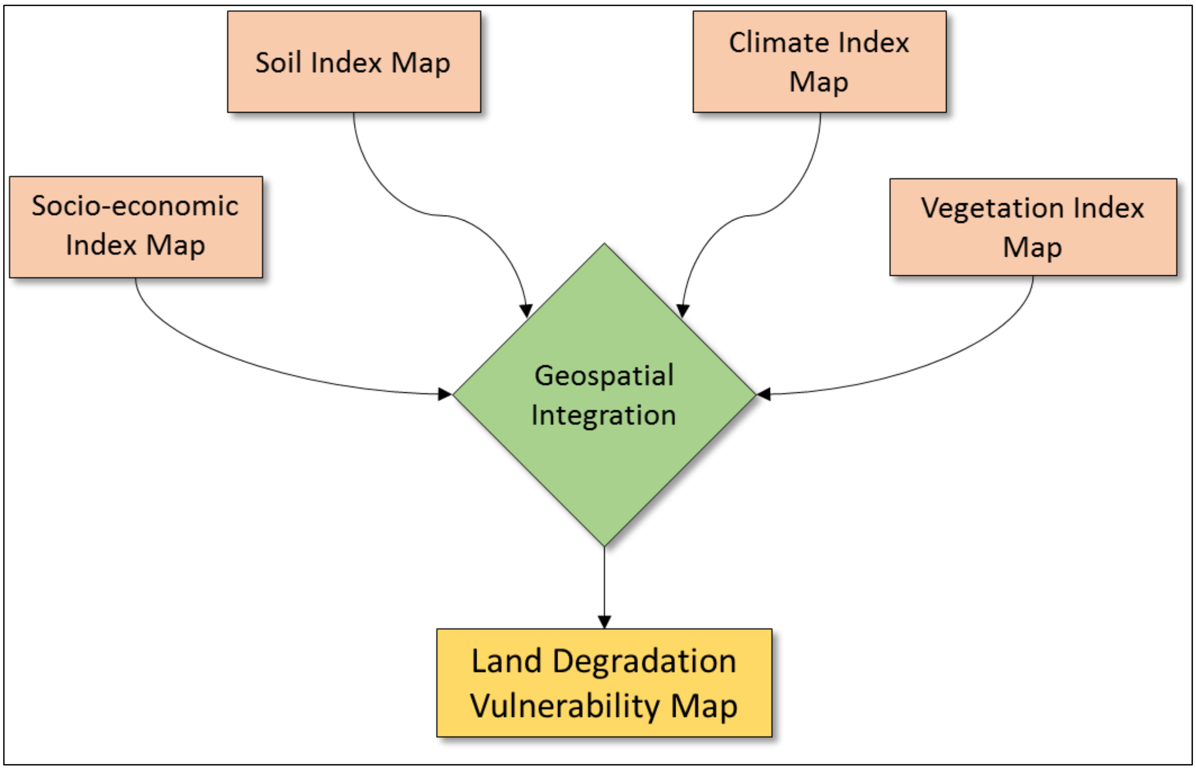


Figure -4: Indexing based methodology for land degradation vulnerability assessment

4.7.2. Hierarchy based indexing method

The Hierarchy based indexing method is essentially a modified version of the indexing method, where a four level hierarchy is prepared comprising all the input layers. Land degradation status and land utilisation maps are the additional datasets considered as input/intermediate datasets in this method. The geospatial integration at each level of the hierarchy is carried out to derive/ generate next level of information (Parmar et al., 2021). Availability of all input datasets is a must for this methodology. The flow of methodology is shown in figure-5 below.

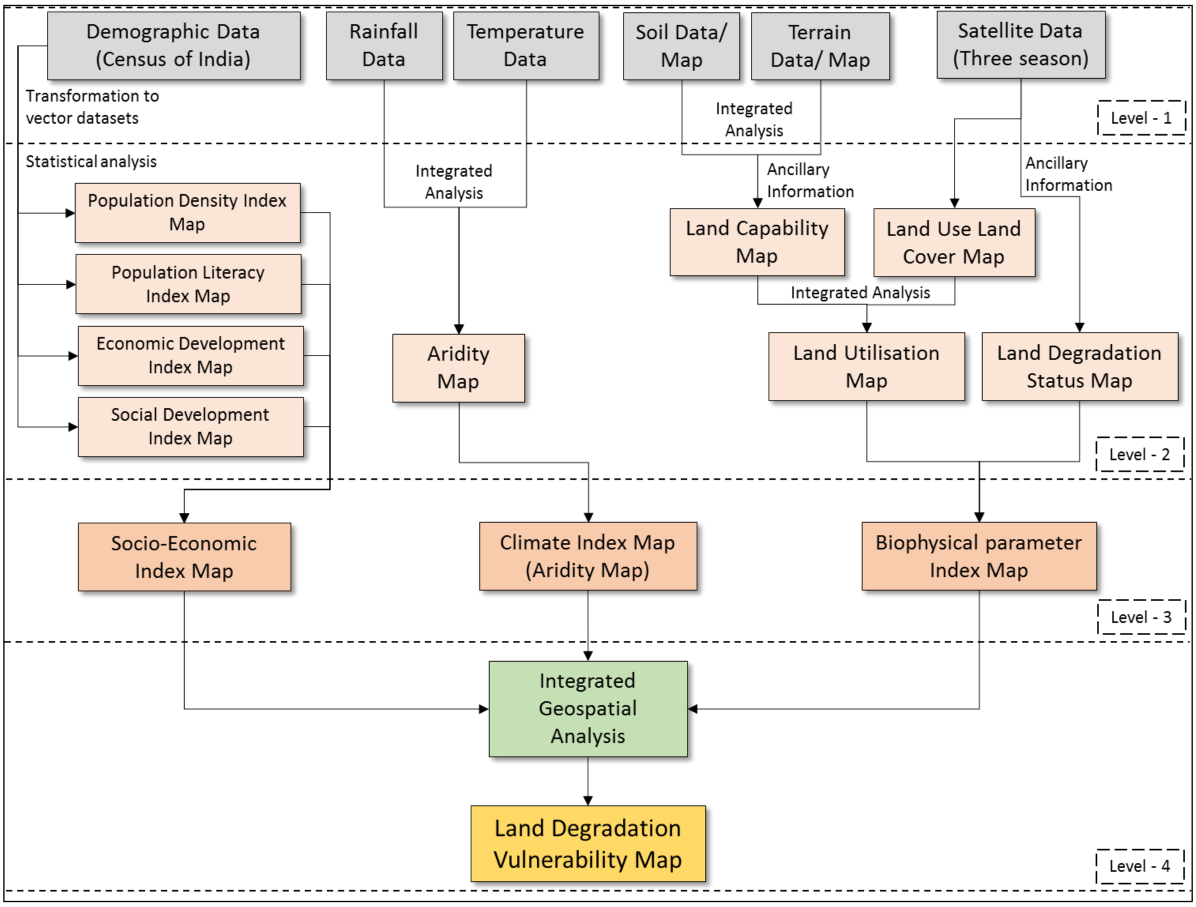


Figure-5: Hierarchy based Indexing methodology for land degradation vulnerability assessment

4.7.3. Weighted hierarchy based indexing method

The weighted hierarchy based indexing method is extended version of the hierarchy based Indexing method, with an addition of assigning weightages at each integration step. The weightages are calculated based on the fuzzy analytical hierarchy process. The hierarchy followed in this method is same as shown in fugure-5. The process of assigning weightages at each level is depicted in figure-6 and further explained in detail.

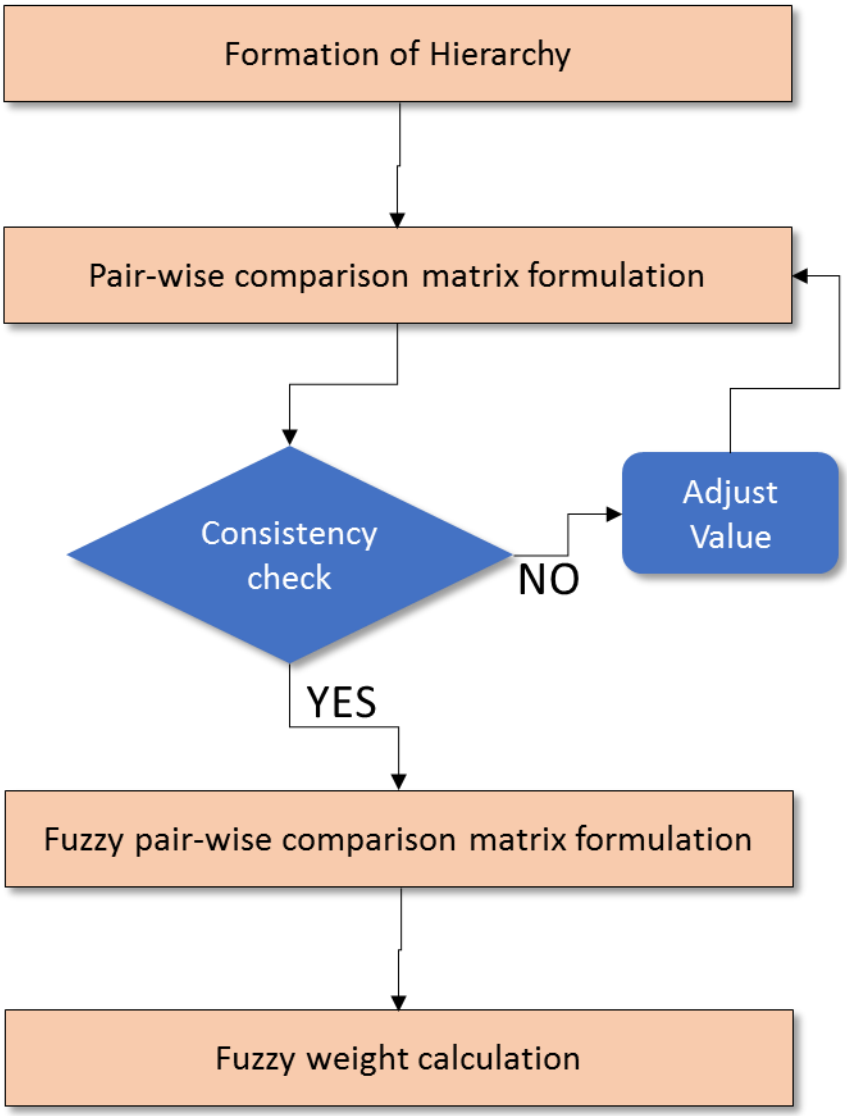


Figure-6: process of assigning weightage in analytical hierarchy based method

Step-1: Formation of hierarchy:

Formation of the Hierarchy tree is decomposition of the problem to be solved in the hierarchical structure, which is indeed the process of conventional AHP. The hierarchy followed is shown in figure-5.

Step-2: Comparison matrix:

Preparation of pair-wise comparison matrix is based on the user's judgments on the basis of relative impacts, or the priorities of elements (e.g., criteria, alternatives) in the hierarchy. Each input layer in the level of hierarchy is compared pair-wise in comparison matrix as shown below:

$$A = \begin{pmatrix} 1 & \frac{W1}{W2} & \ldots.. & \frac{W1}{Wn} \\ \frac{W2}{W1} & 1 & \ldots.. & \frac{W2}{Wn} \\ \frac{W3}{W1} & \frac{W3}{W1} & \ldots.. & 1 \end{pmatrix}$$

This pair- wise comparison judgment is given with the help of saaty's semantic scale, as given in table-12 (Saaty, 1980).

Table-12: pair- wise comparison judgment

Preference expressed in numerical variables	**Preference expressed in linguistic variables**
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values between adjacent scale values

Step-3: Consistency check:

checking of the consistency of the judgment of the users is carried out as follows:

$$CI = \frac{\lambda max - n}{n - 1}$$

Where, λmax is the biggest Eigen value of matrix and N is the size of the matrix

$$CR = \frac{CI}{RI}$$

Where CR is the consistency ratio and RI is random index. Now, If the CR is less than 0.1, then the judgment is taken as consistent. And If not, readjustment in the judgment is carried out and rechecking of the consistency.

Step-4: Formation of fuzzy triangular matrix and weight calculation:

Now, once the consistency check is through, the conventional AHP matrix is reformed into the fuzzy triangular matrix on the basis of semantic scale (Pei et al., 2015), as shown in table-13 below:

Table-13: Importance values setting of pairwise comparison for fuzzy analytic hierarchy process

Linguistic scale of importance	AHP number scale	Triangular fuzzy scale	Reciprocal triangular fuzzy numbers
Just equal	1	(1,1,1)	(1,1,1)
Equal importance	1	(1/2,1,3/2)	(2/3,1,2)
Moderate importance	3	(1,3/2,2)	(1/2,2/3,1)
Strong importance	5	(3/2,2,5/2)	(2/5,1/2,2/3)
Very strong importance	7	(2,5/2,3)	(1/3,2/5,1/2)
Extreme importance	9	(5/2,3,7/2)	(2/7,1/3,2/5)

The importance value of indicator i compared to indicator j could be assumed as (l_{ij}, m_{ij}, u_{ij}), where l, m, u are the abscissa values of the fuzzy trigonometric function. Conversely, the importance value of indicator j compared to indicator i could be set as ($1/u_{ij}$, $1/m_{ij}$, $1/l_{ij}$) (Table 13). Further, the fuzzy cumulative extension value of i (Mg_i), which represented the importance of indicator i compared to all indicators, is calculated using the following equation. (Wu et al., 2018)

$$M_{g_i} = (l_{i1} + l_{i2} + \cdots + l_{in},\ m_{i1} + m_{i2} + \cdots + m_{in},\ u_{i1} + u_{i2} + \cdots + u_{in}) = \left(\sum_{\alpha=1}^{n} l_{i\alpha},\ \sum_{\alpha=1}^{n} m_{i\alpha},\ \sum_{\alpha=1}^{n} u_{i\alpha} \right)$$

Then, the fuzzy cumulative extension value of pairwise comparison matrix could be gained as follows:

$$\sum_{i=1}^{n} \sum_{\alpha=1}^{n} M_g = \left(\sum_{i=1}^{n} \sum_{\alpha=1}^{n} l_{i\alpha},\ \sum_{i=1}^{n} \sum_{\alpha=1}^{n} m_{i\alpha},\ \sum_{i=1}^{n} \sum_{\alpha=1}^{n} u_{i\alpha} \right)$$

Also, the fuzzy synthetic extension value of i (Si), which represented the synthetic importance proportion of indicator i in the matrix, is be calculated using the following equation

$$S_i = M_{g_i} \times \left[\sum_{i=1}^{n} \sum_{\alpha=1}^{n} M_g \right]^{-1} = (l_i,\ m_i,\ u_i)$$

where n is the indicator number. For S_i & S_j, their comparison value could be expressed as

$$V(S_i \geq S_j) = hgt(S_i \cap S_j) = \mu_{S_i}(a) = \begin{cases} 1, & m_i \geq m_j \\ 0, & l_j \geq u_i \\ \frac{l_j - u_i}{(m_i - u_i) - (m_j - l_j)}, & others \end{cases}$$

The di′ and w′ were the transitional value and matrix:

$$d_i' = min(V(S_i \geq S_k)),\ i \neq k,\ k = 1,\ 2, \cdots n w' = (d_1', d_2', \cdots, d_n')^T$$

The weight matrix w was generated by standardizing w′:

$$w = (d_1, d_2, \cdots, d_n)^T$$

In these calculation processes, comparison matrix standardization is necessary, while the phenomenon V(Si >= Sk) = 0 might appear frequently, which would make the result unreasonable.

The above listed three methods have been applied on the LDVA analysis of selected districts, based on the availability of the data. The table below gives district wise details of the method used:

Table-14: District wise list of the methods used for LDVA

S. No.	State	District	Method
1	Andhra Pradesh	Anantapur	Hierarchy based indexing method
2	Arunachal Pradesh	Tawang	Indexing based method
3	Assam	Hailakandi	Hierarchy based indexing method
4	Bihar	Bhabua	Indexing based method
5	Chhattisgarh	Raipur	Hierarchy based indexing method
6	Goa	North Goa	Indexing based method
7	Gujarat	Kachchh	Weighted hierarchy based indexing method
8	Gujarat	Panch Mahals	Indexing based method
9	Himachal Pradesh	Kangra	Indexing based method
10	Haryana	Sirsa	Indexing based method

S. No.	State	District	Method
11	Jharkhand	Bokaro	Hierarchy based indexing method
12	Jammu & Kashmir	Udhampur	Hierarchy based indexing method
13	Karnataka	Chamrajanagar	Hierarchy based indexing method
14	Kerala	Kasaragod	Indexing based method
15	Meghalaya	West Khasi	Hierarchy based indexing method
16	Maharashtra	Ahmadnagar	Weighted hierarchy based indexing method
17	Manipur	Churachandpur	Indexing based method
18	Madhya Pradesh	Morena	Hierarchy based indexing method
19	Mizoram	Aizawl	Indexing based method
20	Nagaland	Kohima	Indexing based method
21	Odisha	Kendujhar	Hierarchy based indexing method
22	Punjab	Hoshiarpur	Indexing based method
23	Rajasthan	Pali	Hierarchy based indexing method
24	Sikkim	Sikkim	Indexing based method
25	Telangana	Mahabubnagar	Hierarchy based indexing method
26	Tamil Nadu	Virudhunagar	Indexing based method
27	Tripura	South Tripura	Indexing based method
28	Uttarakhand	Chamoli	Indexing based method
29	Uttar Pradesh	Kanpur Dehat	Hierarchy based indexing method
30	West Bengal	Purulia	Indexing based method

5. RESULTS & DISCUSSIONS

Assessment of land degradation vulnerability is carried out for all selected district using the datasets as mentioned in section-3 and the methodologies as listed under section-4 of this report. The methodologies used for deriving LDVA for individual district is listed in table-14. The final outcome provides the area classified into five categories of vulnerability, viz. Very Low, Low, Moderate, High and Very High.

The availability of input datasets is a deciding factor in selection of methodology. Further, the selection of methodology is very crucial and affect the final results. In case of availability of detailed datasets, hierarchy based indexing method gives better results over Indexing based method. The weighted hierarchy based indexing method further enhances the results as the weightage assignment to the input data enhances the contribution of their overall impact on land degradation. Moreover, the assigning of weightages is crucial and hence the decision and knowledge of the analyst plays important role in assigning of the weightages and thus affect the final outcome.

The districts selected in this study fall into different agro-climatic zones of the country. These districts also have variety in terms of LULC practices, demography, water sources, soil, etc. The analysis of intermediate as well as final results indicate that depending upon the overall combination of input datasets, one or more factors/indicators dominate (in either positive or negative way) in the analysis and affect the final derivation of land degradation vulnerability. The climate index dominates for districts falling into arid and semi-arid regions. Similarly, the socio-economic index dominates for densely populated areas and also for areas which are economically backward or lacking the basic infrastructures. For the districts engaged with intense agriculture, the land utilisation index dominates. On the other hand, the areas falling into non-dry land region and rich in natural resources (LULC, soil, water, etc.) are showing majority of the area falling into low vulnerability category.

The summary of results of LDVA for all districts is given in table-15 below. The statistics reveals that the area falling into arid and semi-arid regions are showing large part of the area falling into high and moderate vulnerability index. Kachchh district in Gujarat has 67.20 % area under high and 27.79% under moderate vulnerable category. Similarly, Pali district in Rajasthan has 18.52% area under high and 66.95% under moderate vulnerable category.

Also, for districts falling in semi-arid region, a large part of area falls into moderate, high and very-high vulnerability category. For Chamrajanagar district in Karnataka, almost 70% of the area falls into moderate to very-high vulnerability class. Similarly, for Ahmadnagar district in Maharashtra state, 67.84% area under moderate and 22.19% under high vulnerable category. Similarly, for Mahabubnagar district in Telangana, almost 65% area falls under moderate to very-high vulnerability. Chamrajanagar in Karnataka, Morena in Madhya Pradesh, Virudhunagar in Tamil Nadu and Kanpur Dehat in Uttar Pradesh are the other districts falling under semi-arid region and their statistics are given in table-15.

Also, for districts falling in dry sub-humid region, a large part of area falls into low vulnerability class. For Raipur district in Chhattisgarh, almost 69% area falls under low-very-low vulnerability class. Similarly, for Purulia district in West Bengal, almost 72% area falls under low-very-low vulnerability class. Other districts falling in dry sub-humid region are Bhabua in Bihar, Kangra in Himachal Pradesh, Bokaro in Jharkhand, Udhampur in Jammu & Kashmir, Kendujhar in Odisha, Hoshiarpur in Punjab and Chamoli in Uttarakhand.

For the districts falling into non dryland region (other than arid, semi-arid and dry sub-humid), the large part of the area falls into low-very low vulnerability category. For Hailakandi district in Assam, more than 84% area falls under low vulnerability. Similarly, for North Goa district in Goa, more than 66% area falls under low-very low vulnerability class. Tawang in Arunachal Pradesh, Kasaragod in Kerala, Churachandpur in Manipur, West Khasi in Meghalaya, Aizawl in Mizoram, Kohima in Nagaland, Sikkim, South Tripura in Tripura are the other districts falling in non-dryland regions.

The final outcome of the work for all selected districts is produced as map compositions along with vulnerability class wise statistics. The final maps of all the districts are placed after section-6. The other class in the legends includes Settlements, water bodies, rocky area, rann and snow covered areas.

Table-15: LDVA index wise area distribution for all the districts

SN	State	District	LDVA - Index Wise Area (% of district TGA)					
			Very Low	Low	Moderate	High	Very High	Others
1	Andhra Pradesh	Anantapur	16.45	22.30	21.02	21.80	17.32	1.11
2	Arunachal Pradesh	Tawang	5.12	55.99	10.12	0.00	0.00	28.77
3	Assam	Hailakandi	0.01	84.78	11.88	1.29	0.00	2.03
4	Bihar	Bhabua	31.95	43.55	23.99	0.01	0.00	0.50
5	Chhattisgarh	Raipur	5.02	63.94	21.33	4.99	0.09	4.64
6	Goa	North Goa	10.75	55.87	18.01	2.36	0.00	13.02
7	Gujarat	Kachchh	0.00	0.14	27.79	67.20	0.72	4.15
8	Gujarat	Panch Mahals	10.72	35.53	30.91	13.15	0.00	9.69
9	Himachal Pradesh	Kangra	0.00	61.12	15.64	14.84	0.01	8.40
10	Haryana	Sirsa	0.11	46.23	35.72	0.12	0.00	17.82
11	Jharkhand	Bokaro	0.45	26.30	61.13	5.26	0.00	6.85
12	Jammu & Kashmir	Udhampur	1.79	17.71	28.20	12.29	34.07	5.94
13	Karnataka	Chamrajanagar	13.04	15.71	25.27	28.06	16.50	1.41
14	Kerala	Kasaragod	0.00	8.33	91.41	0.26	0.00	0.00
15	Madhya Pradesh	Morena	0.49	48.31	23.67	21.18	2.28	4.08
16	Maharashtra	Ahmadnagar	0.00	1.42	67.84	22.19	0.00	8.55
17	Manipur	Churachandpur	0.00	0.13	98.48	0.00	0.00	1.39
18	Meghalaya	West Khasi	0.00	65.90	31.56	0.02	0.00	2.52
19	Mizoram	Aizawl	0.00	83.00	13.14	0.00	0.00	3.86
20	Nagaland	Kohima	0.00	72.08	22.64	0.00	0.00	5.28
21	Odisha	Kendujhar	0.04	62.47	14.63	16.79	0.87	5.20
22	Punjab	Hoshiarpur	0.00	50.40	41.19	0.22	0.00	8.19
23	Rajasthan	Pali	0.00	13.58	66.95	18.52	0.03	0.93
24	Sikkim	Sikkim	0.02	38.56	8.56	0.00	0.00	52.87
25	Tamil Nadu	Virudhunagar	0.00	1.42	65.42	0.16	0.00	0.00
26	Telangana	Mahabubnagar	16.23	16.23	20.05	25.82	19.09	2.58
27	Tripura	South Tripura	1.36	87.84	2.53	0.00	0.00	8.27
28	Uttarakhand	Chamoli	0.00	26.93	22.89	0.01	0.00	50.17
29	Uttar Pradesh	Kanpur Dehat	1.43	5.23	86.15	7.18	0.01	0.00
30	West Bengal	Purulia	8.53	63.40	23.81	0.74	0.00	3.51

6. CONCLUSION

Land Degradation Vulnerability Assessment (LDVA) is carried out for all the selected areas by geospatial integration of the Socio-economic, climate, soil and biophysical datasets. This type of outcomes provides an assessment of the nature of fragility of the area towards desertification/ land degradation. Datasets from multiple sources are used for this analysis. IRS LISS3 satellite data was used to generate various land related information, viz. land use land cover and land degradation status maps.

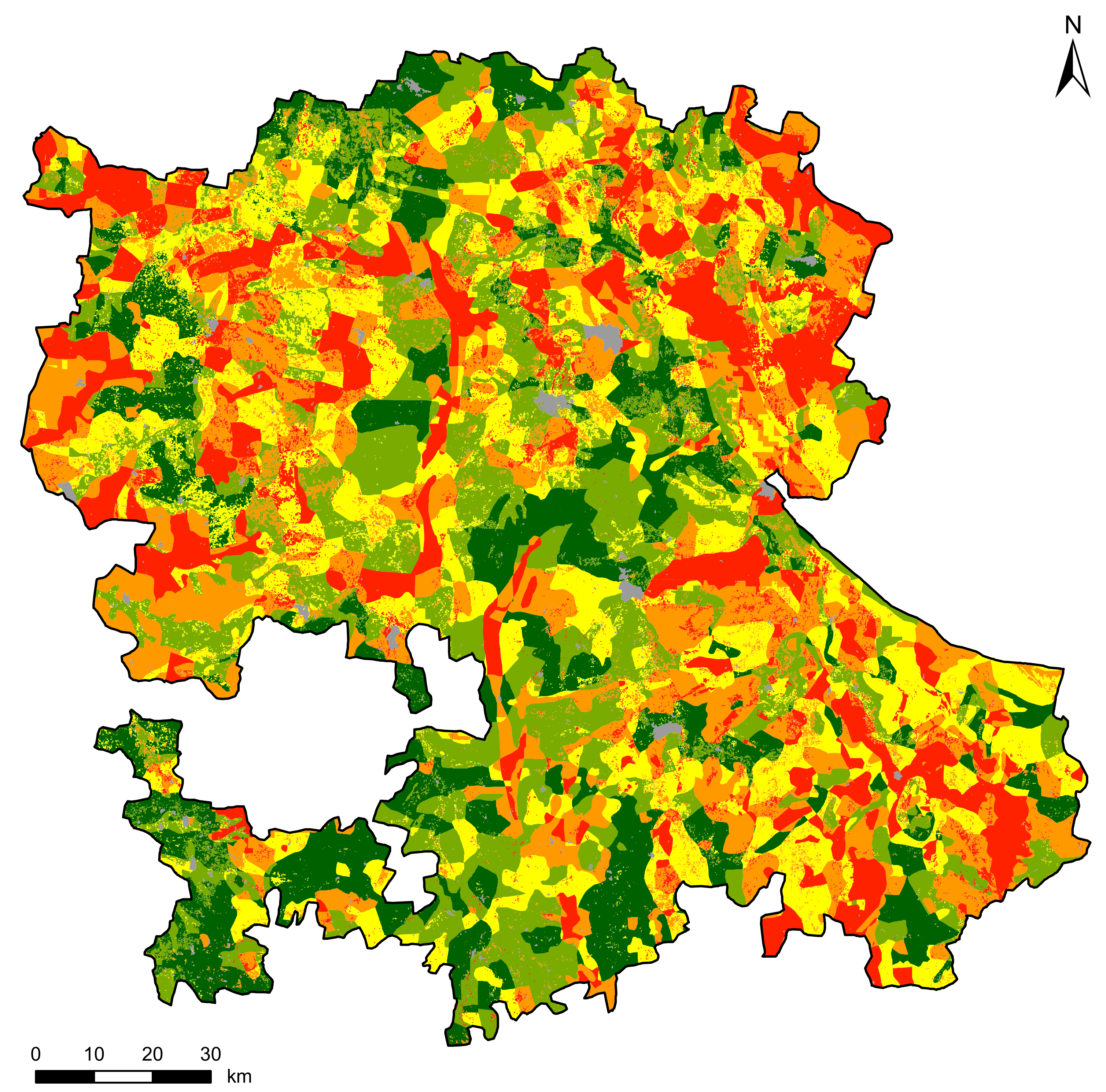
For the area falling in dry regions (arid, semi-arid) of the country, viz. Kachchh district in Gujarat and Pali district in Rajasthan, witness harsh climatic conditions with less rainfall and high temperatures. These area also have limited availability of water for agriculture and other purposes. In spite of the optimal utilisation of land/water resources in most of the areas, the large area of these districts falls under high - very high vulnerability class. Here the driving or the dominating factor for these area are climatic conditions.

On other side, for districts which are rich in natural resources, viz. large area with forest cover, productive soil, easy availability of water, etc., large area falls under low – very low vulnerability class. The overall demographic pressure is also low for such cases. Districts in north east regions of the country are mostly fall under low – very low vulnerability class.

The area with intense/commercial agriculture practices (2-3 season agriculture frequency), viz. districts in Andhra Pradesh, Haryana, Karnataka, Madhya Pradesh, Punjab, Telangana, Uttar Pradesh etc., do also have productive soils, favorable climatic conditions and water availability. Such areas also are comparatively dense populous. Such area witness over utilisation of the resources and hence fall under moderate - high vulnerability category.

This analysis and such outputs may serve as a robust base data for the policy makers for prioritising of the area and also for conceptualizing and implementation of action plans on the ground to combat and reverse land degradation. Along with the final LDVA outcome, the intermediate results may also be very useful to understand the dominating factors and accordingly for preparing the action plans.

Furthermore, there is always scope for developing new methodologies for carrying out such analysis. Along with geospatial and statistical analysis, time series analysis and regression analysis tools can be explored for LDVA. The machine learning and artificial intelligence technologies can also be explored for assessment of land degradation. Moreover, more datasets linking with the processes of land degradation can also be explored in order to include in the analysis. satellite derived high resolution soil moisture map (generated by SAC, Ahmedabad) could be one of the important parameters to consider in the analysis.

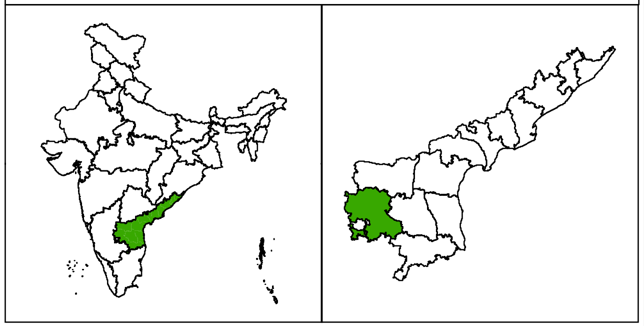


Land Degradation Vulnerability Assessment Map
Anantapur District, Andhra Pradesh

Legend

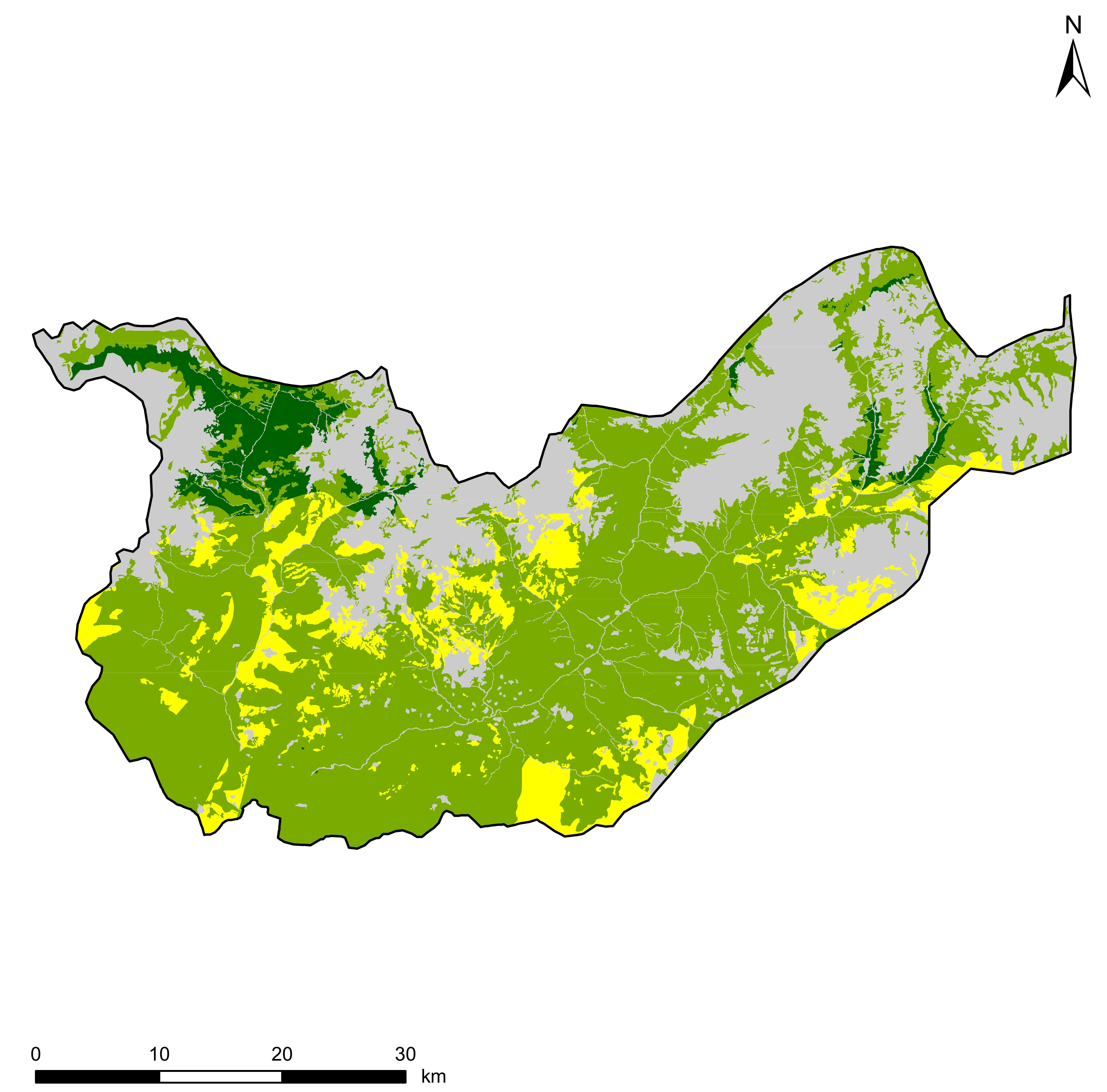
Symbol	Vulnerability Index	Area (%)
	Very Low	16.45
	Low	22.30
	Moderate	21.02
	High	21.80
	Very High	17.32
	Others	1.11

Location Map



Prepared by:
National Bureau of Soil Survey and Land Use Planning, Bangalore
&
Space Applications Centre, ISRO, Ahmedabad

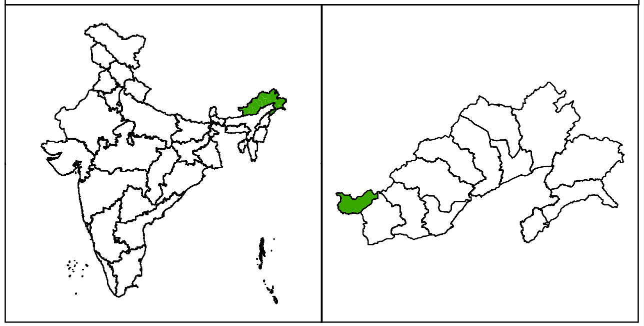
Land Degradation Vulnerability Assessment Map
Anantapur District, Andhra Pradesh



Legend

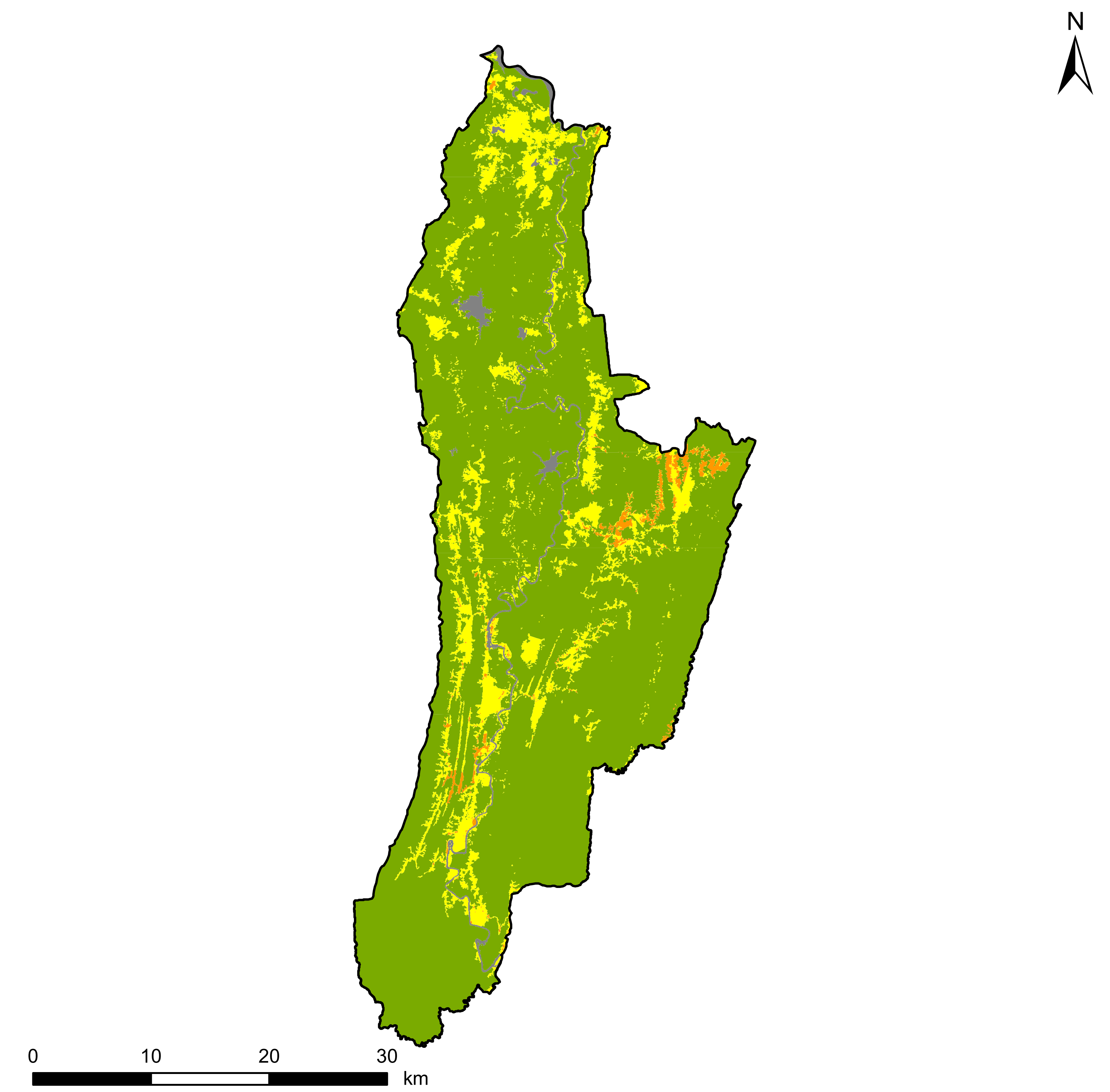
Symbol	Vulnerability Index	Area (%)
	Very Low	5.12
	Low	55.99
	Moderate	10.12
	High	0.00
	Very High	0.00
	Others	28.77

Location Map



Prepared by:
North Easrern Space Applications Centre, Meghalaya
&
Space Applications Centre, ISRO, Ahmedabad

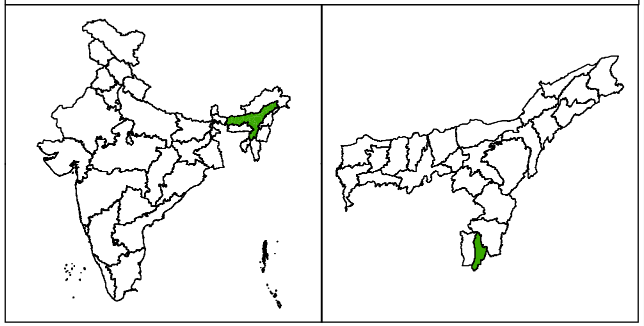
Land Degradation Vulnerability Assessment Map
Hailakandi District, Assam



Legend

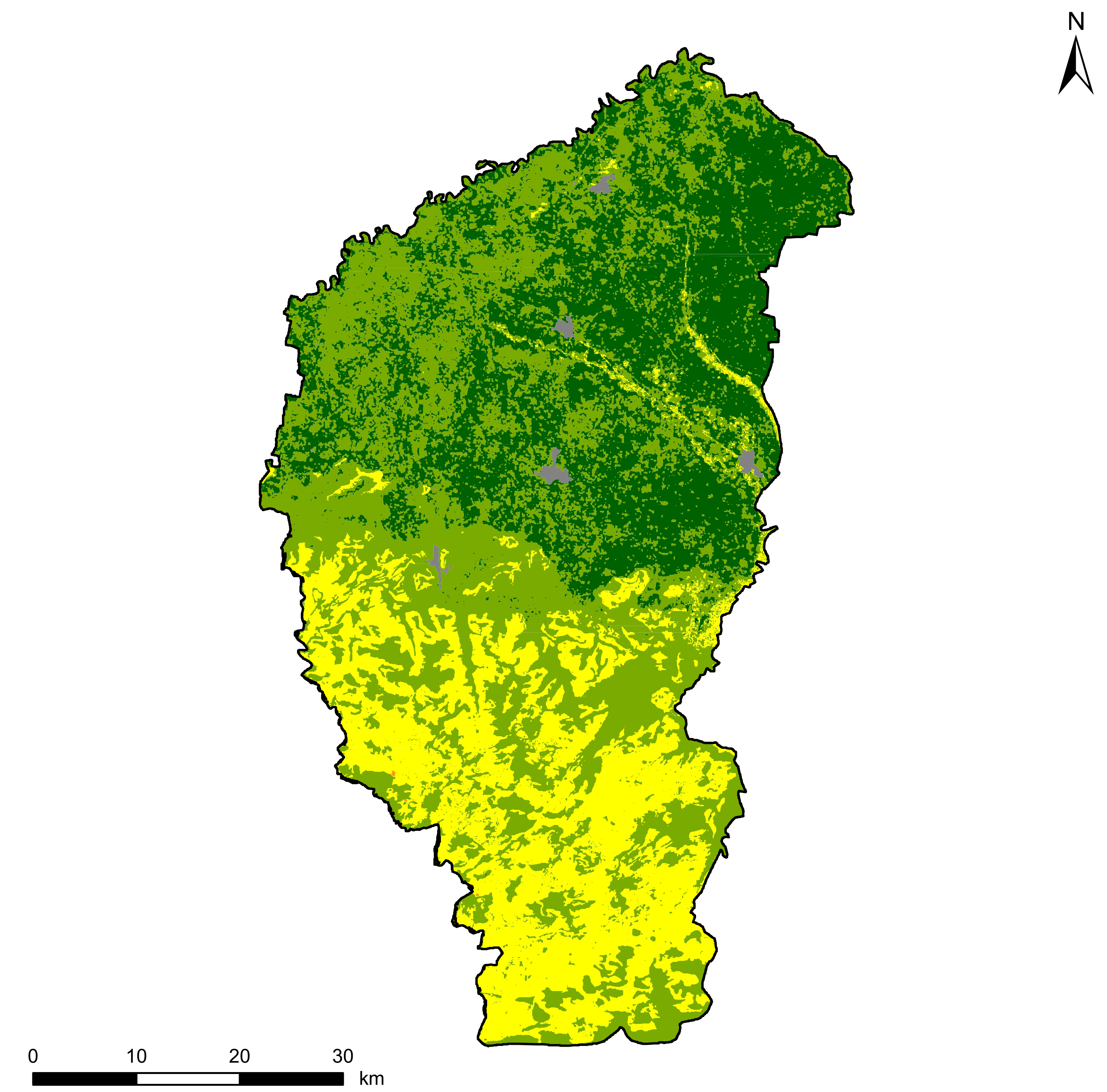
Symbol	Vulnerability Index	Area (%)
	Very Low	0.01
	Low	84.78
	Moderate	11.88
	High	1.29
	Very High	0.00
	Others	2.03

Location Map



Prepared by:
North eastern Hill University, Shillong
&
Space Applications Centre, ISRO, Ahmedabad

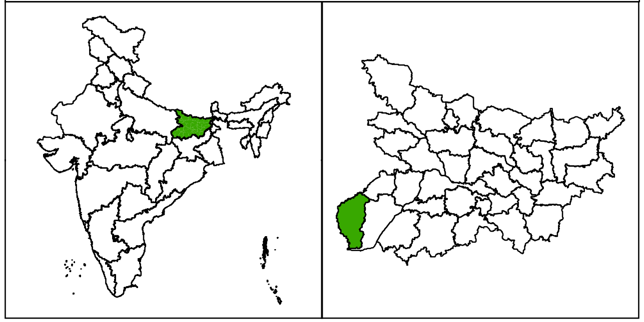
Land Degradation Vulnerability Assessment Map
Bhabua District, Bihar



Legend

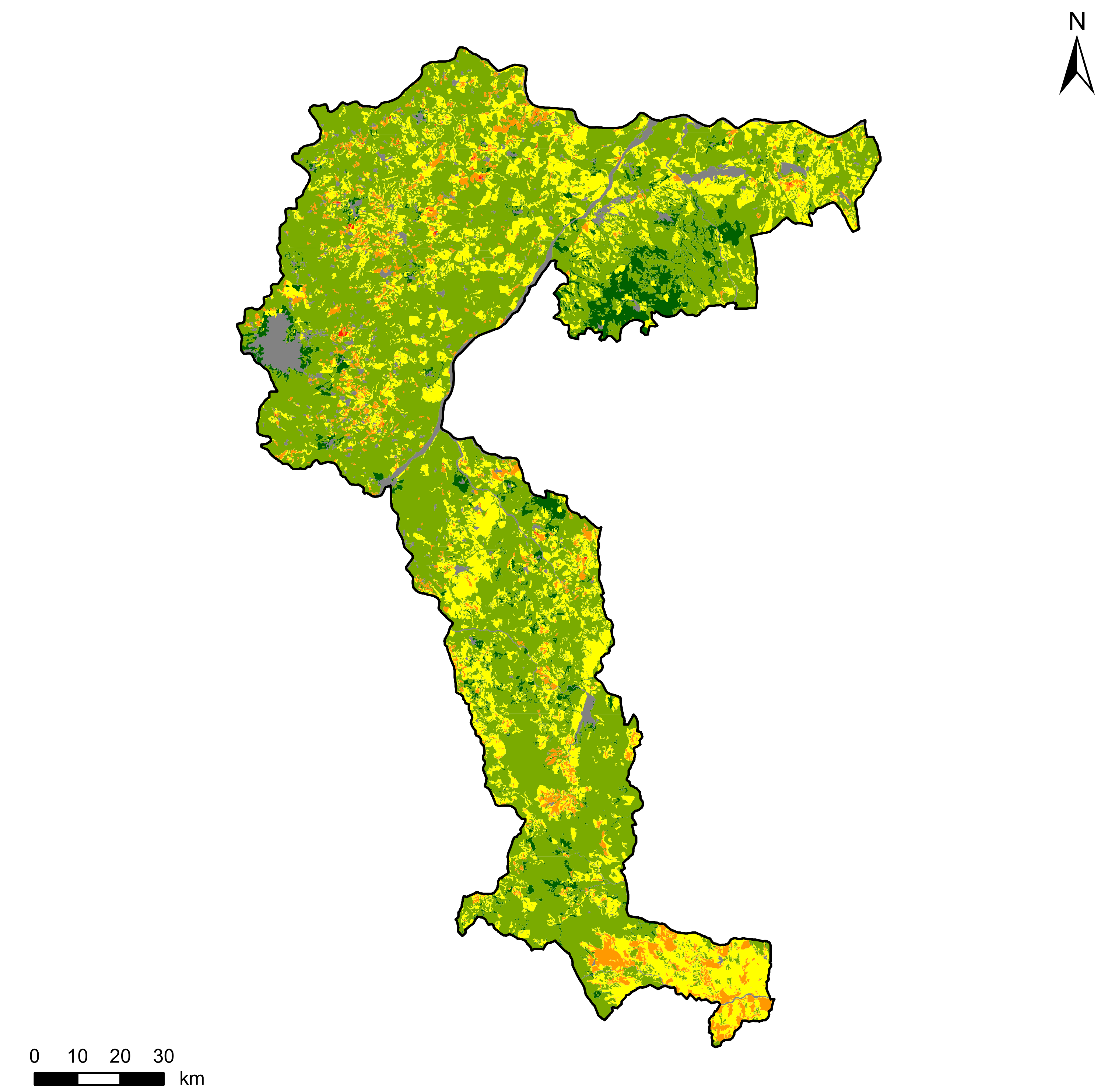
Symbol	Vulnerability Index	Area (%)
	Very Low	31.95
	Low	43.55
	Moderate	23.99
	High	0.01
	Very High	0.00
	Others	0.50

Location Map



Prepared by:
Remote Sensing Applications Centre, Uttar Pradesh, Lucknow
&
Space Applications Centre, ISRO, Ahmedabad

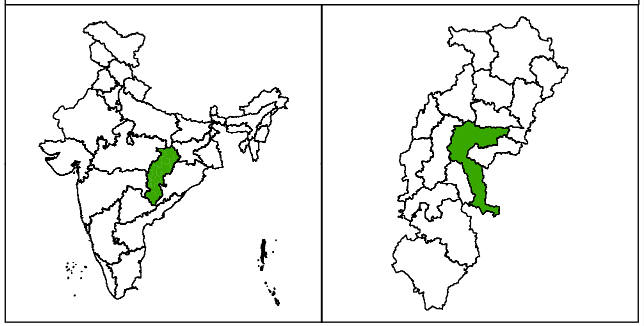
Land Degradation Vulnerability Assessment Map
Raipur District, Chhattisgarh



Legend

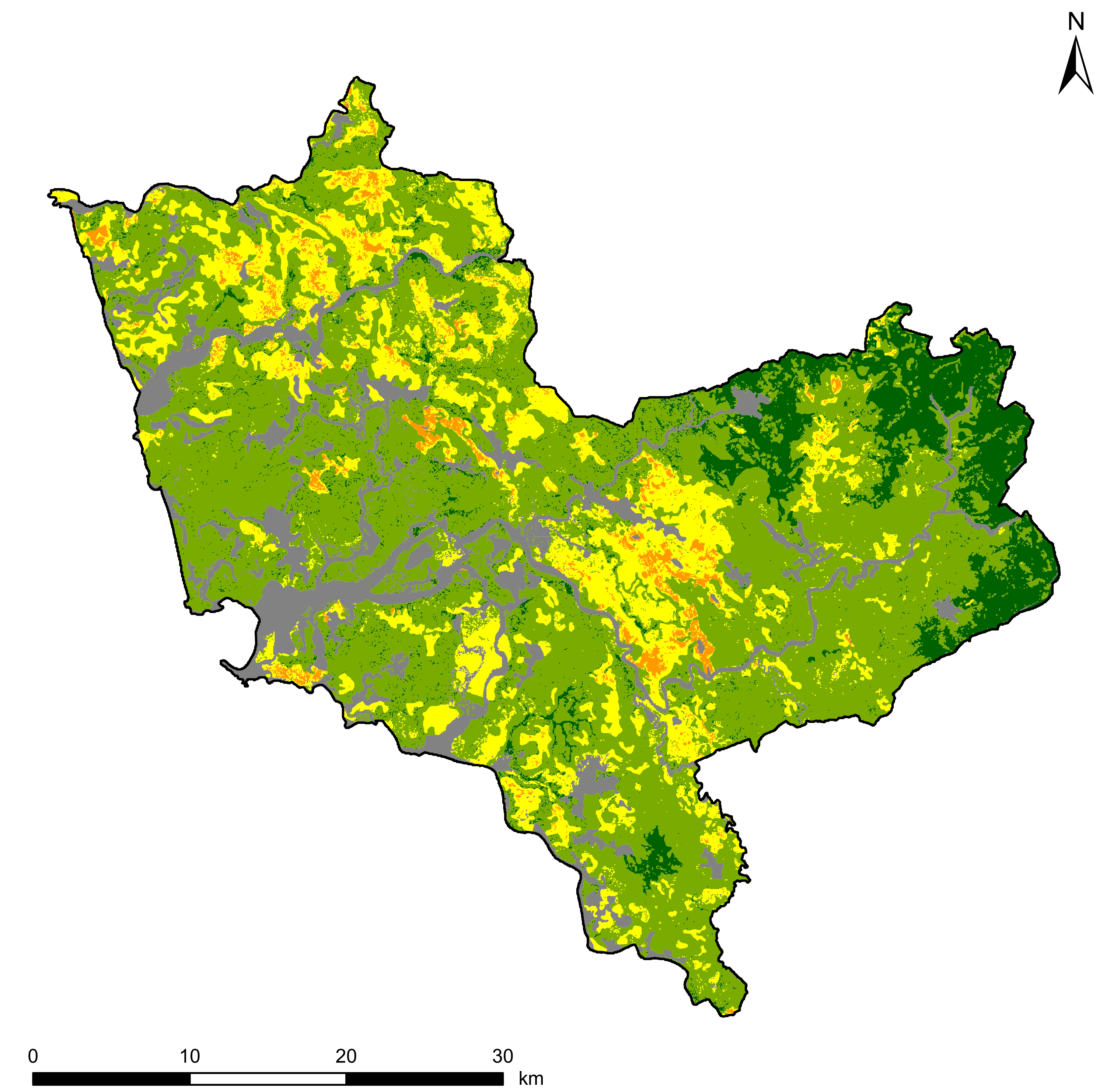
Symbol	Vulnerability Index	Area (%)
	Very Low	5.02
	Low	63.94
	Moderate	21.33
	High	4.99
	Very High	0.09
	Others	4.64

Location Map



Prepared by:
MP Council of Science and Technology, Bhopal
&
Space Applications Centre, ISRO, Ahmedabad

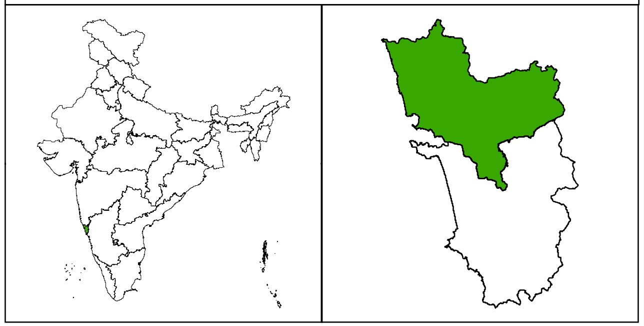
Land Degradation Vulnerability Assessment Map
North Goa District, Goa



Legend

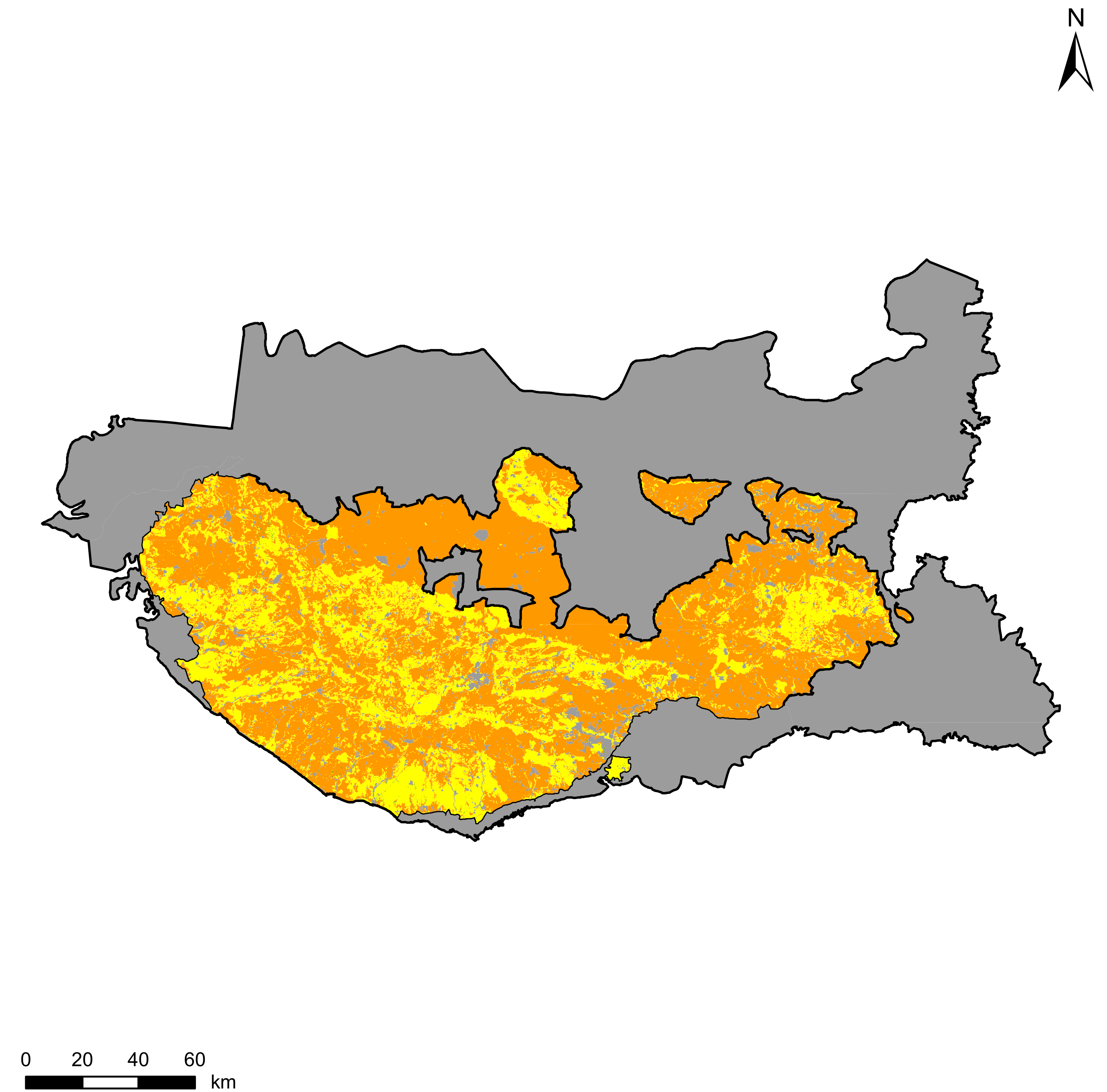
Symbol	Vulnerability Index	Area (%)
	Very Low	10.75
	Low	55.87
	Moderate	18.01
	High	2.36
	Very High	0.00
	Others	13.02

Location Map



Prepared by:
Maharashtra Remote Sensing Applications Centre, Nagpur
&
Space Applications Centre, ISRO, Ahmedabad

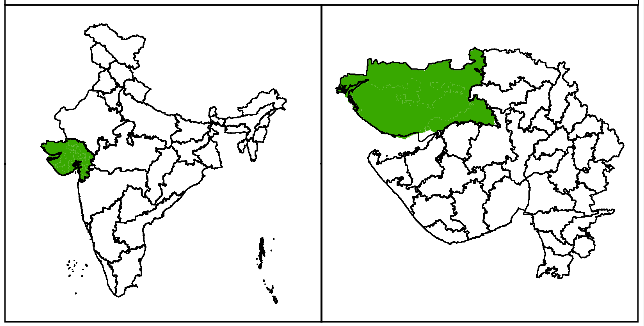
Land Degradation Vulnerability Assessment Map
Kachchh District, Gujarat



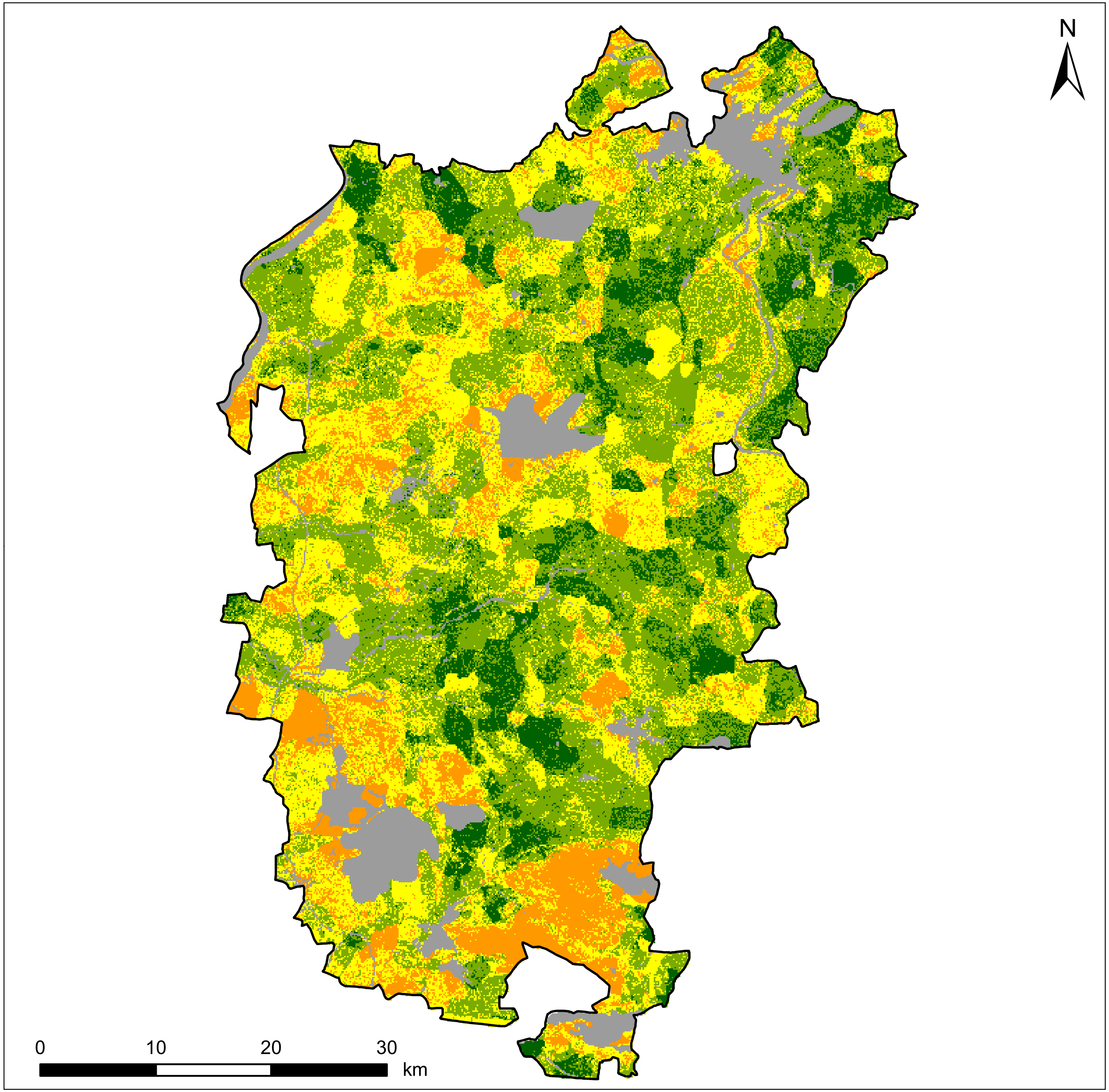
Legend

Symbol	Vulnerability Index	Area (%)
	Very Low	0.00
	Low	0.14
	Moderate	27.79
	High	67.20
	Very High	0.72
	Others	4.15

Location Map



Prepared by:
MG Science Institute, Ahmedabad
&
Space Applications Centre, ISRO, Ahmedabad

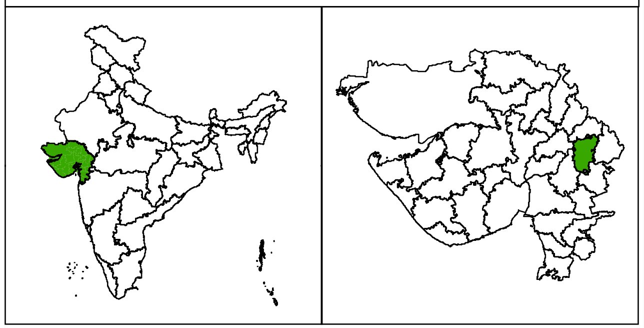


Land Degradation Vulnerability Assessment Map
Panch Mahals District, Gujarat

Legend

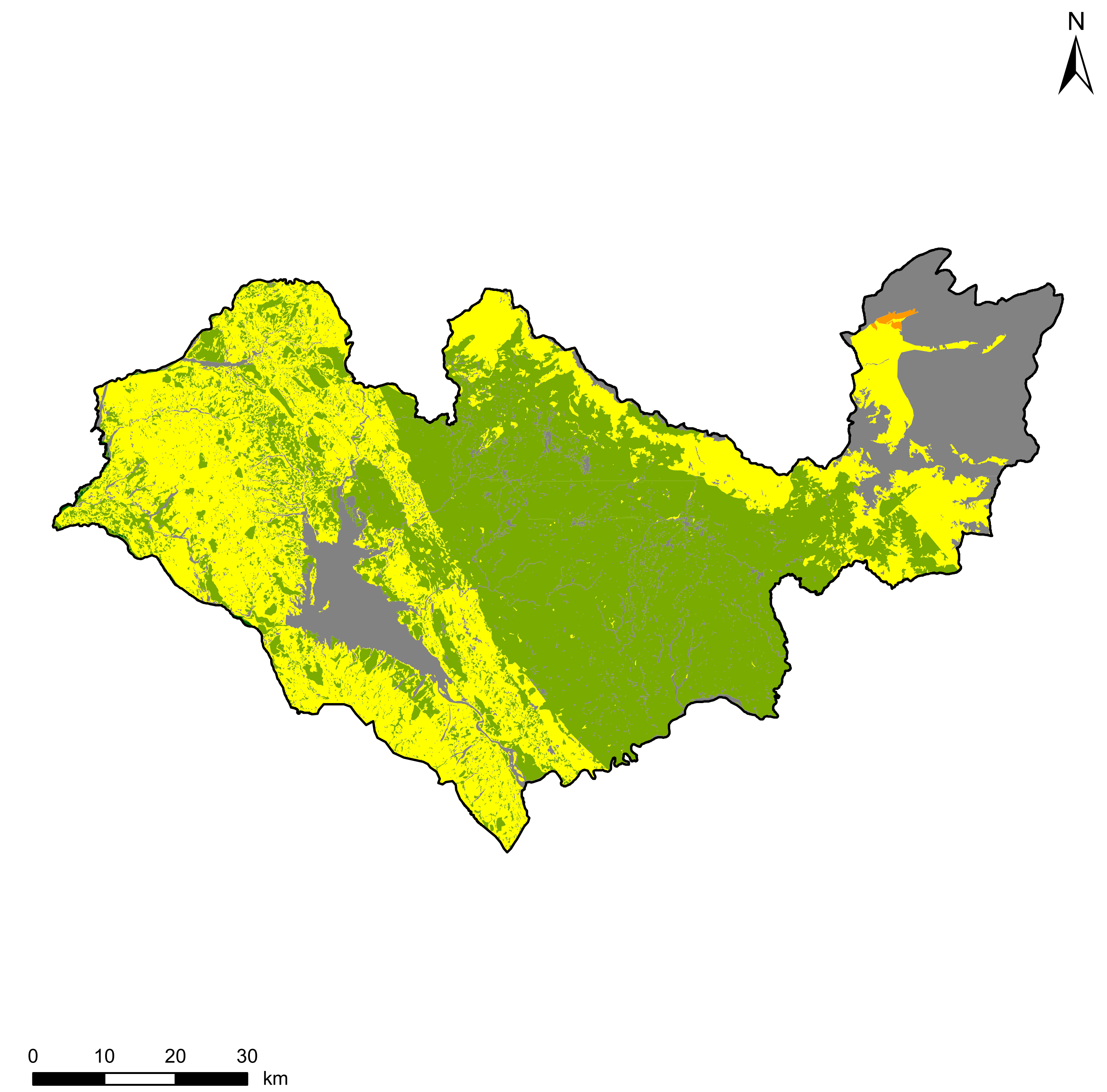
Symbol	Vulnerability Index	Area (%)
	Very Low	10.72
	Low	35.53
	Moderate	30.91
	High	13.15
	Very High	0.00
	Others	9.69

Location Map



Prepared by:
Dhirubhai Ambani Institute of Information & Communication Technology, Gandhinagar
&
Space Applications Centre, ISRO, Ahmedabad

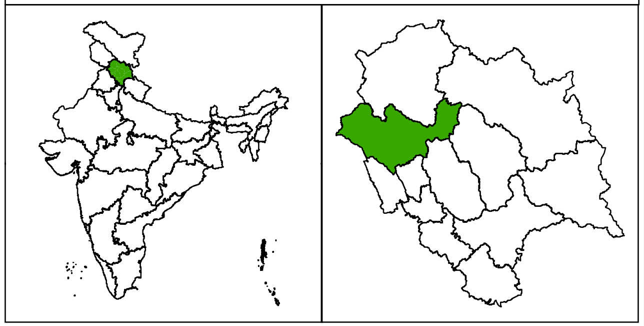
Land Degradation Vulnerability Assessment Map
Kangra District, Himachal Pradesh



Legend

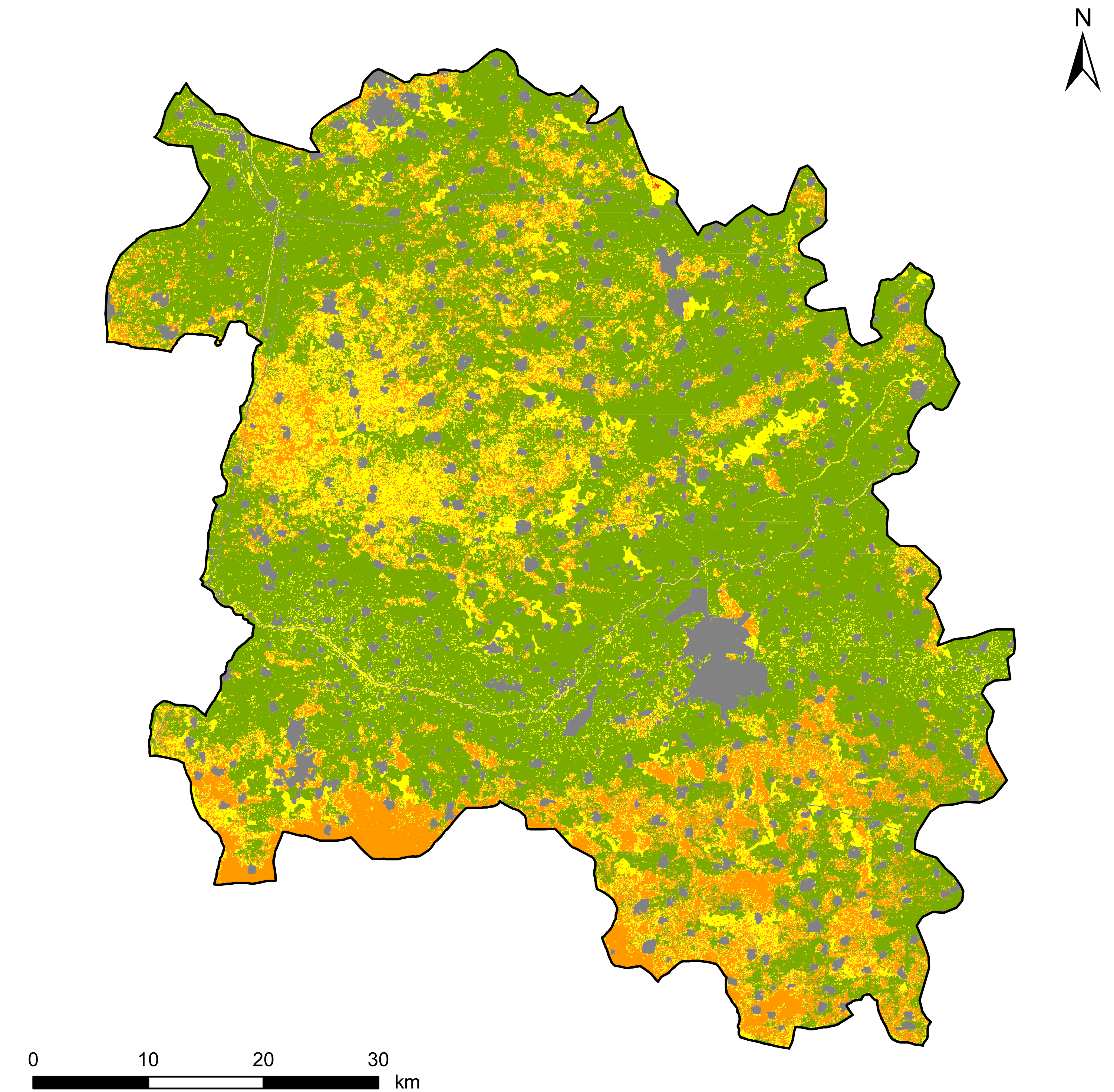
Symbol	Vulnerability Index	Area (%)
	Very Low	0.11
	Low	46.23
	Moderate	35.72
	High	0.12
	Very High	0.00
	Others	17.82

Location Map



Prepared by:
Jawaharlal Nehru University, Delhi
&
Space Applications Centre, ISRO, Ahmedabad

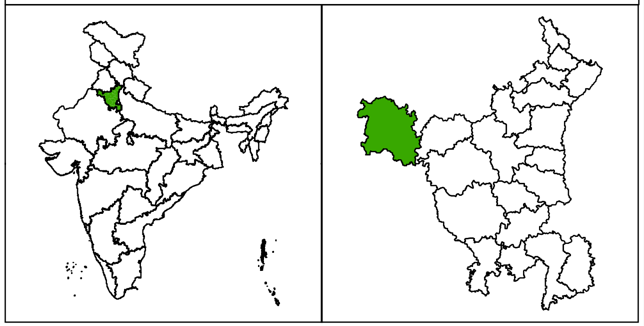
Land Degradation Vulnerability Assessment Map
Sirsa District, Haryana



Legend

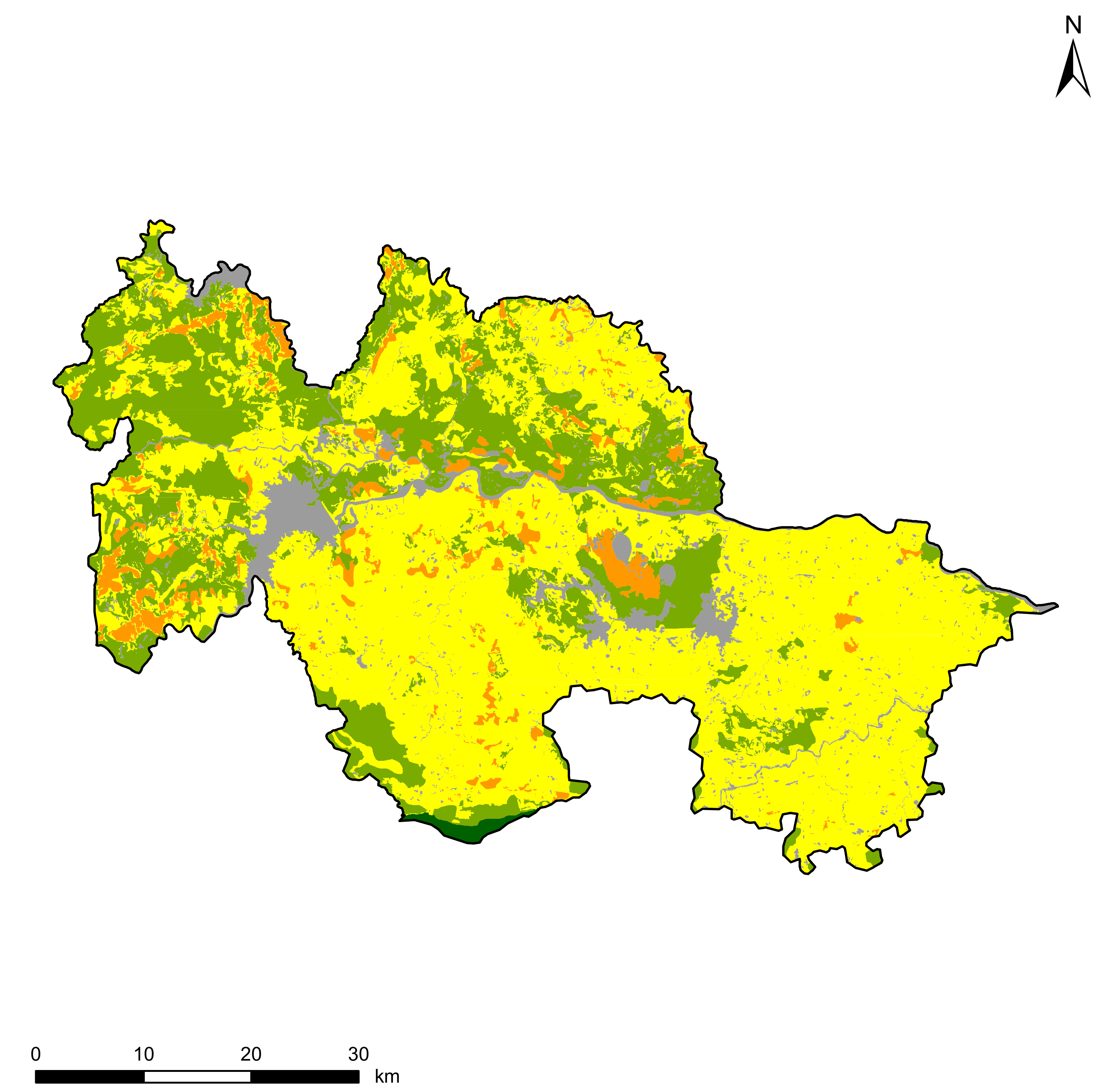
Symbol	Vulnerability Index	Area (%)
	Very Low	0.00
	Low	61.12
	Moderate	15.64
	High	14.84
	Very High	0.01
	Others	8.40

Location Map



Prepared by:
Jawaharlal Nehru University, Delhi
&
Space Applications Centre, ISRO, Ahmedabad

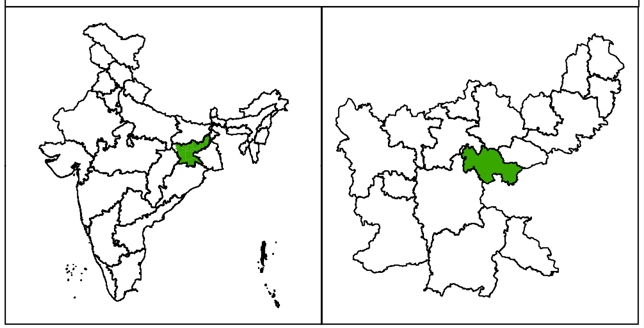
Land Degradation Vulnerability Assessment Map
Bokaro District, Jharkhand



Legend

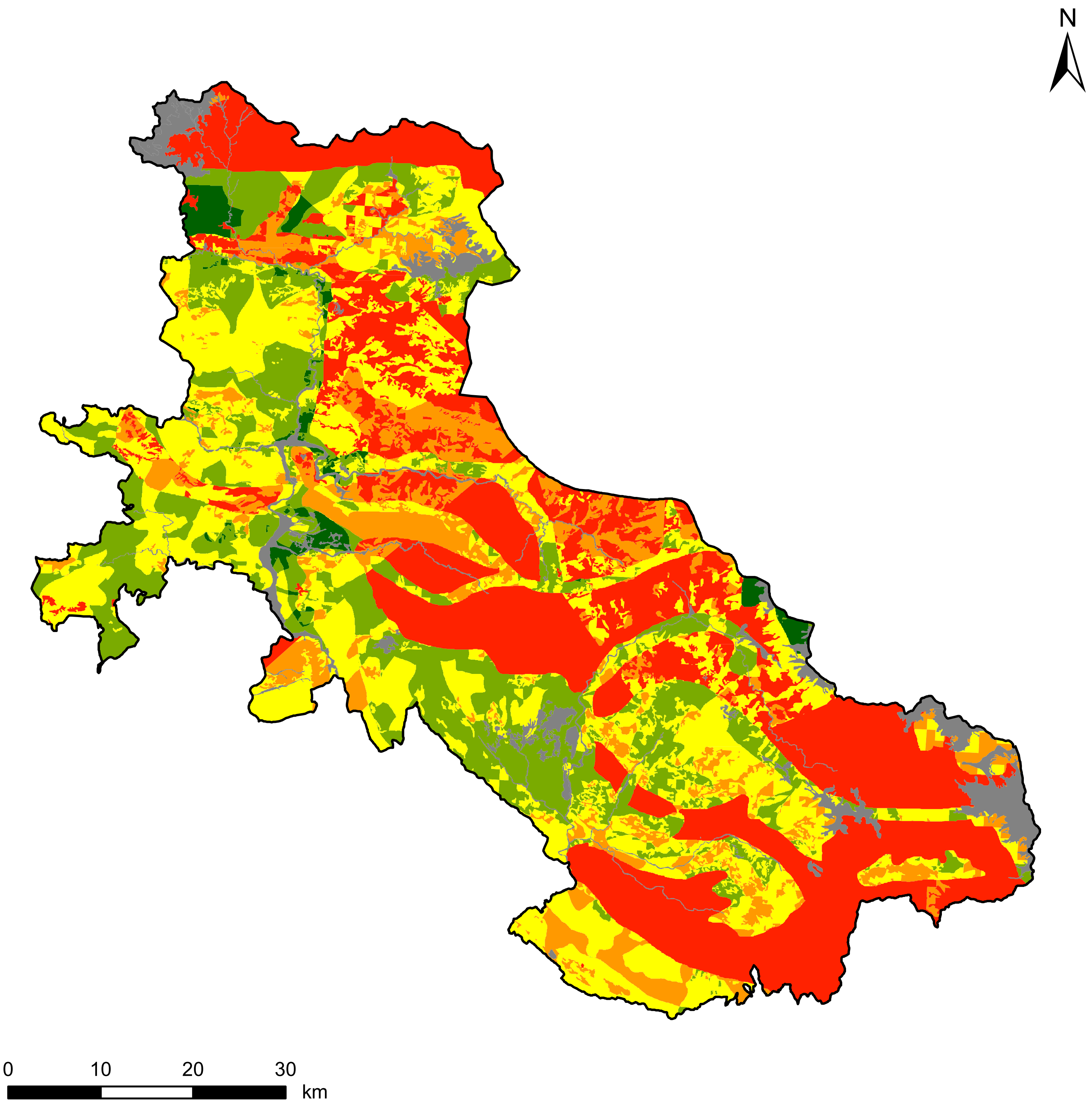
Symbol	Vulnerability Index	Area (%)
	Very Low	0.45
	Low	26.30
	Moderate	61.13
	High	5.26
	Very High	0.00
	Others	6.85

Location Map



Prepared by:
Jharkhand Space Applications Center, Ranchi
&
Space Applications Centre, ISRO, Ahmedabad

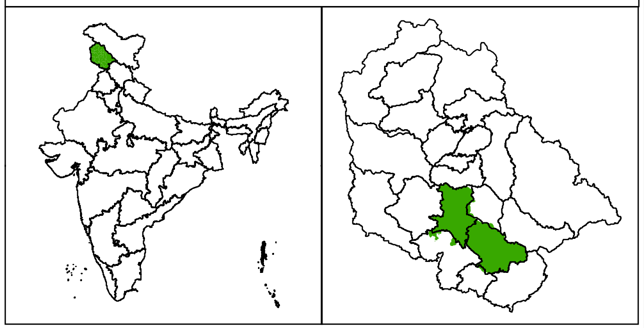
Land Degradation Vulnerability Assessment Map
Udhampur District, Jammu & Kashmir



Legend

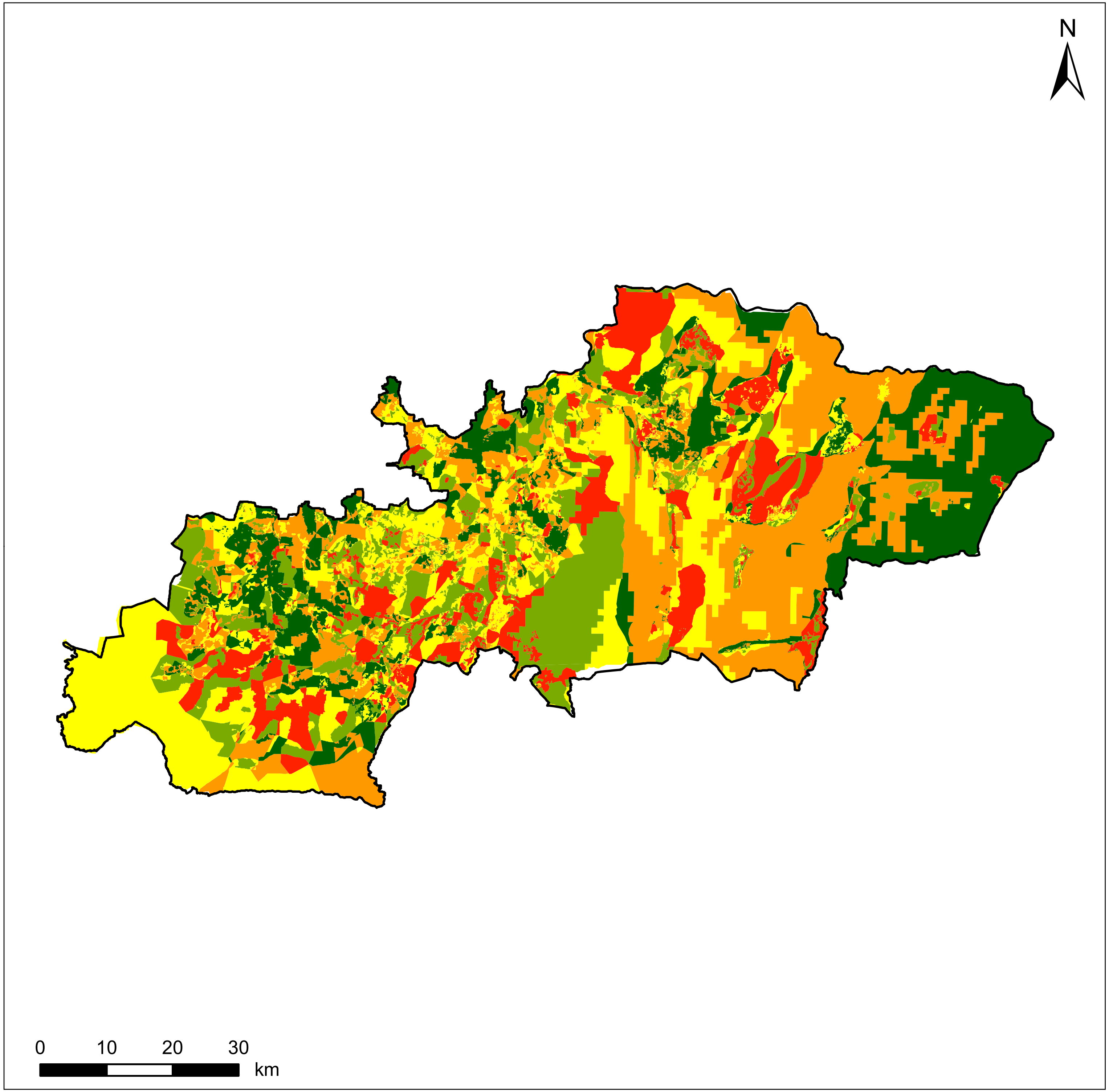
Symbol	Vulnerability Index	Area (%)
(dark green)	Very Low	1.79
(light green)	Low	17.71
(yellow)	Moderate	28.20
(orange)	High	12.29
(red)	Very High	34.07
(grey)	Others	5.94

Location Map



Prepared by:
University of Kashmir, Srinagar
&
Space Applications Centre, ISRO, Ahmedabad

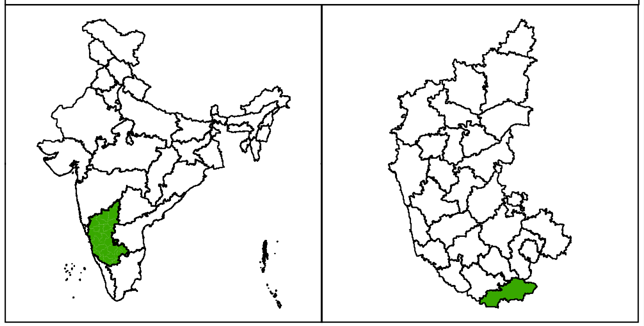
Land Degradation Vulnerability Assessment Map
Chamrajanagar District, Karnataka



Legend

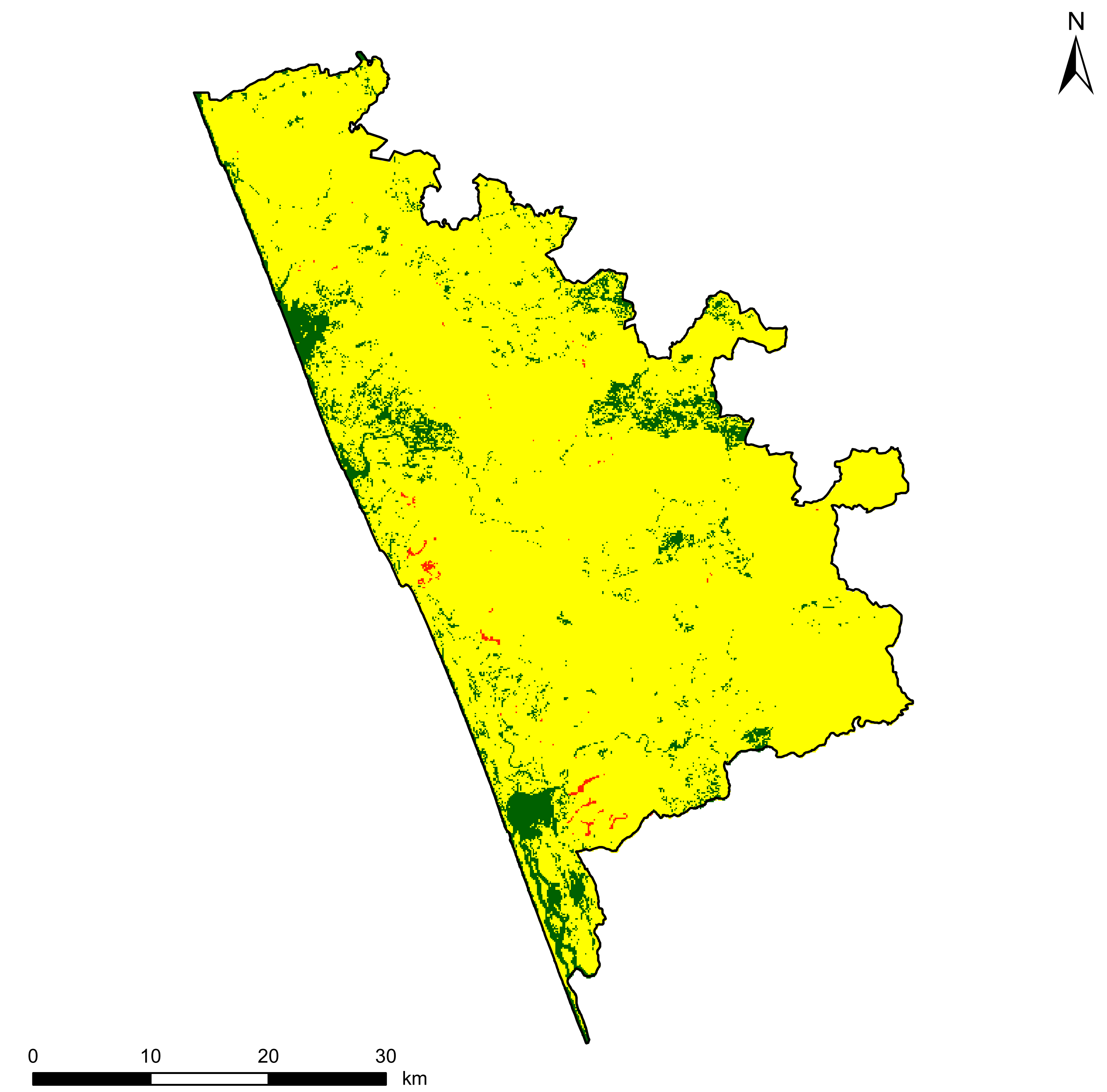
Symbol	Vulnerability Index	Area (%)
	Very Low	13.04
	Low	15.71
	Moderate	25.27
	High	28.06
	Very High	16.50
	Others	1.41

Location Map



Prepared by:
National Bureau of Soil Survey and Land Use Planning, Bangalore
&
Space Applications Centre, ISRO, Ahmedabad

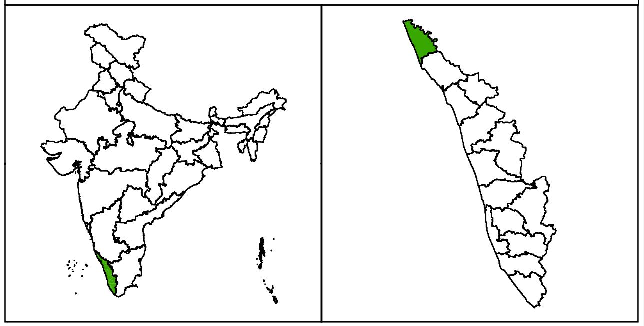
Land Degradation Vulnerability Assessment Map Kasaragod District, Kerala



Legend

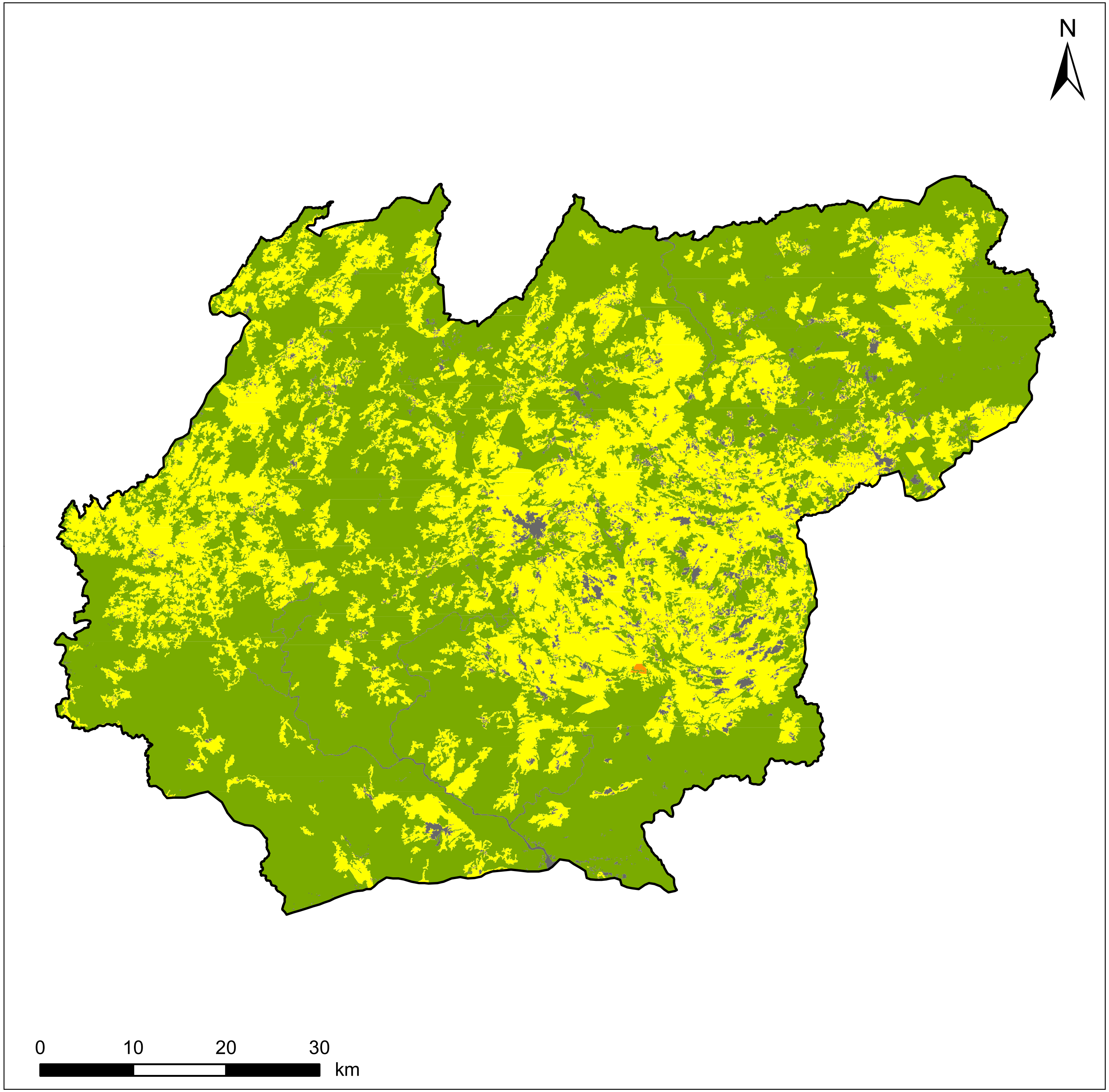
Symbol	Vulnerability Index	Area (%)
(dark green)	Low	8.33
(yellow)	Moderate	91.41
(red)	High	0.26

Location Map



Prepared by:
National Centre for Earth Science Studies, Thiruvananthapuram
&
Space Applications Centre, ISRO, Ahmedabad

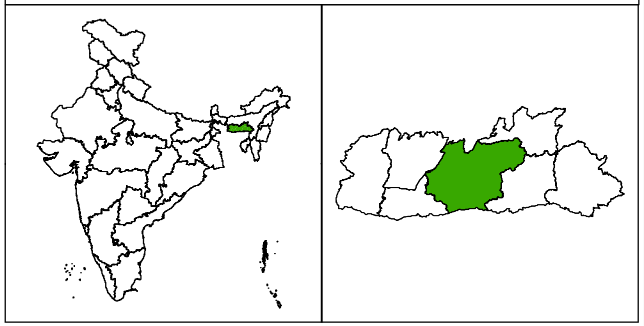
Land Degradation Vulnerability Assessment Map
West Khasi Hills District, Meghalaya



Legend

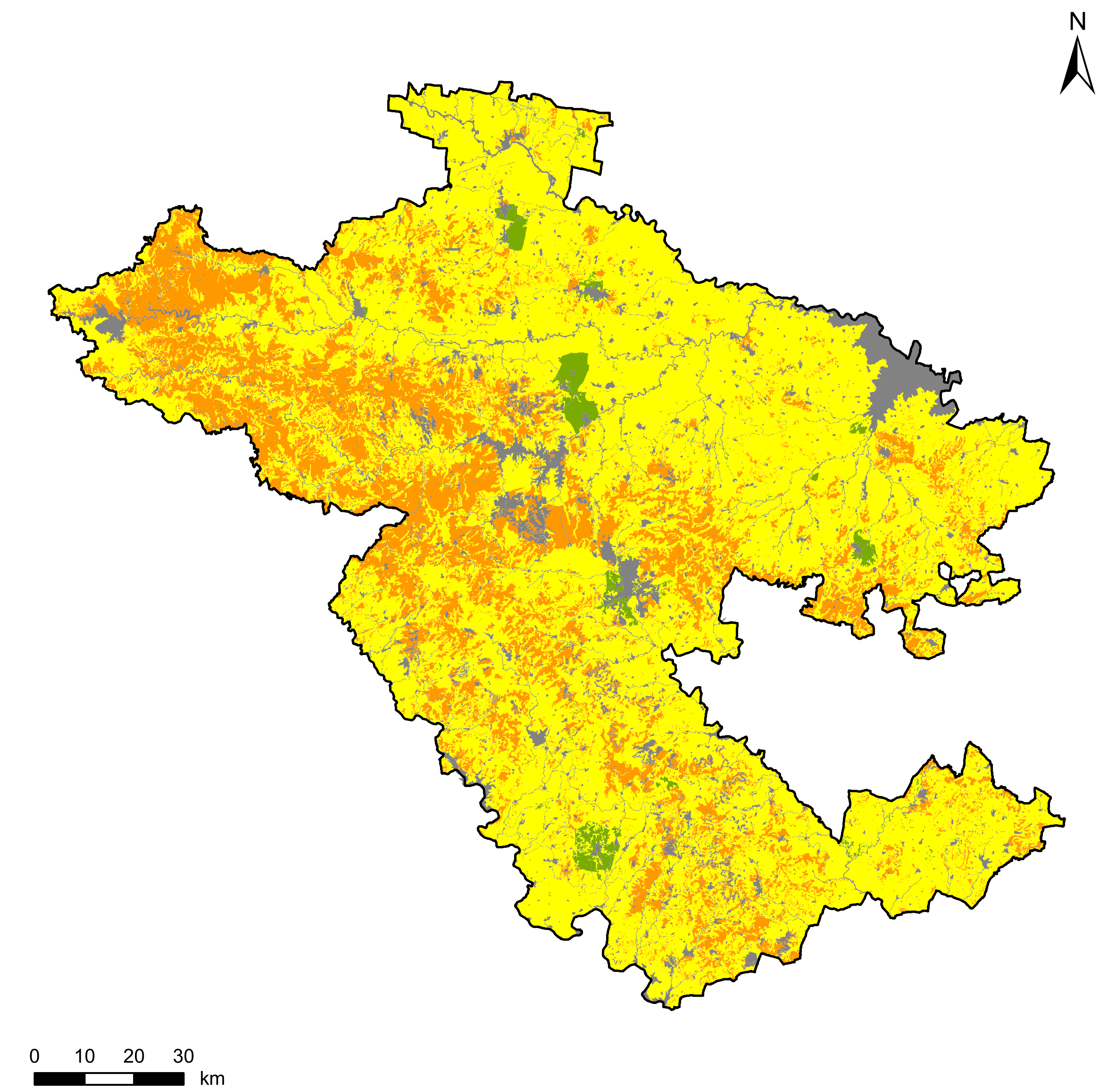
Symbol	Vulnerability Index	Area (%)
	Very Low	0.00
	Low	65.90
	Moderate	31.56
	High	0.02
	Very High	0.00
	Others	2.52

Location Map



Prepared by:
North eastern Hill University, Shillong
&
Space Applications Centre, ISRO, Ahmedabad

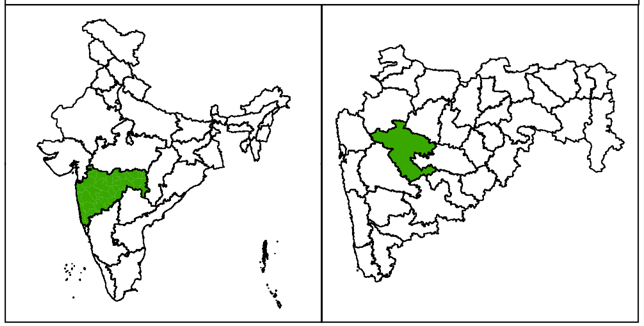
Land Degradation Vulnerability Assessment Map
Ahmadnagar District, Maharashtra



Legend

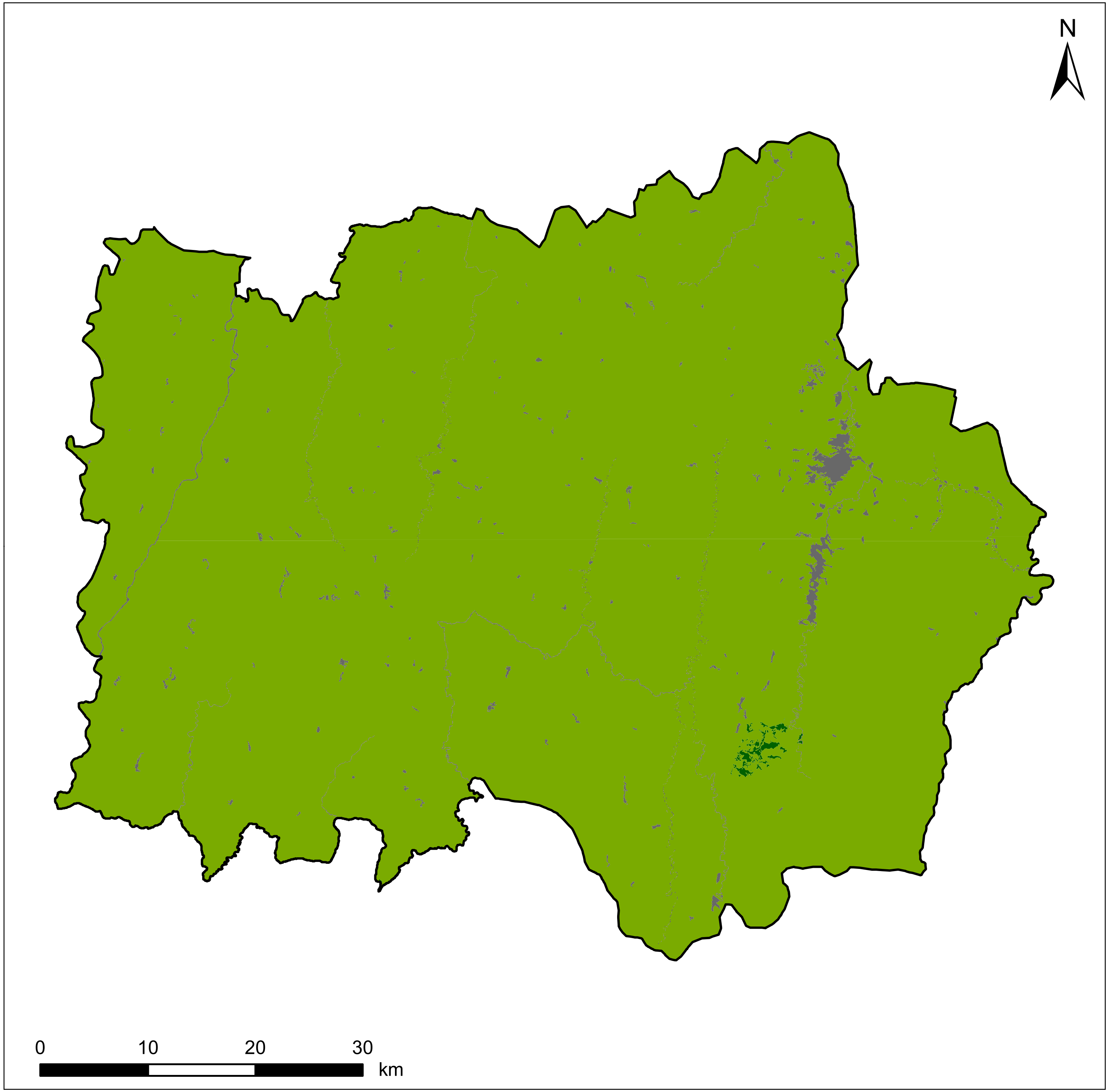
Symbol	Vulnerability Index	Area (%)
	Very Low	0.00
	Low	1.42
	Moderate	67.84
	High	22.19
	Very High	0.00
	Others	8.55

Location Map



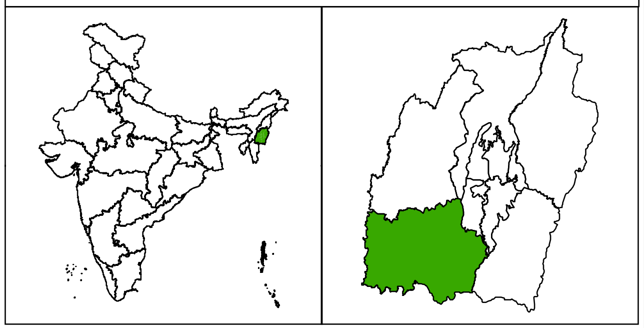
Prepared by:
Maharashtra Remote Sensing Applications Centre, Nagpur
&
Space Applications Centre, ISRO, Ahmedabad

Land Degradation Vulnerability Assessment Map
Churachandpur District, Manipur



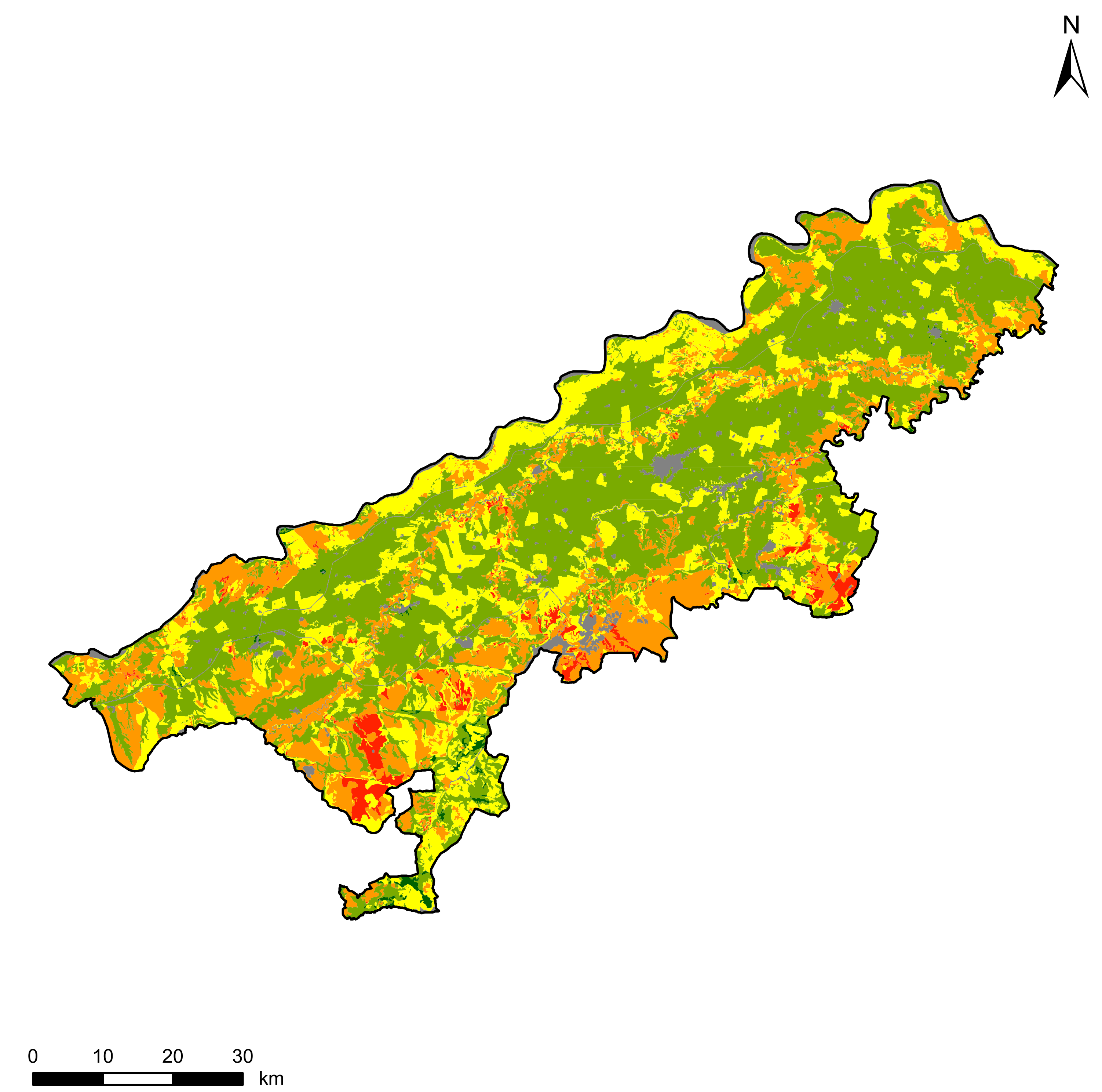
Legend

Symbol	Vulnerability Index	Area (%)
	Very Low	0.00
	Low	0.13
	Moderate	98.48
	High	0.00
	Very High	0.00
	Others	1.39



Prepared by:
North Easrern Space Applications Centre, Meghalaya
&
Space Applications Centre, ISRO, Ahmedabad

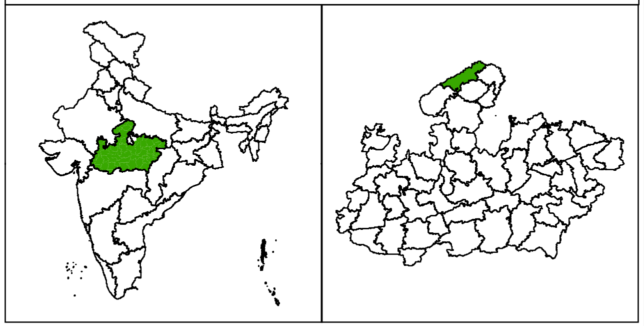
Land Degradation Vulnerability Assessment Map
Morena District, Madhya Pradesh



Legend

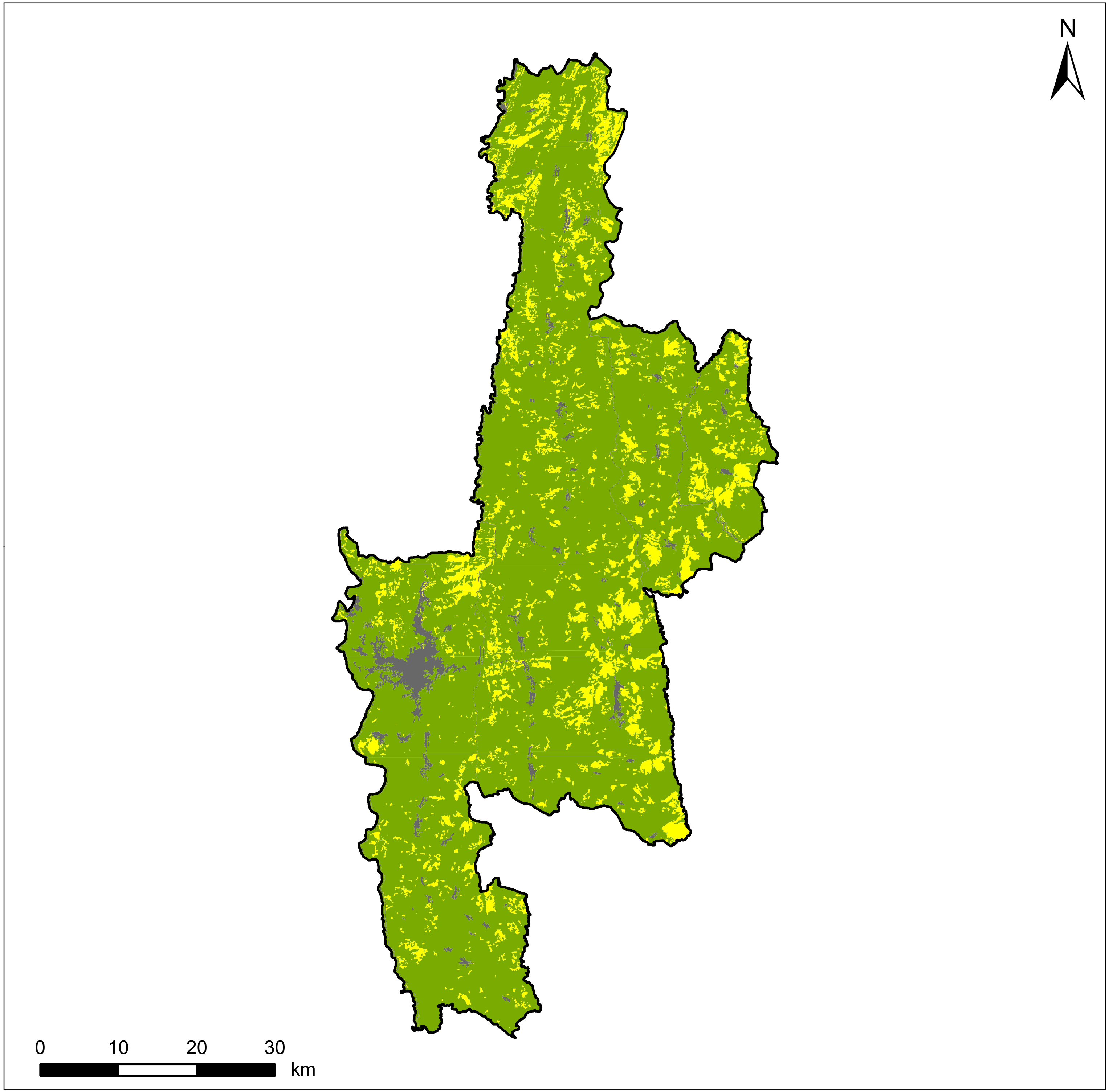
Symbol	Vulnerability Index	Area (%)
	Very Low	0.49
	Low	48.31
	Moderate	23.67
	High	21.18
	Very High	2.28
	Others	4.08

Location Map



Prepared by:
MP Council of Science and Technology, Bhopal
&
Space Applications Centre, ISRO, Ahmedabad

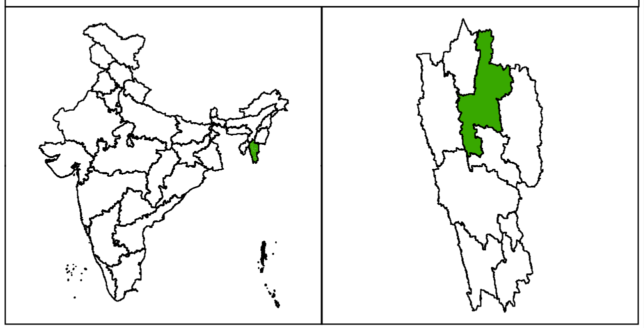
Land Degradation Vulnerability Assessment Map
Aizawl District, Mizoram



Legend

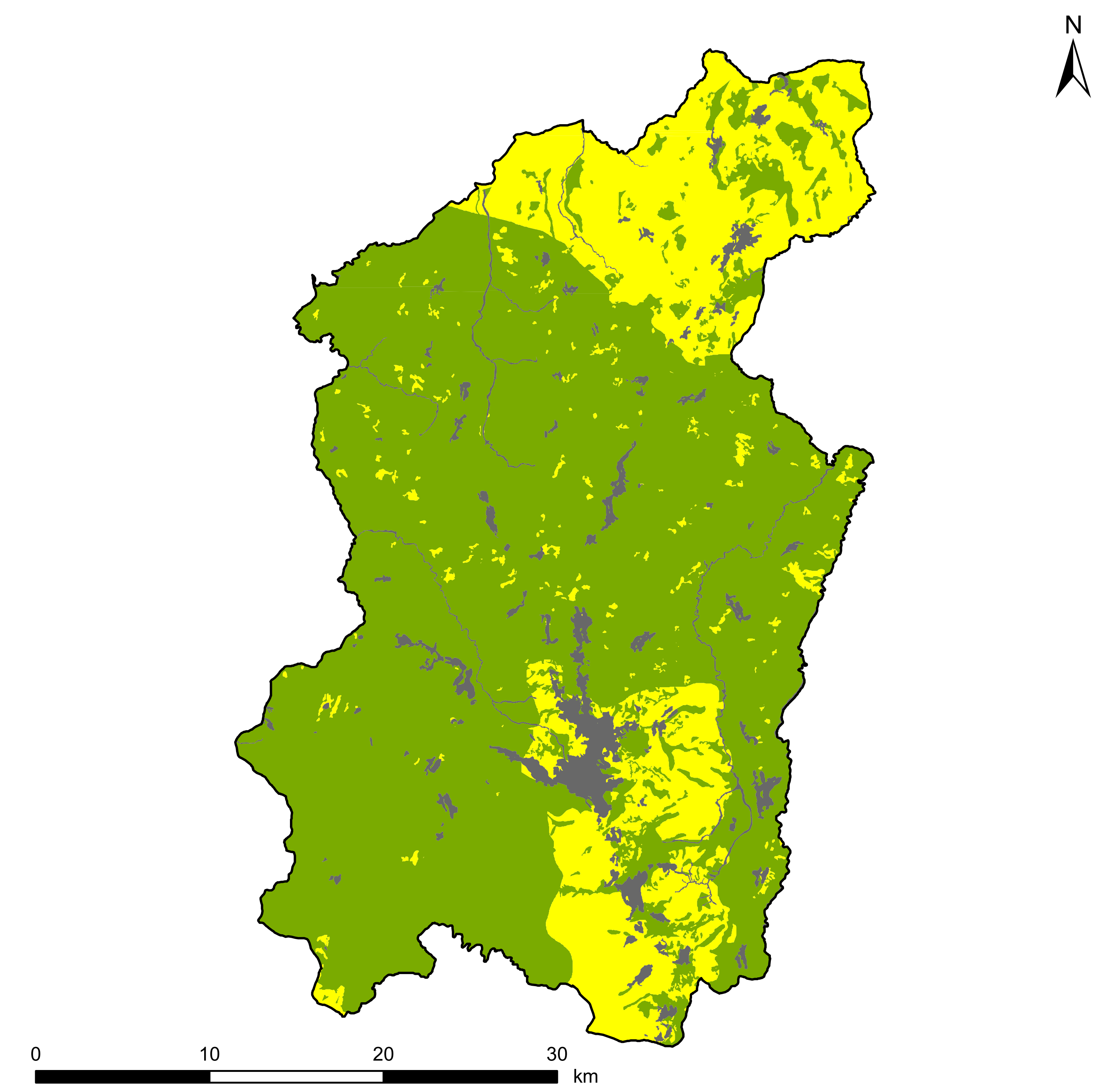
Symbol	Vulnerability Index	Area (%)
	Very Low	0.00
	Low	83.00
	Moderate	13.14
	High	0.00
	Very High	0.00
	Others	3.86

Location Map



Prepared by:
North Easrern Space Applications Centre, Meghalaya
&
Space Applications Centre, ISRO, Ahmedabad

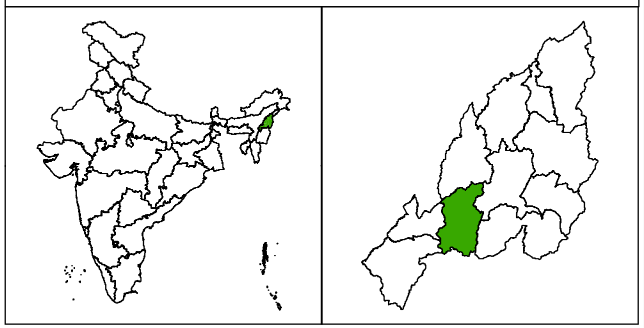
Land Degradation Vulnerability Assessment Map
Kohima District, Nagaland



Legend

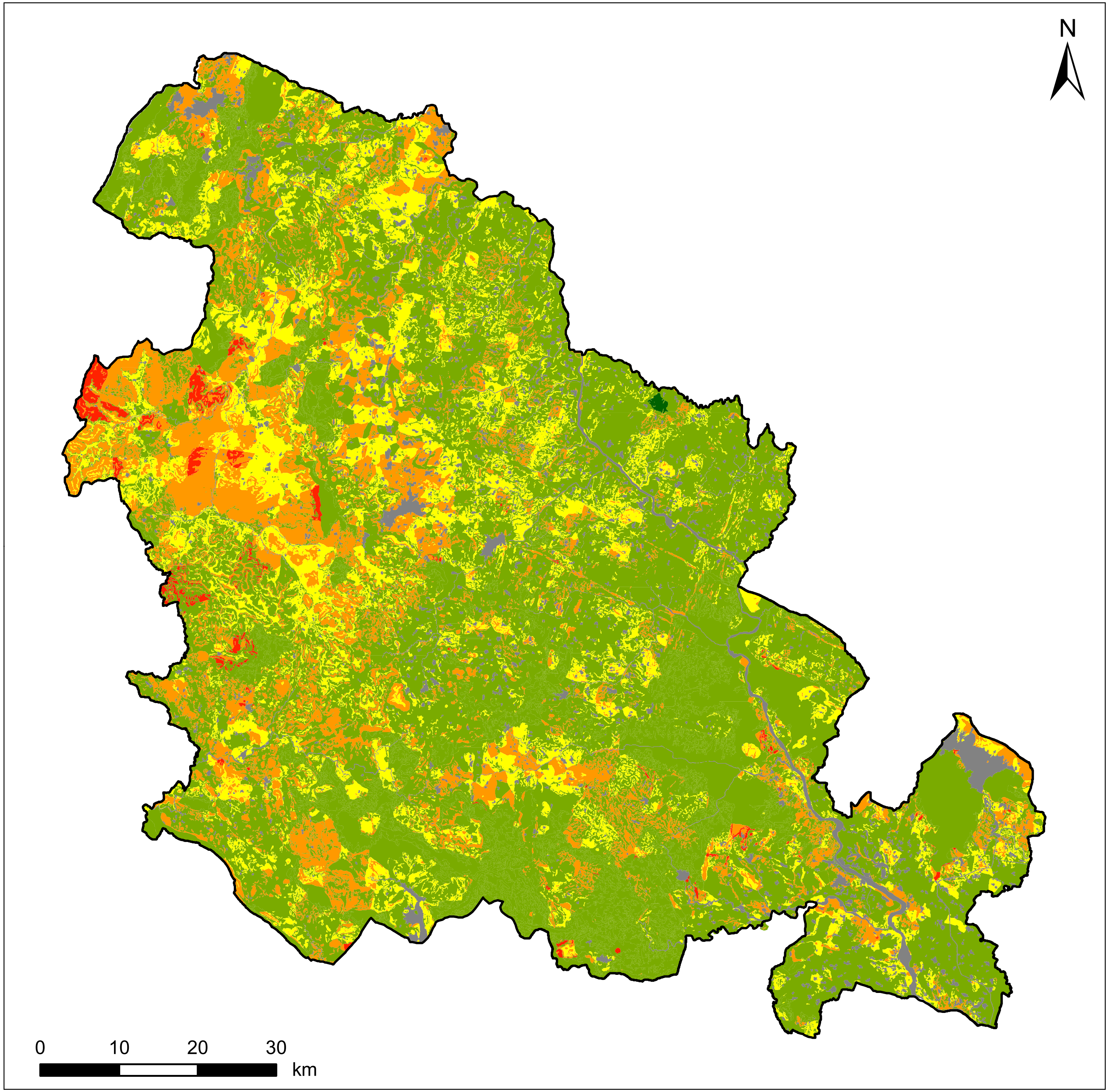
Symbol	Vulnerability Index	Area (%)
(dark green)	Very Low	0.00
(green)	Low	72.08
(yellow)	Moderate	22.64
(orange)	High	0.00
(red)	Very High	0.00
(grey)	Others	5.28

Location Map



Prepared by:
North Easrern Space Applications Centre, Meghalaya
&
Space Applications Centre, ISRO, Ahmedabad

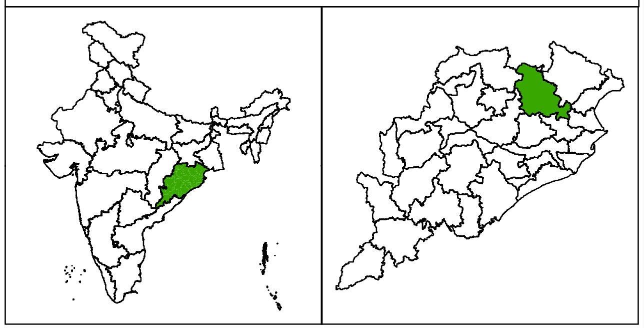
Land Degradation Vulnerability Assessment Map
Kendujhar District, Odisha



Legend

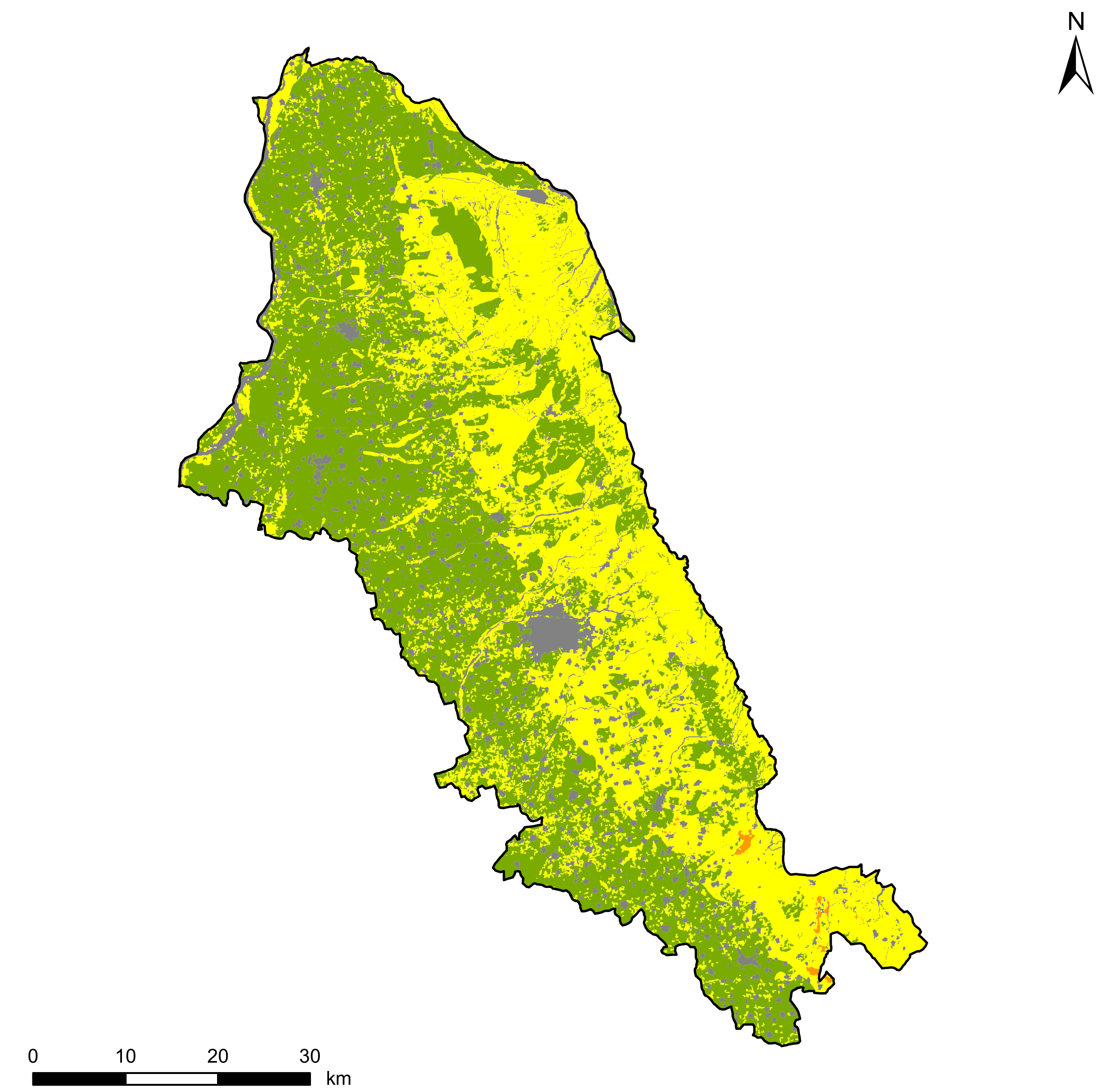
Symbol	Vulnerability Index	Area (%)
	Very Low	0.04
	Low	62.47
	Moderate	14.63
	High	16.79
	Very High	0.87
	Others	5.20

Location Map



Prepared by:
Orissa Remote Sensing Applications Centre, Bhubaneshwar
&
Space Applications Centre, ISRO, Ahmedabad

Land Degradation Vulnerability Assessment Map
Hoshiarpur District, Punjab



Legend

Symbol	Vulnerability Index	Area (%)
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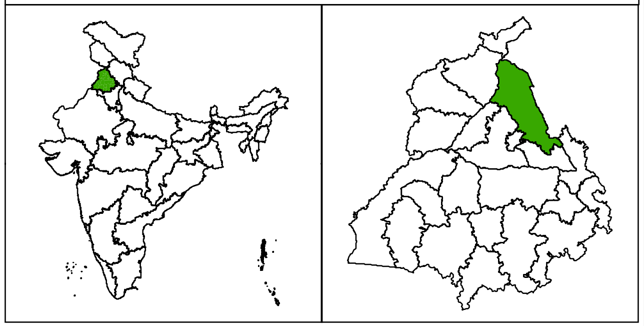
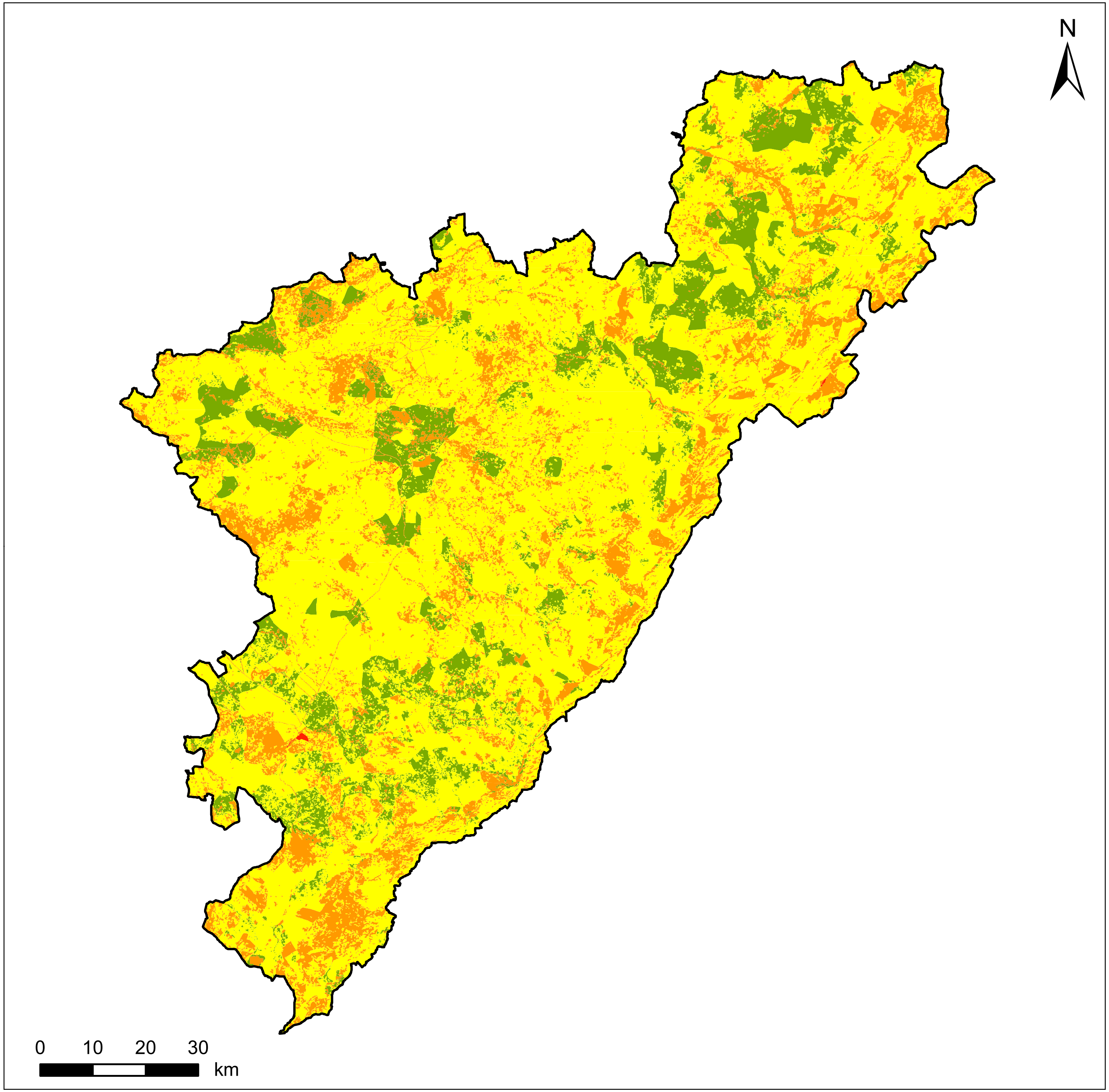
	Low	50.40
	Moderate	41.19
	High	0.22
	Very High	0.00
	Others	8.19

Location Map



Prepared by:
Jawaharlal Nehru University, Delhi
&
Space Applications Centre, ISRO, Ahmedabad

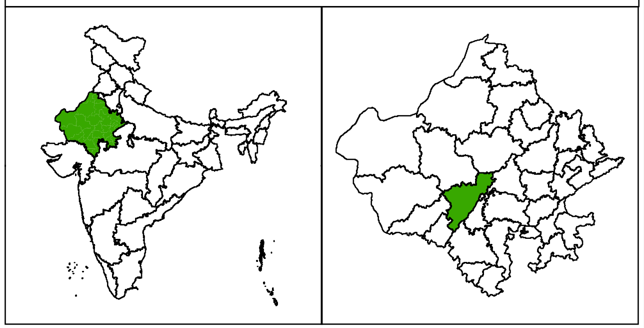
Land Degradation Vulnerability Assessment Map
Pali District, Rajasthan



Legend

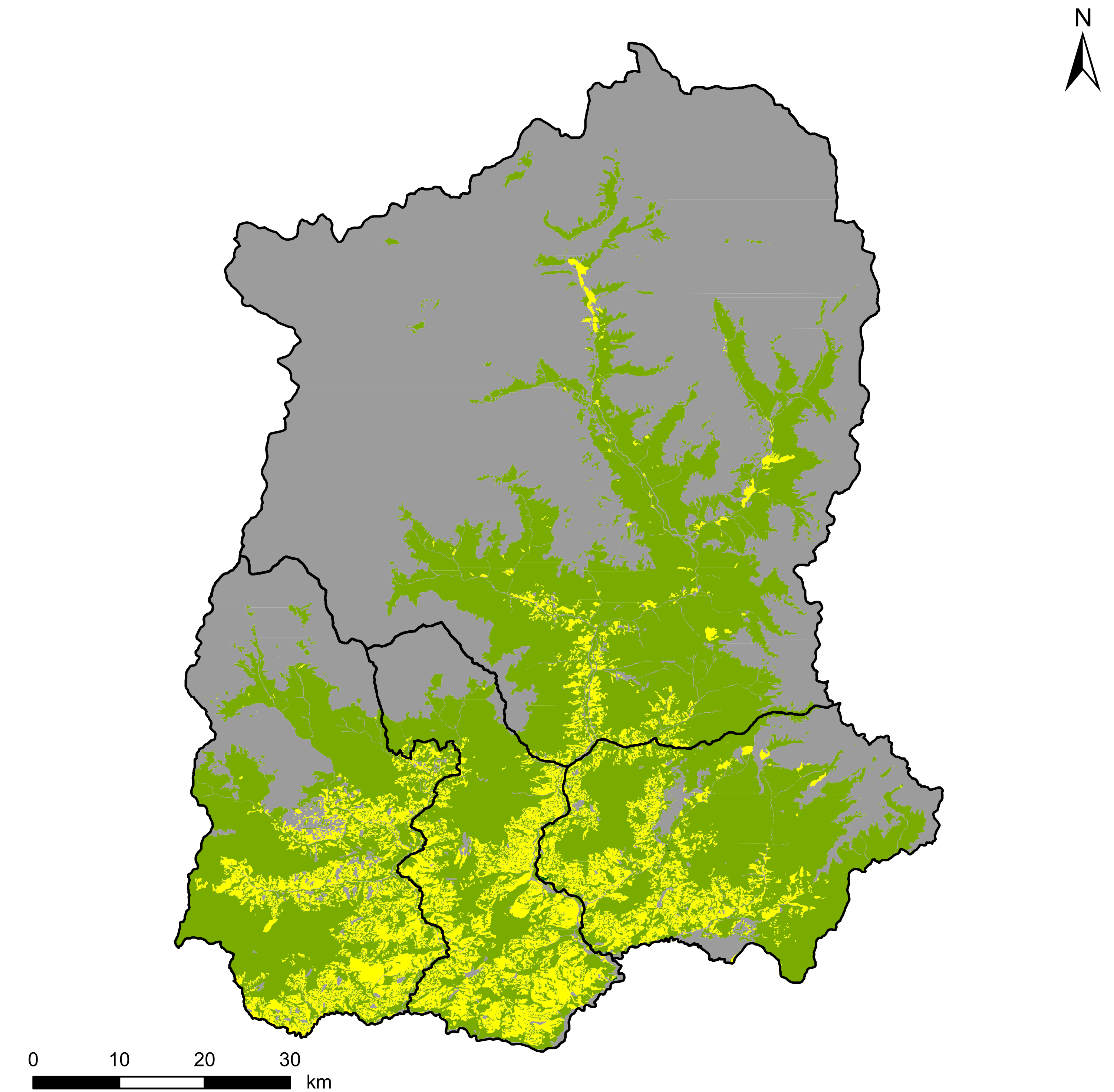
Symbol	Vulnerability Index	Area (%)
	Very Low	0.00
	Low	13.58
	Moderate	66.95
	High	18.52
	Very High	0.03
	Others	0.93

Location Map



Prepared by:
ICAR - Central Arid Zone Research Institution, Jodhpur
&
Space Applications Centre, ISRO, Ahmedabad

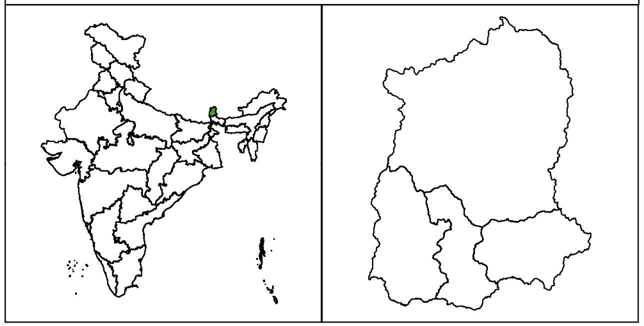
Land Degradation Vulnerability Assessment Map Sikkim



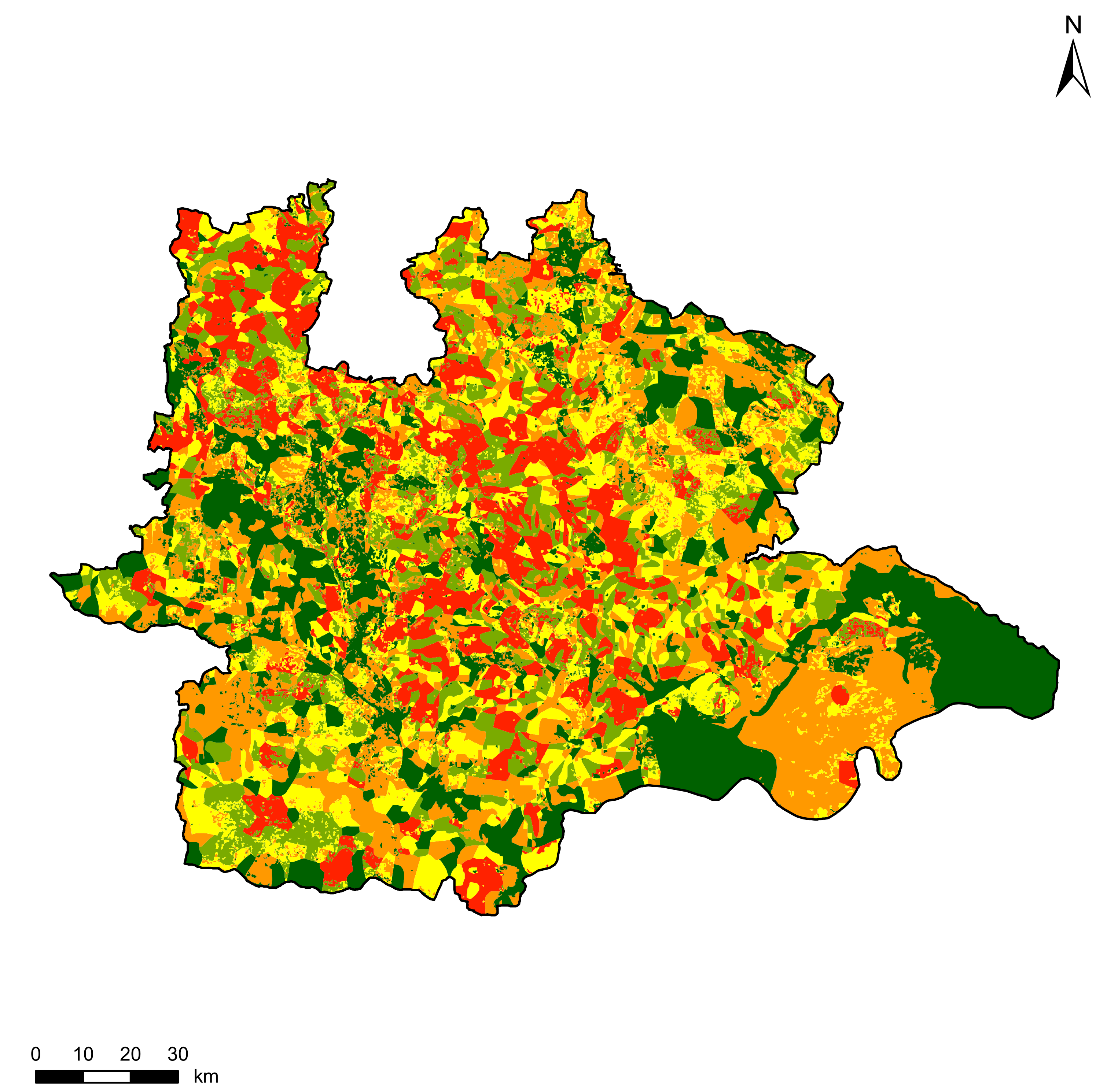
Legend

Symbol	Vulnerability Index	Area (%)
	Very Low	0.02
	Low	38.56
	Moderate	8.56
	High	0.00
	Very High	0.00
	Others	52.87

Location Map



Prepared by:
North Easrern Space Applications Centre, Meghalaya
&
Space Applications Centre, ISRO, Ahmedabad

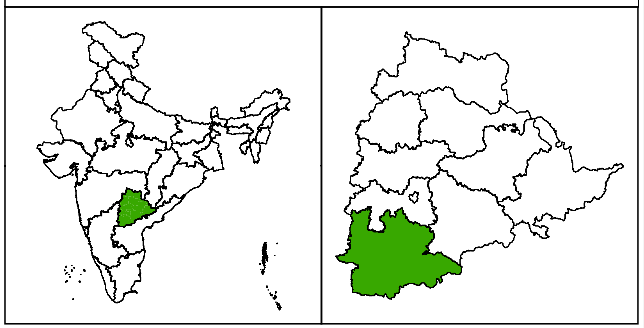


Land Degradation Vulnerability Assessment Map
Mahabubnagar District, Telangana

Legend

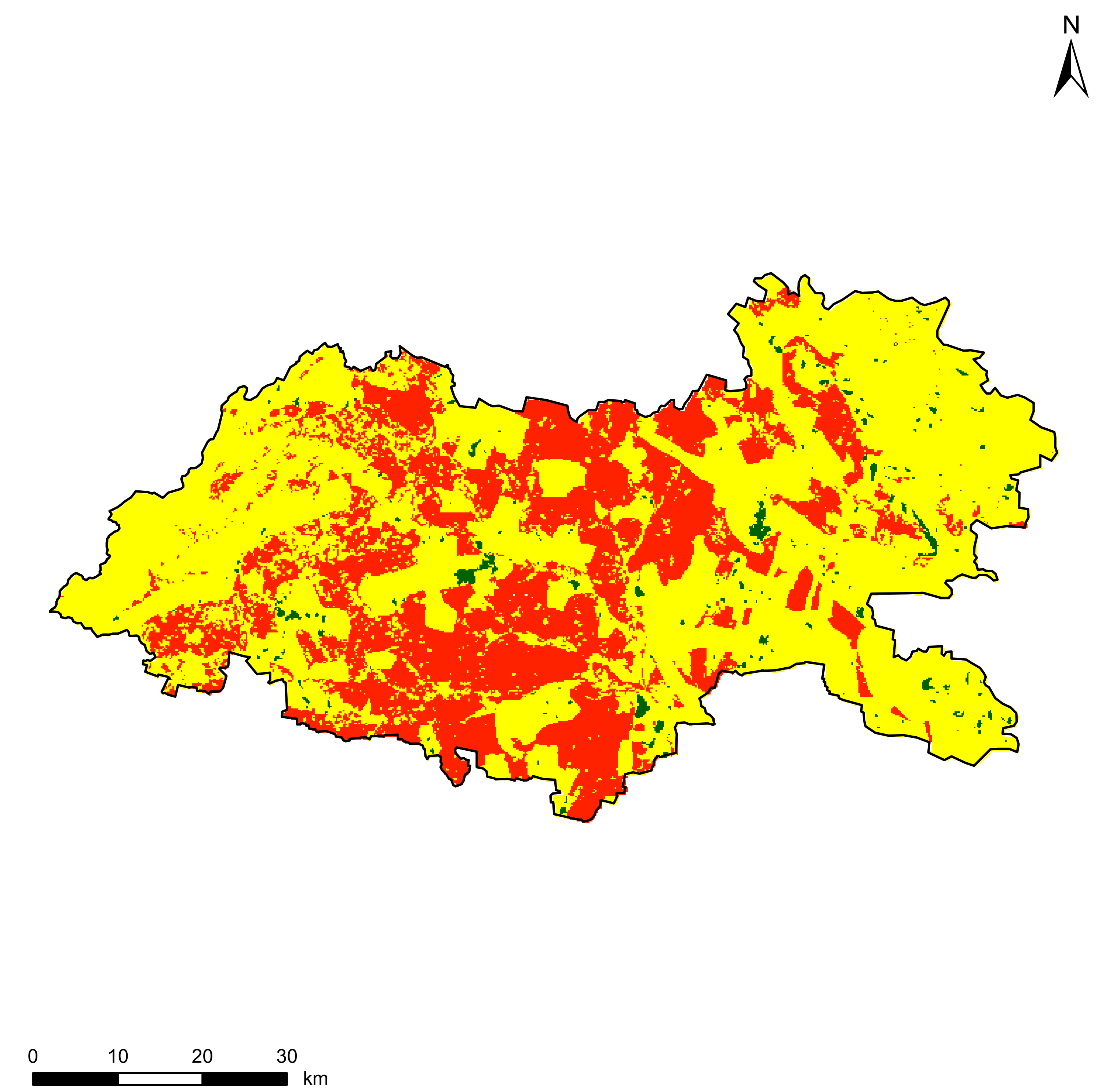
Symbol	Vulnerability Index	Area (%)
	Very Low	16.23
	Low	16.23
	Moderate	20.05
	High	25.82
	Very High	19.09
	Others	2.58

Location Map



Prepared by:
National Bureau of Soil Survey and Land Use Planning, Bangalore
&
Space Applications Centre, ISRO, Ahmedabad

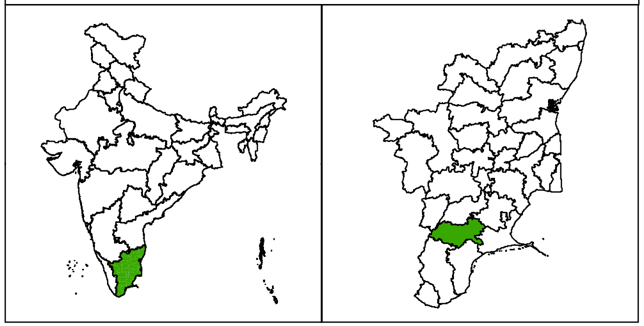
Land Degradation Vulnerability Assessment Map
Virudhunagar District, Tamil Nadu



Legend

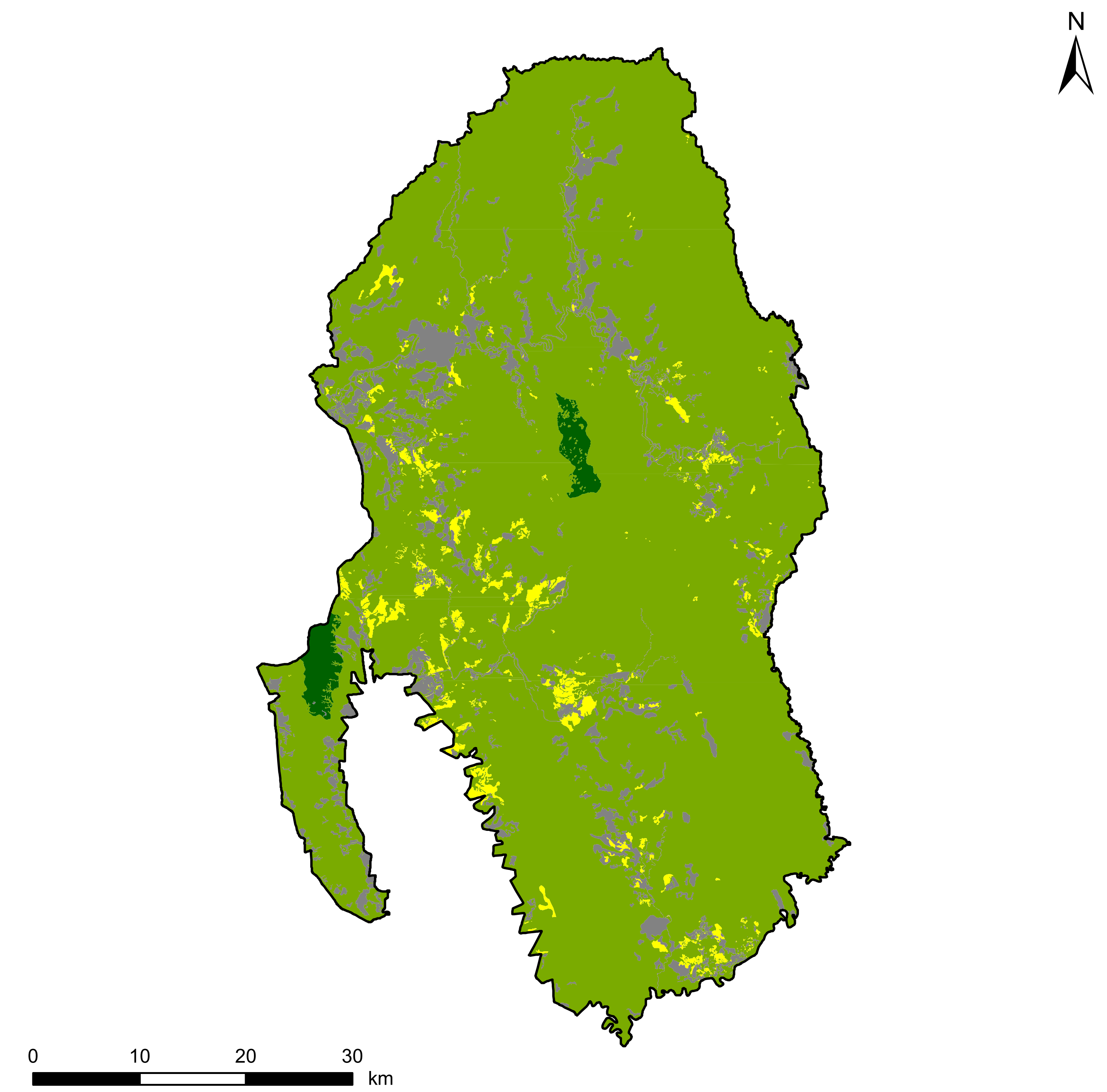
Symbol	Vulnerability Index	Area (%)
(dark green)	Low	1.42
(yellow)	Moderate	65.42
(red)	High	33.16

Location Map



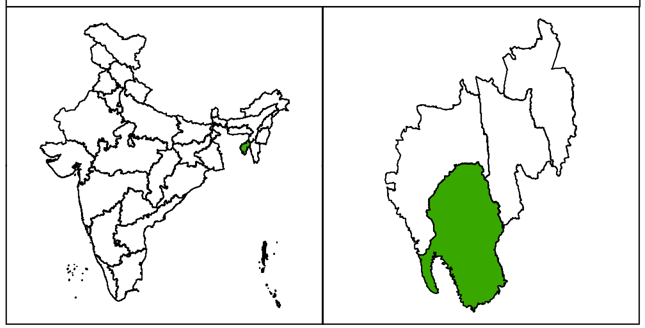
Prepared by:
National Centre for Earth Science Studies, Thiruvananthapuram
&
Space Applications Centre, ISRO, Ahmedabad

Land Degradation Vulnerability Assessment Map
South Tripura District, Tripura



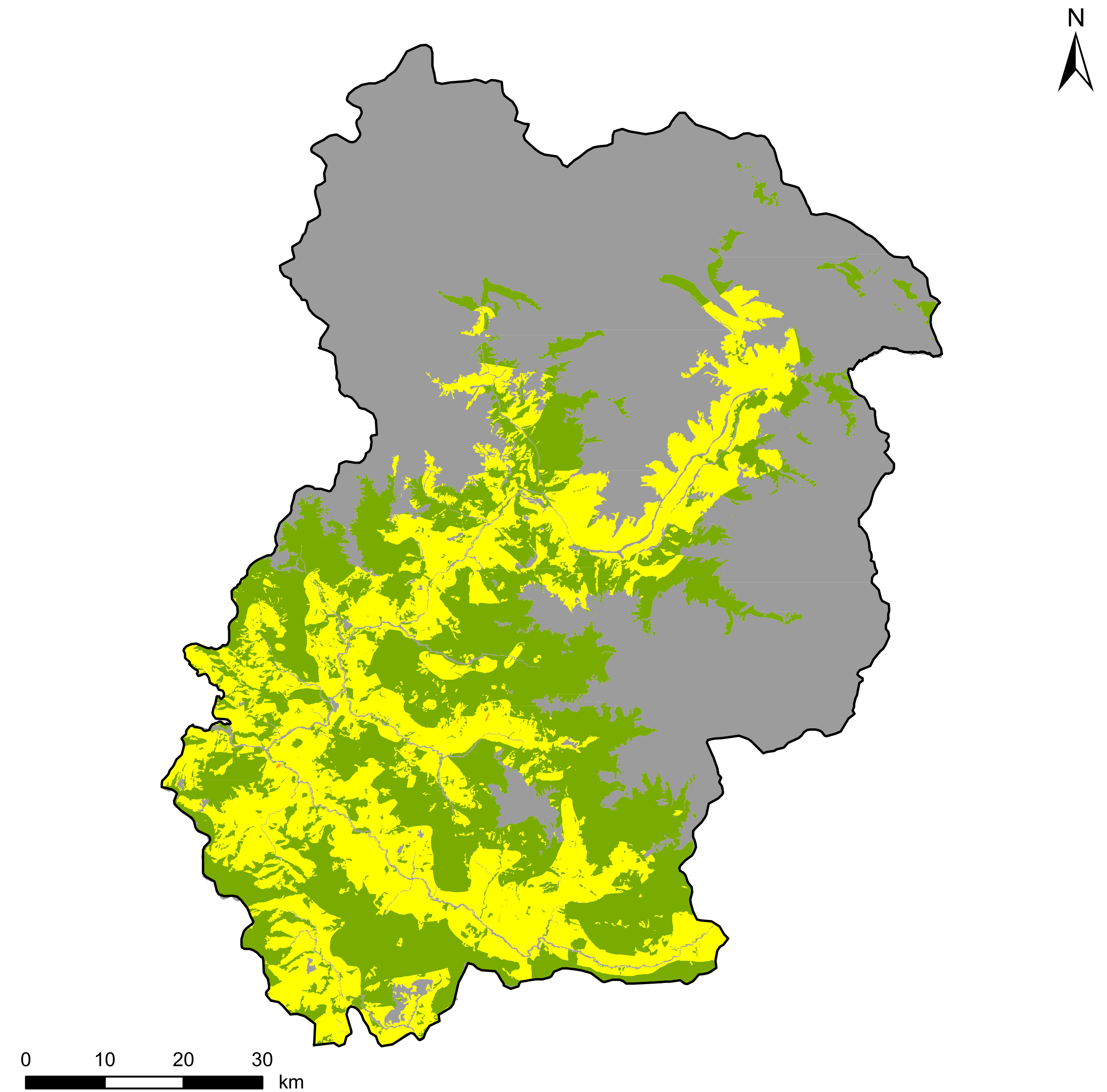
Legend

Symbol	Vulnerability Index	Area (%)
	Very Low	1.36
	Low	87.84
	Moderate	2.53
	High	0.00
	Very High	0.00
	Others	8.27



Prepared by:
North Easrern Space Applications Centre, Meghalaya
&
Space Applications Centre, ISRO, Ahmedabad

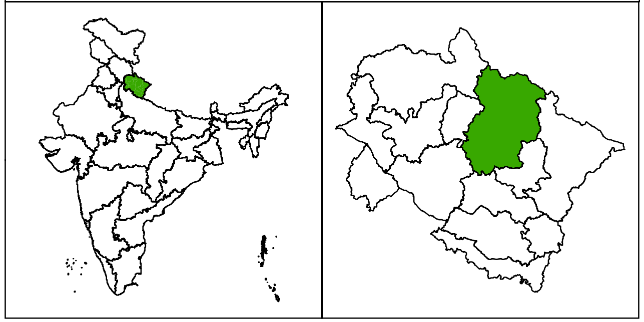
Land Degradation Vulnerability Assessment Map
Chamoli District, Uttarakhand



Legend

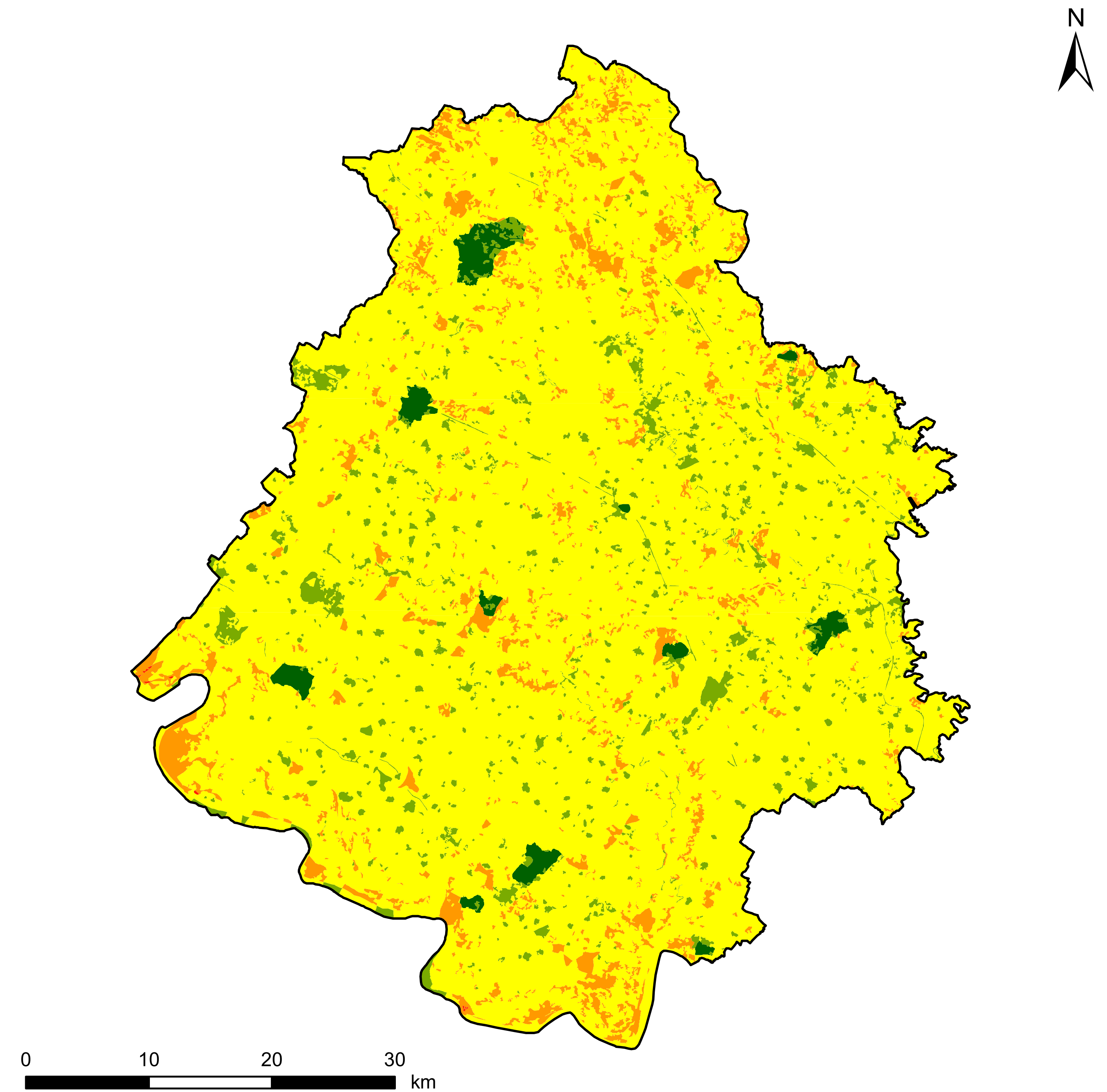
Symbol	Vulnerability Index	Area (%)
	Very Low	0.00
	Low	26.93
	Moderate	22.89
	High	0.01
	Very High	0.00
	Others	50.17

Location Map



Prepared by:
Jawaharlal Nehru University, Delhi
&
Space Applications Centre, ISRO, Ahmedabad

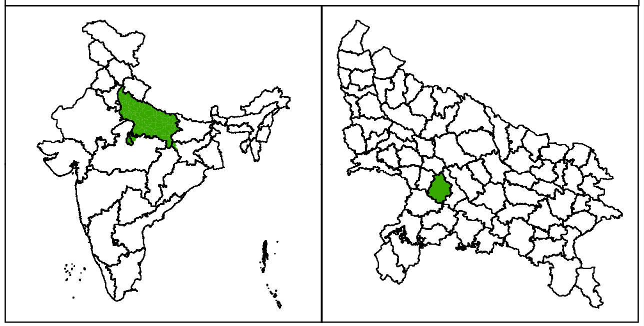
Land Degradation Vulnerability Assessment Map
Kanpur Dehat District, Uttar Pradesh



Legend

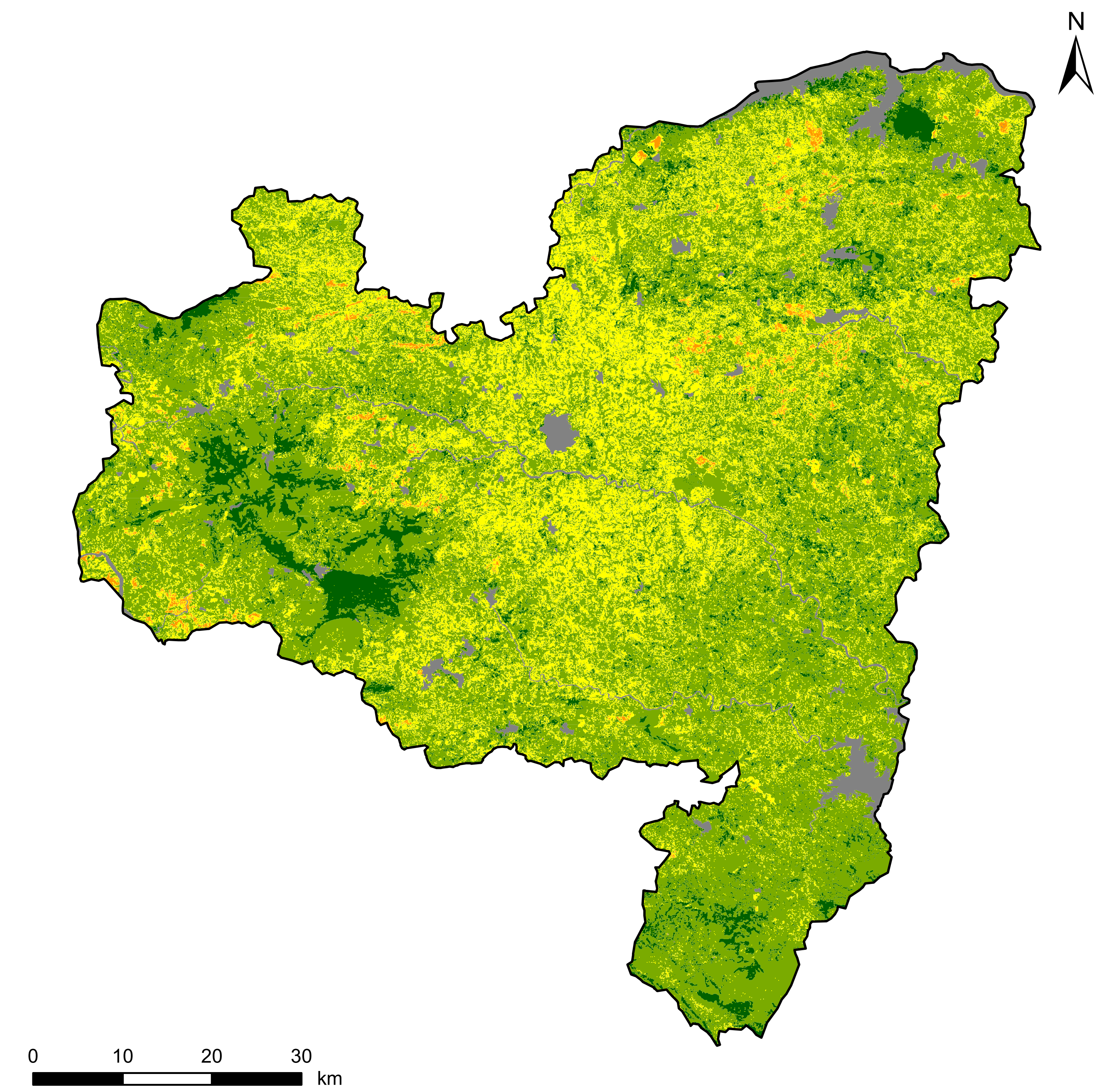
Symbol	Vulnerability Index	Area (%)
	Very Low	1.43
	Low	5.23
	Moderate	86.15
	High	7.18
	Very High	0.01
	Others	0.00

Location Map



Prepared by:
Remote Sensing Applications Centre, Uttar Pradesh, Lucknow
&
Space Applications Centre, ISRO, Ahmedabad

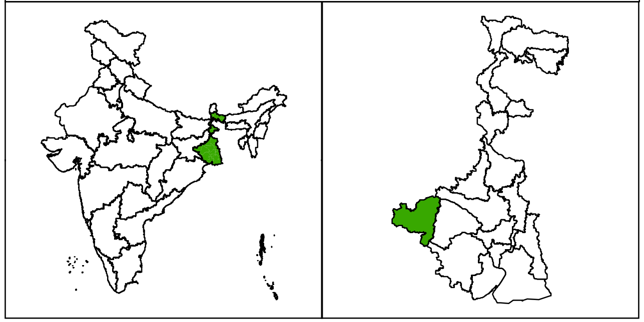
Land Degradation Vulnerability Assessment Map
Purulia District, West Bengal



Legend

Symbol	Vulnerability Index	Area (%)
	Very Low	8.53
	Low	63.40
	Moderate	23.81
	High	0.74
	Very High	0.00
	Others	3.51

Location Map



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&
Space Applications Centre, ISRO, Ahmedabad

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