Assessment of Eco-Environmental Vulnerability Using Remote Sensing and GIS Tools in Maharashtra Region, India

Abstract:

Maharashtra region is prone to various disasters such as drought, floods, cyclones and earthquakeand has been exposed to extreme weather events like dry spells. Communities within these dry lands are poor and face extreme conditions of water stress. This study has been carried out to analyze and quantify climatic and anthropogenic effect on eco-environmental vulnerability dynamicchange.To achieve that a numerical model is set up, consisting of eight factors that are elevation, land use, drought, slope, NDVI, soil-type, soil erosion (water), and population density index & has been evaluated using the method of spatial principle component analysis (SPCA) on Remote Sensing and GIS platform. The integrated eco-environmental vulnerability index (EVI) of study area is estimated to analyse spatial-temporal dynamic vulnerability changes in the 11 years gap from 2000 and 2011. The results show that the study area has become eco-environmental vulnerable slightly (about 80% of the region) with an increased eco-environmental vulnerability integrated index (EVSI) value by more than 50% (i.e., about 74%) and the driving force of dynamic change is mainly caused by socio-economic activities.

In addition the estimation has been regionalized into thirty-four districts to serve as a base for decision-making for eco-environmental recovering and rebuilding. It is found that the most vulnerable district in 2011 is Ratnagiri and the least one is Sangli. There are nine districts which shows more than 100% increase in EVSI value, with the highest increase in Hingoli(100.65%), indicating that the districts have become most environmental vulnerable in the study-period.The research concludes that the method, supported by G.I.S using SPCA can't only represent distinctly the input spatial distribution of plain-mountain-belt feature, but also respect the whole river-valley as a single unit.

Keywords: *Eco-environmental Vulnerability Index (EVI): Spatial Principal Component Analysis (SPCA); Standardized Precipitation Index (SPI); Revised Universal Soil Loss Equation (RUSLE).*

1. Introduction

Climate change in nature has introduced sever effects that are also felt at local and regional levels. Vulnerability to climate change raises not only due to experience of climatic hazards, but also due to scarcityof thesensitive resource systems. The State of Maharashtra have a varied geography, large poor population, long coastline, and an economy closely related to climate sensitive zones like agriculture. The agriculture activities of the stateis probable to be extremely vulnerable to the influence of changes in precipitation intensity, patterns, frequency and temperature of dangerous events such as floods, droughts, heat waves, cyclones etc. In this framework, measuring current and future vulnerabilities, impacts of climate change and adaptation needs is of dynamic importance to the policy of state making and planning process (Teri, 2014).

Skondras et al (2011) studied the Application and assessment of the Environmental Vulnerability Index (EVI) in Greece. The EVI uses fifty (50) indicators that are classified into different categories reflecting a spherical view of vulnerability. By comparing the vulnerability scores, it may be concluded that the possibility for damage suffered due to potential hazards has been increased. Biodiversity plays a significant role in sustaining the resilience of ecosystems and therefore in reducing environmental vulnerability. The weakness of the EVI is that when applied at national level, it is to locate the most vulnerable area of the country. It has to be applied at regional level and such application would be time consuming and costly. Nandya et al (2015) estimated Environmental vulnerability assessment of eco-development zone of Great Himalayan National Park, India using spatial principal component analysis (SPCA) model. This model considered five factors: land-use/land-cover, forest canopy density, forest fire risk, landslide susceptibility and human population density. The primary factor responsible for the increase in vulnerability overtime was land use/land cover change due to hydro-electric power projects, construction of roads and other infrastructure developments. Forest fire and decreased forest canopy density are other major contributing factors, responsible for the increase in the environmental vulnerability.

Environmental vulnerability is the tendency of the environment to respond either positively or negatively to the changes in climatic conditions and human activities. It depends upon many factors such as land use, extent of construction, the nature of populations and ability to take quick and effective actions. Many methods for the vulnerability evaluation have been proposed, such as the comprehensive evaluation method, the fuzzy evaluation method, the artificial neural-network evaluation method, the landscape evaluation method and the analytical hierarchy process (AHP) method.This research evaluate environmental vulnerability by creating environmental vulnerability index (EVI) with aid of remote sensing and GIS techniques in Maharashtra and explore the influencing factors responsible for spatial-temporal variation of resources quality.

This study has been carried out in the Maharasthra area to analyze and quantify the climatic and anthropogenic effect on eco-environmental vulnerability, with a focus to the spatio-temporal decadal change district wise from 2000 to 2011. Maharashtra, the second largest state of Indiaby population and third by size, is prone to various disasters such as drought, floods, cyclones, and earthquake. An analysis ofhailstorms between 1981 and 2015 across the country by IMD (India Meteorological Department) has found that the country is exposed to extreme weather events. More than 30 % area of the state falls under the rain shadow area, about 84 % of the total cultivated area is rain-fed, and dry-landsthat face the combined stress of human pressures and drought. Communities within these dry lands are poor and face extreme conditions of water stress. In the view of the State environmental conditions and past research reviews, this work addresses the specific objectives as: (i) to evaluate an eco-environmental vulnerability index (EVI) model, using spatial principal component analysis (SPCA), supported by GIS & Remote sensing & (ii) to work out the regionalization at district level as the basis for the eco-environmental rebuilding planning in the Maharashtra region.

2. Materials and Methods

2.1 Study area

Maharashtrais an Indian state, located between 16^0 N to 22^0 N latitudes and 72.8^0 E to 80.89^0E longitudes, is spread over 307,713 km^2. It is the third largest state of India by size and the second largest by population. The location map of the State has been shown in Figure 1. There are 9 agro climatic zones and 9 major river basins are present in Maharashtra (Kalyankar*et al*., 2008*)*.Mahanadi basin is the largest basin of this region.

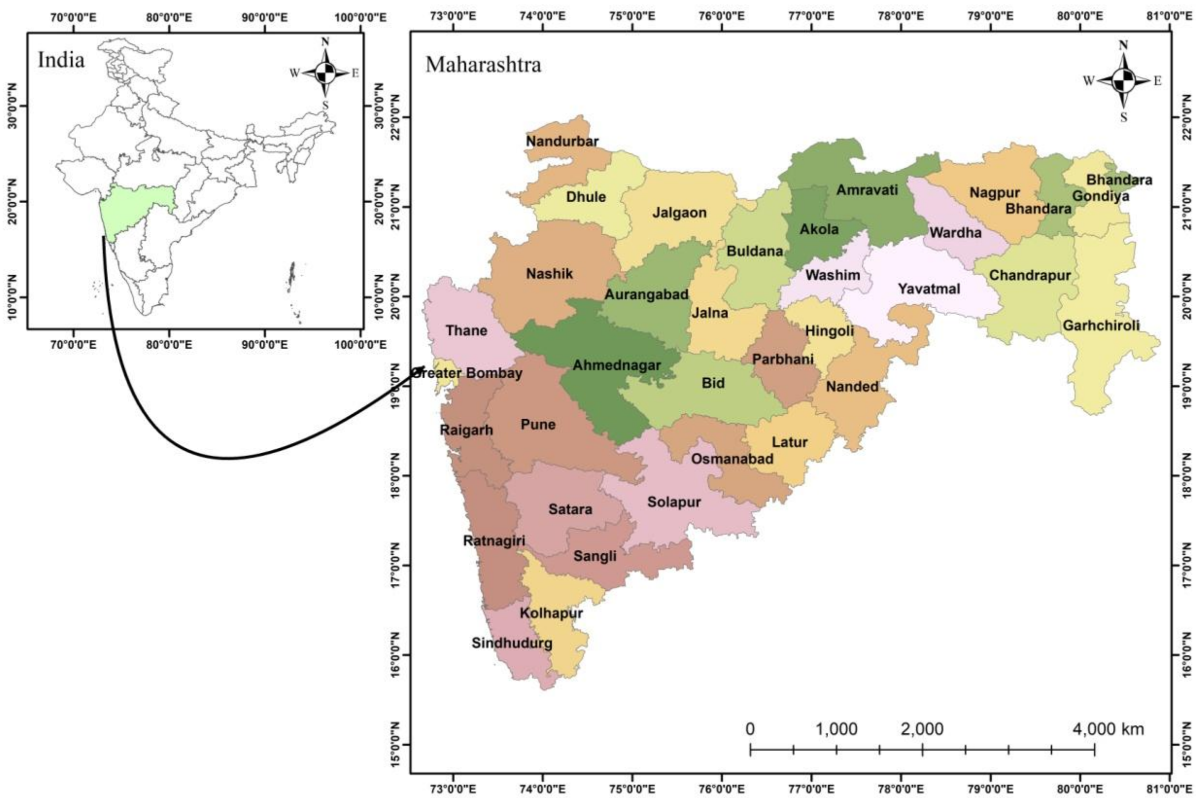


Fig 1: - Location Map of Study Area

It is the first state to adopt 'Dry Land Farming Technology' & also stands first in the country with more than 60% area under drip irrigation. Almost 82% of the state rural population depends on agriculture for livelihood. Both foods as well cash crops are grown in the state. The main food crops grown are mangoes, grapes, bananas, oranges, wheat, rice, jowar, bajra & pulses.Maharashtra experiences a tropical monsoon climate, and the annual precipitation of the state *varies* from 400-6000 mm. Maharashtra has typical monsoon climate, tropical conditions prevail all over the state. The months of March, April and May are the hottest summer months, while in winter, cool dry spell, with clear skies gentle breeze and pleasant weather prevails from November to February. Rainfall starts normally in the first week of June. July is the wettest month in Maharashtra, while August too gets substantial rain.

The state has a large amount of black soil, formed from basalt rocks (Mankad et al., 2009). The topography is quite level, but altitude increases particularly in the eastern region and also near Mumbai.

2.2. Datasets Used:

Basically the data used in the research comprise: (i) daily gridded rainfall data from 1991 to 2011 collected from IMD (ii) soil map from ICAR-NBSS&LUP, Nagpur, (iii) SRTM DEM (90m) (iv) LULC, for the year 2000 and 2011 from IIRS, Dehradun, (v) 16 days composite NDVI from MODIS version-6 (250m) & (vi) Maharashtra district wise statistical population data from Indian census for the year 2000 & 2011. The details of the dataset have been listed in Table 1.

Table 1: Data their Resolution and their Sources

Sr. No.	Types of Data	Data Resolution	Source of data
1.	Rainfall	0.25 degree	India Meteorological Department(https://mausam.imd.gov.in)
2.	Soil map	scale 1:1 million	National Bureau of Soil Survey and Land Use Planning,India
3.	DEM	90 meter	Shuttle Radar Terrain Mapper (SRTM), (http://www. usgs.gov)
4.	LU/LC	100 m	Indian institute of remote sensing (https://www.iirs.gov.in)
5.	NDVI	250 m	MODIS, National Aeronautics and Space Administration’s

2.3. Methodology

The selection of evaluating methods plays a peculiar role in eco-environmental vulnerability evaluation and should be indicative, operational and representative. The anthropogenic and natural factors are crucial to the Maharashtra vulnerability. Based on the eco-environment qualitative analysis in study area, an integrated quantitatively evaluation criteria system has been set-up containing eight factors: elevation, slope, drought index, land use, vegetation, soil, water-soil erosion and population density. Presently, there are methods like IWM, AHP, to convert the parameters of land use, landform, and human interfere into an integrated index, however, these methods are function of expert’s evaluation to weigh the factors, and the understanding of experts affects the final result evaluation directly. The principle component analysis (PCA), using coefficients of linear correlation, offers the possibility to weight the contribution of factors more effectively. This research evaluates the EVI model by SPCA (a modified PCA approach). The flowchart of the numerical model is shown in Figure 2.

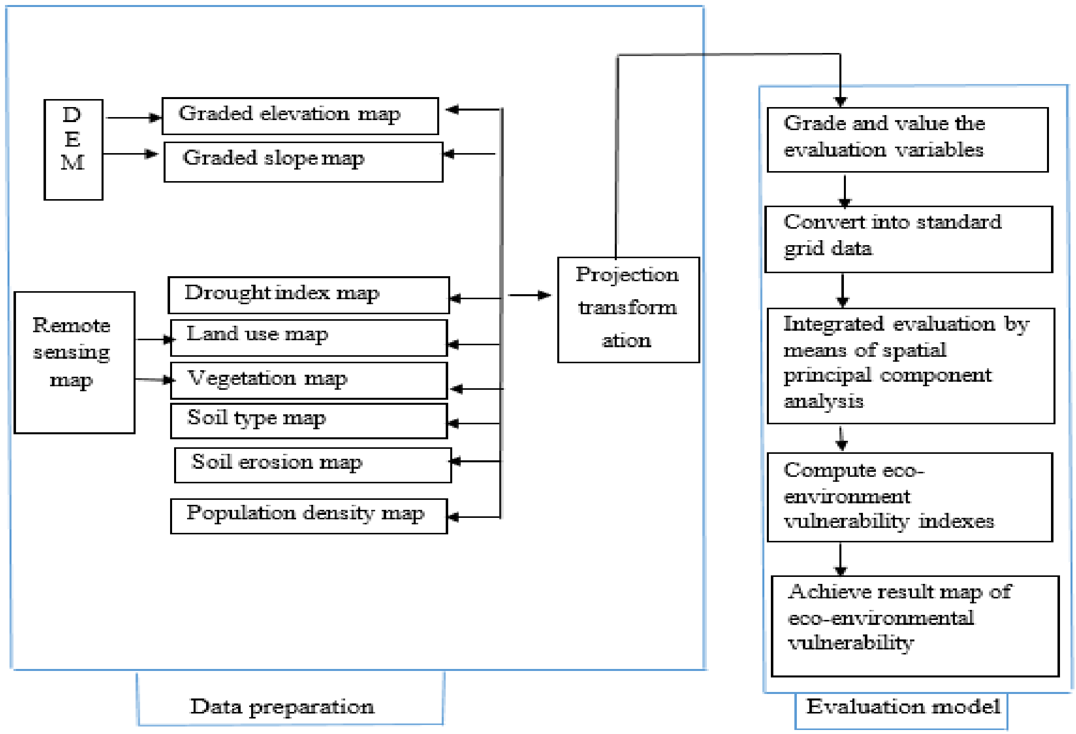


Fig. 2: Evaluation Model Flowchart

2.4. Data Input Maps Preparation

Drought index map is prepared based on 3-months SPI statistics.The SPI is based on the probability of precipitation for any time scale, which is then transformed into an index. A 3-month SPI reflects short- and medium-term moisture conditions and provides a seasonal estimation of precipitation. In primary agricultural regions, a 3-month SPI might be more effective in highlighting available moisture conditions than the slow-responding Palmer Index & other currently available drought indices. (SPI, User Guide, WMO, 2012; McKee, T.B et al., 1995).The similar index of SPI-3 has been analyzed for agricultural drought severity assessment and monitoring in south Bihar region of India(Singh et.al., 2021; Singh et.al.,2022).The drought evaluated by SPI has been validated by the results of drought assessed by rainfall departure and rainfall probability analysis (Singh et.al., 2021).The 3-months SPI values of the corresponding districts for the year 2000 & 2011, so calculated are checked for the most severe month when maximum districts have high negative SPI values. In 2000 & 2011 it is found that November & December are the extremely dry month. The SPI values of November & December for the year 2000 & 2011 are used & interpolated in arc platform to get the respective year drought index map. NDVI maps of November 2000 & December 2011 are used in this study, on the basis of minimum precipitation value as assured by SPI evaluation to analyses the most severe moisture deficit time situation. The NDVI map is extracted from LP DAAC (Land Processes Distributed Active archive Center), Version-6, MODIS products. District wise population density of Maharashtra from Census of India 2000 & 2011 are used to prepare the density maps for the years. Water soil erosion map is prepared using RUSLE model.The Revised Universal Soil Loss Equation, (Eqn. no: 1, Renard, K. G., 1997)is improved form of USLE (Wischmeier and Smith 1965, 1978), used to estimate average annual soil erosion potential using the Equation 1.

$$A \text{ (tons/ha/year)} = R \times K \times L \times S \times C \times P \qquad \text{(Eqn. no. 1)}$$

Where, *A* = soil loss (t ha-1yr-1), *R* = rainfall-runoff erosivity factor (MJ-mm ha-1hr-1yr-1), *K* = soil erodibility factor (t ha-1 h ha-1MJ-mm), *L* = slope length factor, *S* = slope steepness factor, *C* = cover-management factor and *P* = conservation practice factor.The similar method has been adopted for soil erosion estimation in Maharasthra region (Singh et.al., 2021)

3. Analysis of SPCA Result:

3.1 Processing of data:

The data input maps so prepared are re-projected to UTM WGS 1984, re-sampled to 90m × 90m grid unit & the result maps of each eight factors: elevation, slope, drought index, land use, vegetation, soil, water-soil erosion and population density is re-classified into five levels (2, 4, 6, 8, and 10) and integrated using SPCA on GIS platform to evaluate the final EVI map.

3.2 Evaluation Method

This study set up an eco-environmental vulnerability evaluation (EVI) model by SPCA method, which is a modified PCA approach. The process of eco-environmental vulnerability evaluation by SPCA are explained as follows: (a) to standardized primary data,(b) to establish a covariance matrix R of each variable,(c) to compute an Eigen-value λi of matrix R and its corresponding eigenvectors α_i&(d) to group α_i by linear combination and put out m principal components. In the software environment of the ARC, the function PRINCOMP is used to transform the data in a stack from the input multivariate attribute space to a new multivariate attribute space whose axes are rotated with respect to the original space. The axes in the new space are un-correlated. According to the cumulative contribution of components, the number of principal components is affirmed 8 and SPCA is accomplished. Then, an evaluation function is used to compute an integrated evaluation index on the basis of selected components. Environmental vulnerability index (EVI) is defined as sum of a couple of weighted principal components as defined by Equation 2.

$$EVI = \alpha 1Y1 + \alpha 2Y2 + \cdot \cdot \cdot + \alpha_{m} * Y_{m} \qquad \text{(Eqn. 2)}$$

Where Yi is i^{th} principal component & α_i is its corresponding contribution percentage. According to the vulnerability level, EVI map is graded & given a quantified value, as: a) potential vulnerability (EVI <4.7), is given '1',b) slight vulnerability (EVI 4.7 to 6.1) is given '2', c) light vulnerability (EVI 6.1-7.8) is given '3',d) medial vulnerability (EVI, 7.8-9.2) is given '4', and e) heavy vulnerability (EVI ≥9.2) is given '5'.

4. Results and Discussion

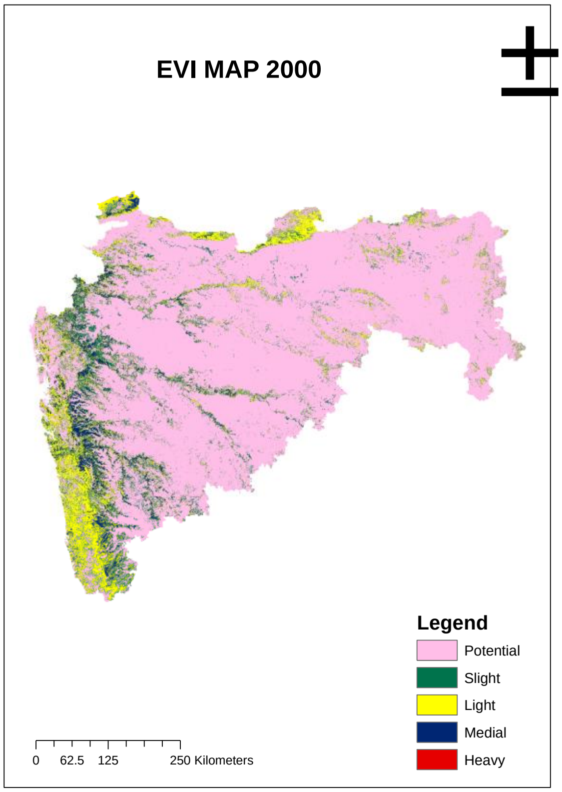
In the soil erosion map of Maharashtra (2000 & 2011) wide area is covered with the soil erosion rate (0-10 tons/ha/yr.) about 80%. The minimum soil erosion rate area % have declined in the period of 2000 to 2011 by 3.23%

The area having maximum erosion vulnerability (greater than 40.00 tons/ha/yr.) have increased by about 32% in the eleven years gap & lies in the western coastal part (eg: Raigarh, Ratnagiri, Sindudurg, Kolhapur, Pune, Satara etc.) and some area of northern coastal part (Nasik, Nandurbar, Jalgaon, Amravati, Buldana etc.).For the final EVI evaluation, the SPCA is accomplished with eight data inputs and eight principal components outputs. The results are listed in the Table 2.

Table 2Results of spatial principal component analysis

Principal components	1	2	3	4	5	6	7	8
Year: 2000								
Eigen value ʎi	3.891	2.358	1.5463	1.052	0.5095	0.399	0.102	0.052
Contribution ratios (%)	39.256	23.791	15.602	10.616	5.141	4.033	1.030	0.528
Cumulative contribution (%)	39.256	63.048	78.650	89.266	94.407	98.441	99.471	100
Year : 2011								
Eigen value ʎi	3.951	2.159	1.362	0.812	0.725	0.558	0.436	0.352
Contribution ratios (%)	38.151	20.848	13.150	7.844	6.999	5.394	4.214	3.399
Cumulative contribution (%)	38.151	58.998	72.148	79.993	86.993	92.386	96.601	100

The Table 2, shows the eight principal components as output, their corresponding Eigen values & contribution as well as cumulative contribution ratios, for both the two years 2000 & 2011. According to each components weight and generated stack, the algebra computation is worked out following the Equation 2, in the raster calculator and EVI map are generated pointing the situation of eco-environmental vulnerability. The EVI maps so created are continuous, which is classified into several levels standing for different eco-environmental vulnerability, as potential vulnerable, slight vulnerable, light vulnerable, medial vulnerable, and heavy vulnerable as per the vulnerability evaluation method as shown in Figures 2 &3 .Taking the year of 2011 as an example, the map is analysed and resulted that the slight vulnerable zone lies within average-value range with the largest area proportion accounting for 78.4%, the light vulnerable zone account for 7.93 %, the heavy vulnerable zone accounts for 6.6 % & the medial vulnerable zone account for 7.12% while potential vulnerable zone accounts zero as depicted in Table 2.



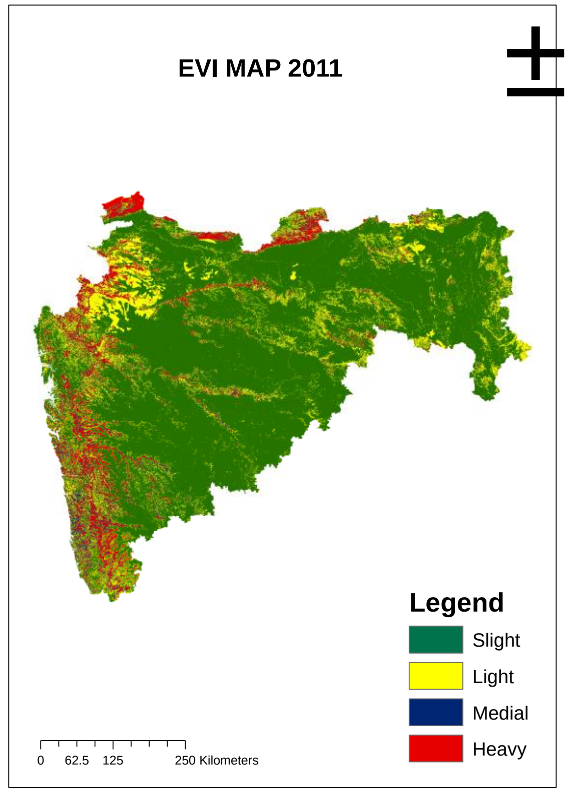
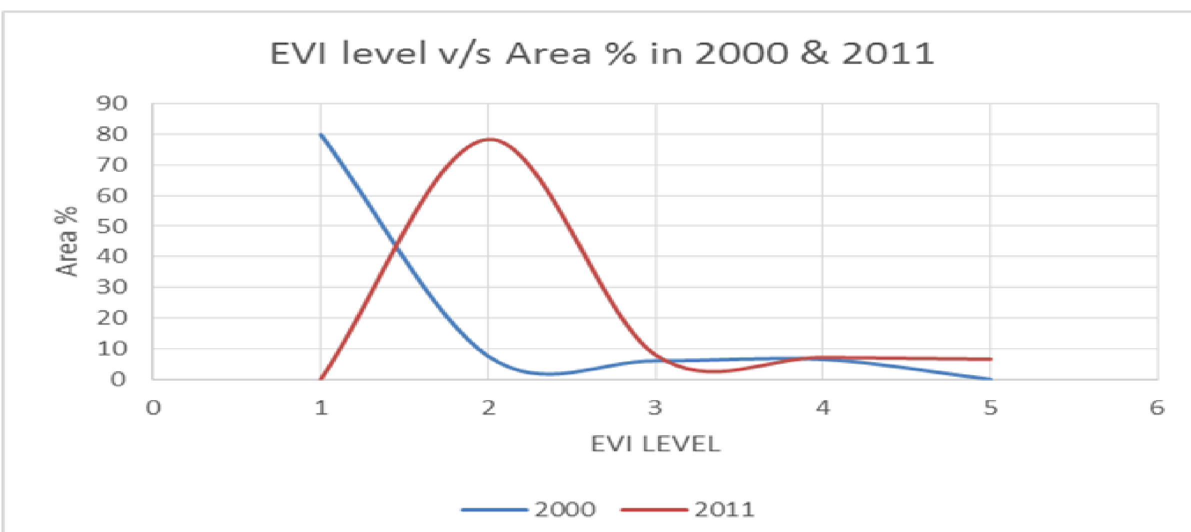


Fig.3: EVI Map, 2000 **Fig. 4: EVI Map, 2011**



(1) Potential vulnerability, (2) Slight vulnerability, (3) Light vulnerability, (4) Medial vulnerability & (5) Heavy vulnerability

Fig. 5: EVI Level v/s Area % in 2000 & 2011

The current (2011) profile of index shows an asymmetry distribution and the centre of profile lean to "heavy" level, as shown in Figure 5.

4.1 Analysis of changing trend of vulnerability:

According to the Equation 4& 5, the value of EVSI and its percentage increment in the whole study area and each district is worked out for the two years as shown in Table 3.

EVSI % increase = (EVSI in 2011 - EVSI in 2000) / (EVSI in 2000)*100. (Eqn. no. 4)

$EVSI_j = \sum_{i=1}^{n} Pi * \frac{A_i}{S_j}$ (Eqn. no. 5)

In this formula, EVSIj is the Eco-environmental Vulnerability Integrated Index in unit j, n is the number of valuation grade in the unit j, Pi is the graded value of grade i, Ai the occupied area of grade i in analysis unit j &Sj the total area of analysis unit j.

Table 3: EVI level area % of the study area in 2000 & 2011

Year	2000	2000	2000	2011	2011	2011	2000-2011
EVI-level	Grid- No:	Area (%)	EVSI	Grid-No:	Area (%)	EVSI	EVSI % increase
1.Potential vulnerability	30365536	79.93		0	0		
2.Slight vulnerability	2866222	7.545		29764205	78.349		
3.Light vulnerability	2284934	6.015	1.391	3014827	7.936	2.419	73.94
4.Medial vulnerability	2472071	6.51		2707115	7.126		
5.Heavy vulnerability	496	0.0013		2503112	6.589		

The general change trend of eco environmental vulnerability is analyzed from Table3,which is the situation in 2000 with an EVSI 1.391, is better than in 2011 with an EVSI 2.419.The higher the value of EVSI means the more serious eco-environmental vulnerability. In sequence of time, change of area % occupied by each evaluation level is surveyed as follows: level I is decreased by 79.94%, while levels II' III, IV and V have been increased by

70.81%, 1.93%, 0.62% & 6.587% respectively, indicating that area becomes more vulnerable in the period from 2000 to 2011. In the duration of eleven years the EVSI value increase by 73.94%. The research concludes that the most vulnerable district in 2011 is Ratnagiri with an EVSI value of 3.62 and the least one is Sangli having EVSI value of 1.58 & also in 2000 the most vulnerable district is Ratnagiri with an EVSI value of 2.50 but the least vulnerable district is Prabhani with an EVSI value of 1.03.The spatial variation of EVSI value district wise & the area % increment in 2000 & 2011 is as depicted below in the Figure 6.

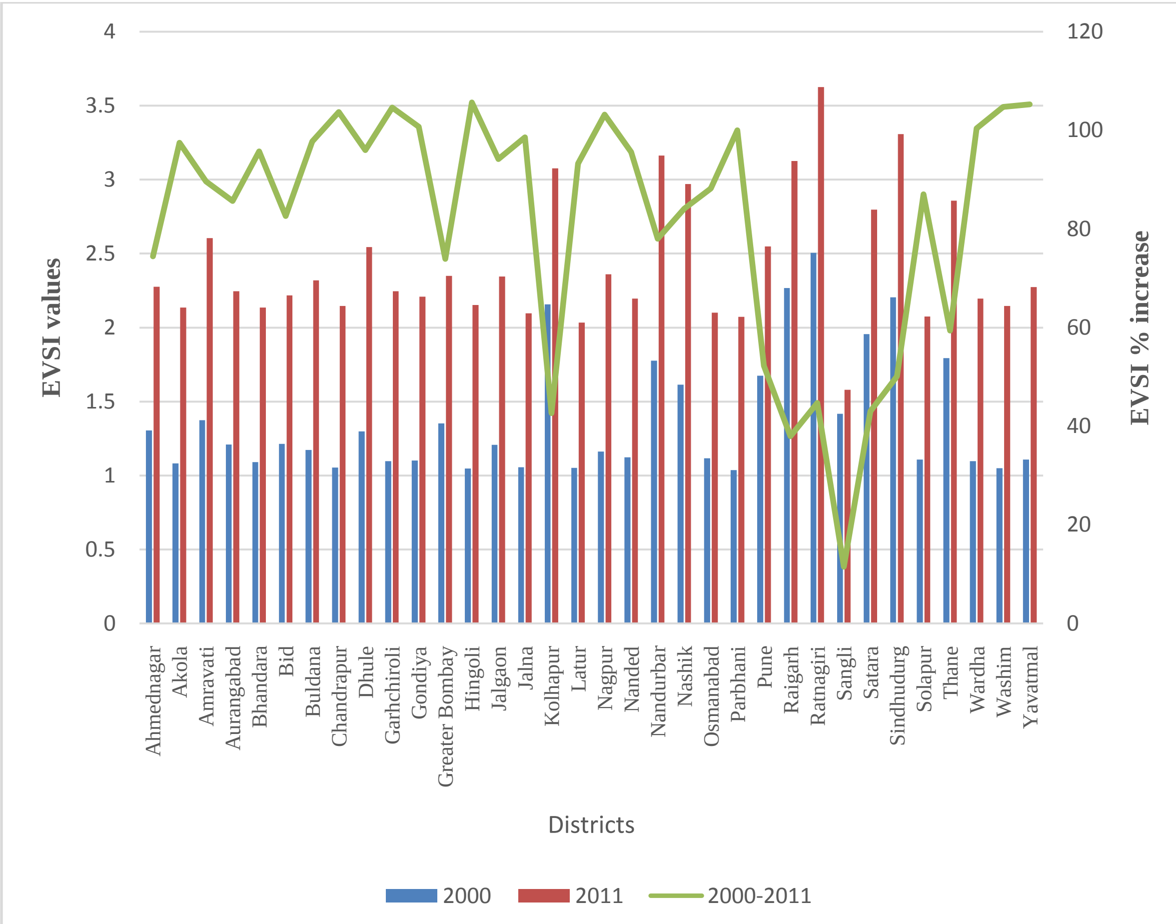


Fig. 6: EVI value district wise & % increase from 2000 to 2011

It can be seen from Figure 6, there are nine districts which shows more than 100% increase in EVSI value, with the highest increase in Hingoli (100.65%) followed by Yavatmal (100.25%), Washim (104.74%), Garhchiroli (104.65%), Chandrapur (103.74%), Nagpur (103.215%), Gondiya (100.74%), Wardha (100.36%) &Prabhani (100.03%). The higher the EVSI percentage increase, the greater the districts have become environmental vulnerable in the period of 11 years.

5. Conclusions:

This study has been carried out to analyze and quantify the district wise, climatic and anthropogenic effect on eco-environmental vulnerability. To achieve that, remote sensing (RS) and geographical information system

(GIS) technologies are adopted, and an environmental numerical model has been used based on spatial principle component analysis (SPCA) method. The model contains eight factors including elevation, slope, drought index, land use, vegetation, soil, water-soil erosion, and population density. Using the model, the integrated eco-environmental vulnerability index (EVI) of study area in 2000, and 2011 are computed. This research focuses on an idea about eco-environmental vulnerability in the Maharashtra region. The study draw the conclusions as:the percentage of area of soil erosion of the study area with a rate above 40 tons/ha/year has increased by about 32%, which indicate that there is an urgent need of an effective soil and water conservation measure. Eco-environmental vulnerability in study area is at slight vulnerable level, i.e., about 80% of the region. In addition the EVSI value of the area have increased by more than 50% i.e., about 74%, which indicate the vast vulnerability change from year 2000 to 2011.There are nine districts which show more than 100% increase in EVSI value, with the highest increase in Hingoli (100.65%). The higher the EVSI percentage increase, the more the districts have become vulnerable to environmental during the study year. The results of this study also indicate that the method that integrates the technologies, such as RS and G.I.S and the SPCA statistical approach to evaluate eco-environment vulnerability in plain-mountainous region, can effectively represent and analyze the environmental condition of the region, considering diverse and dynamic factors.

Conflict of Interests: The authors declare no conflict of interest. There is no conflict among authors regarding the concept, results and conclusions of the research paper. All the authors agree with the results and analysis of the research paper.

References

1. Kalyankar, S.D., Chavan A.A., Khedkar C.D., Kalyankar S.P. (2008). Studies on management practices of buffaloes in different agro-climatic zones of Maharashtra. *Indian J. Anim. Res*., 42 (3): 157-163
2. Mankad, M., Joshi P., Chavan M.,(2009). Agro-climatic zonation of Maharashtra State using GIS. Transactions of the Institute of Indian Geographers. 31(1):25-36.
3. McKee, T. B., Doesken, N. J., Kleist, J., & Canfield, N. L.. Early results of climate data continuity with ASOS. In Preprints, 11th AMS International Conference on Interactive Information and Processing Systems (IIPS) for Meteorology, Oceanography, and Hydrology , 1995, January, pp. 15-20.
4. Nandy, S., Singh C., Das K.K., Kingma N.C, Kushwaha S.P.S. (2015). Environmental vulnerability assessment of eco-development zone of Great Himalayan National Park, Himachal Pradesh, India, *Ecological Indicators*, 57, 182-195.
5. Renard, K. G., *Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE)*. United States Government Printing, 1997.
6. Singh, V., Nema A.K., Chouksey, A., S.K and Das S. (2021). Spatiotemporal soil erosion assessment using RUSLE model on geospatial platform for Maharashtra state, Indian Journal of Soil Conservation, Vol. 49, No. 3, pp 172-180.
7. Singh, V., KAR, S.K., &Nema, A. K. (2021). Drought severity assessment in south Bihar Agro-Climatic zone. *Mausam*, *72*(4), 865-878.

8. Singh, V., Kumar, N. A., Verma, R., & Kumar, K. (2021). Drought monitoring in south Bihar region using standard precipitation index. Current Advances in Agricultural Sciences, Vol. 13, No. 2, 101-108.
9. Singh, V., Nema, A.K., Chouksey, A. et al. Spatiotemporal evaluation of drought characteristics in south Bihar region using Standardized Precipitation Index (SPI). Arab J Geosci 15, 1231 (2022). https://doi.org/10.1007/s12517-022-10473-z
10. Skondras, N.A., Karavitis C.A., Gkotsis I.I., Kaly U.L., Alexandris S.G., (2011). Application and assessment of the Environmental Vulnerability Index in Greece, *Ecological Indicators*,11 (6,) 1699-1706.
11. Svoboda, M., Hayes M. and Wood D., Standardized Precipitation Index User Guide. World Meteorological Organization, 2012.
12. T E R I. (2014). Assessing Climate Change Vulnerability and Adaptation Strategies for Maharashtra: Maharashtra State Adaptation Action Plan on Climate Change (MSAAPC) New Delhi: The Energy and Resources Institute. 302 pp. [Project Report No. 2010GW01].
13. Wischmeier, W.H., Smith D.D. Predicting Rainfall Erosion Losses: a Guide to Conservation Planning. Agriculture Handbook 282 USDA-ARS, USA, 1978.
14. Wischmeier, WH., Smith D., Predicting rainfall erosion losses from Cropland East of the Rocky Mountains. Handbook no. 282, USDSA-ARS, USA, 1965.