FUZZY INTEGRATED DESERTIFICATION VULNERABILITY MODEL

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ABSTRACT:

Desertification and Land Degradation have constantly affected the global environment over the years. Land degradation is a reduction or loss of productivity over land due to natural processes, climate change and human activities. It involves complex set of processes, which interacts over space to decrease in land productivity. In the present study, regional desertification vulnerability assessment was carried out for Bhavnagar district of Gujarat, India. A vulnerability is a basic concept which explains the flaw in any structure of a system. A vulnerability may also refer to any type of shortcoming in systems, sub system parameters or processes, or in anything that leads the system to be exposed to a threat. Fuzzy Logic (FL) method combined with remote sensing (RS) and geographic information system (GIS) techniques has several advantages for assessing vulnerability. Technically FL combines the intricate classical analytic hierarchy process and grey clustering method for estimation of coefficients. Climate, soil, vegetation and land use play a significant role in desertification of any area, hence, in this work, several indices have been generated. However, man's intervention leads to significant changes in the environment, making socio-economic factor as a major input to assess vulnerability for desertification. Thus in this study FL has been integrated with both natural and socioeconomic factors for understanding the vulnerability to desertification in Bhavnagar region.

1. Introduction

Desertification is referred as land degradation in dry lands, it is continuously becoming an alarming global environmental issue in recent times. Specifically Desertification is 'Land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors including climatic variations and human activities', where 'Land' is defined as terrestrial bio-productive system and 'land degradation' is defined as reduction or loss in biological and economic productivity (UNCCD 1992). The definition suggests that environmental degradation is a slow but continuous and prominent problem for human civilizations since ages. There were many disastrous events around the globe that attracted attention related to environmental degradation like drought in South Africa (Glantz, 1977). The Dust Bowl in the United States, in the early thirties of the 19th century, and the apparent expansion of the Sahara (Lockeretz, 1978; Stebbing, 1935). These are some of the events, which could be taken as benchmarks or milestones in the development and evolution of the concept of desertification. Adverse impact of extended drought in the West African Sahel in the early 1970s, and rising interest in environmental conservation in the developed world, eventually leads to the holding of the Stockholm conference of the environment in 1972 and the creation of the United Nations Environmental Programme (UNEP).

The present study was carried out with an objective to recognize areas under the vulnerability of desertification/ land degradation along with their severity in terms of degradation in natural and socio economic parameters. The study emphasized on fuzzy membership analysis model integrated within geospatial environment. The outcome of the model would help to identify the vulnerable areas along with their risk categories in order to mitigate the effects of desertification and lay out proper management plans. The conventional methods to identify vulnerability was to classify basic parameters for land degradation and then defining classes with certain range of values and assigns particular classes. For socio-economic classification this system may not be suitable, as most of them are discrete values derived from certain administrative boundaries. But natural parameters are continuous and there remains some representative values in transitional areas between two classes. But this remained as a basic challenge in the study because the aim was to combine both natural and socio economic factors as input in the FL model. Thus interpolation techniques were applied. If observed in GIS environment, a considerable number of polygons can be found out which do not exactly represent a particular class of value, but a transitional zone. These zones are most important in terms of degradation, as they have the lowest probability to be in a certain consistent class, and highest probability to be in the most vulnerable classes. Thus, to embrace the variability of natural parameters like slope, soil depth, pH, texture and NDVI (the five parameters taken care of in this study) and socio economic parameters fuzzy membership approach is a viable option for risk categorization. Additionally, the use of remote sensing techniques and GIS along with fuzzy logic to evaluate the degree of risk would help an expert in very efficient planning of resource allocation and decision making.

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2. Study Area

Bhavnagar district in Gujarat, India, was selected as area of interest (figure 1). The district extends from 24°41'to 20°25' North latitude and from 69°5' to 70° 25' East longitude. It covers an area of 35200 sqkm^2. Bhavnagar is connected with Ahmedabad, Rajkot, Surendranager, and Amreli Districts with land on three sites where as on eastern sides, it is on the cost of Gulf of Khambhat. Bhavnagar has long Coastal area lies on Gulf of Khambhat. It is climatically semi-arid having three distinct season viz. winter, summer, and monsoon (June to September). The coastline of Bhavnagar is 156 km long. It has long coastal wetlands, which makes it economically suitable for water fowls and hence, important socio-economically it is one of the important districts of Gujarat. The coastline of Bhavnagar is muddy and rocky. The coastline of Bhavnagar District mainly the Mudflats and some of rocky patches are found near Gopnath. A few sandy beaches are also there. The coastline from Gopnath and Ghogha is rocky with small narrow non-calcareous sandy beaches and from Ghogha to the mouth of Sabannati River; it is highly muddy and shows extensive development of mudflats and mud banks.

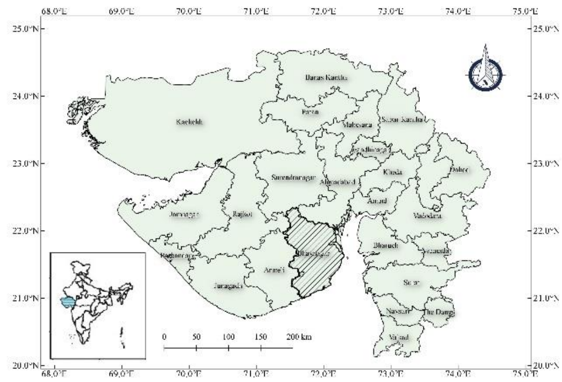

Figure 1: Study Area

3. Data Used

Many parameters are affecting land degradation including climate, soil, vegetation, terrain etc. These all parameters are consider as inputs for vulnablrity assessment. Satellite images of three season (Kharif, Rabi and Zaid) were used to calculate NDVI, soil erosion, soil pH, soil texture, slope maps were used as soil input data along with other ancillary information were used for identifying desertification risk areas of Bhavnagar district in Gujarat as shown in table 1.

4. Methodology

Risk assessment methods are mostly complex. Mostly risk assessment methods are qualitative. Thus main aim of the study was to bring in quantitative decision rules while drawing the conclusion. To march forward towards quantitative assessment fuzzy logic theory was explored so as to combine the decision rules with both risk assessment in qualitative and quantitative ways (Zlateva et al. 2005). Since information and decisions are closely linked, the raw information was connected by fuzzy logic to the qualitative decision rules (Dasgupta et al., 2014). In fuzzy logic system, the input variables are represented and assessed by using bell-shaped membership functions. The entire bell shaped curve was divided as 'low', 'moderate' and 'high' according to its distribution function. The overall methodology is shown in the form of a flowchart in figure 2.

Table1: Data Specification

Data Sets Used	Source	Sensor and Specification
Satellite Image	USGS	Landsat-7 30mtr Jan, May, Oct of year 2011 to 2013
DEM	Bhuvan	Carto DEM of resolution 30 meter
Soil Data	NBSSLUP	Slope, pH, Texture, Erosion, Drainage etc.
Climate Data	CGIAR-CSI	Global Aridity Index database
Census	Census-2011	Population, Education, Income etc.

Natural parameters, aridity, slope, soil and NDVI were used for climate, terrain, soil and vegetation analysis and several socio economic factors were used for understanding economic pressure over the study area. All the parameters were classified into nine classes. Then further each class was divided into three sub classes. The total range of values of single parameter mean as μ and standard deviation as σ, with x being a single variable. The values lying in between μ+2σ of the previous class and μ−2σ of the next class were considered as vulnerable and identified as the risk area.

Class 1	$X \leq \mu - \sigma$
Class 2	$\mu - \sigma < X \leq \mu - \sigma$
Class 3	$X \geq \mu - \sigma$

Normal probability density function was used to obtain the membership of individual variable to be in a particular class, following the statistical formula:

$$f(x, \mu, \sigma) = \frac{1}{\sigma\sqrt{2\mu}} \times e^{-(x-\mu)^2}/2\sigma^2$$

Where x is the value or an individual member of a class of chosen parameter, μ is the arithmetic mean and σ is the standard deviation of the class. Secondly, identification of vulnerable areas is very straight forward from this statistical model it allows easy identification of the tell end parts of its curves. However in the final stage natural parameter and socio-economic parameters, risk values were obtained and one single Desertification Risk index (DRI) was derived integrating individual following the fuzzy rule-based interference system.

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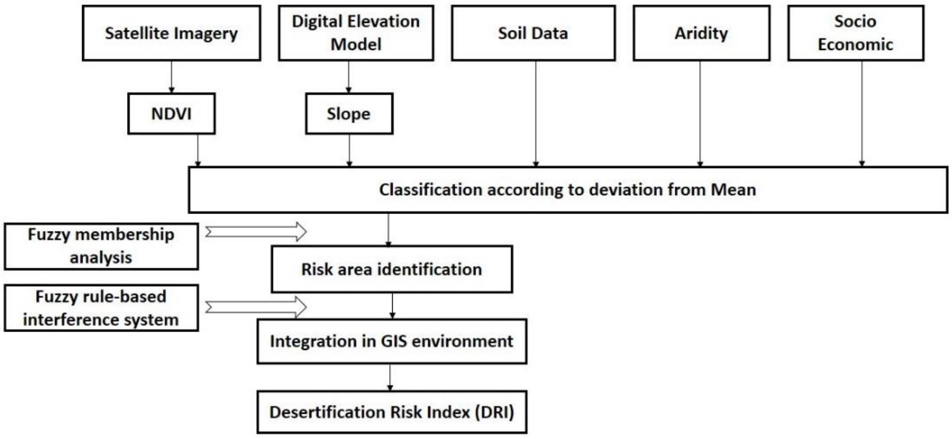

Figure 2: Methodology Flow chart

6. Result and Discussion

The analysis of Desertification Risk Index (DRI) using natural parameters and socioeconomic parameters are explained bellow:

5.1 Slope Index

Slope is mostly positively related to land degradation other than in any exceptional case. Thus slope gradient length, direction and position are important for analysis. Steeper the slope, greater the erosion, as a result velocity of water-flow and wind flow in the downward direction increases with the slope. The range of slope in the study area varied between 0 to 250m. Mean and standard deviation was calculated for the entire range and was divided first into 3 major classes and then sub division of each class was considered and derived.

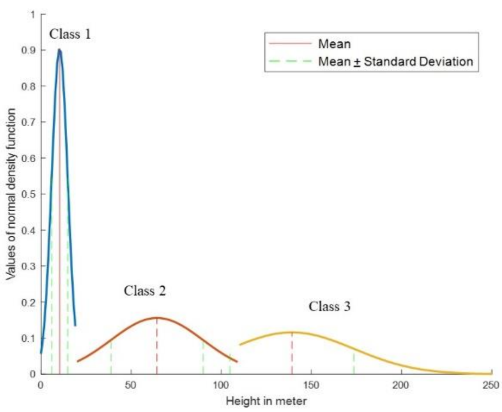

Figure 3: Normal density function of Slope classes to indicate risk categories

The graph (Figure 3) of distributed density function with focus to normal of class 3 shows one interesting thing which might be very significant in risk assessment following the normal probability density function, and accordingly the risk has been associated. Finally a Slope index map (Figure: 4) was generated according to the risk factor into 9 major classes.

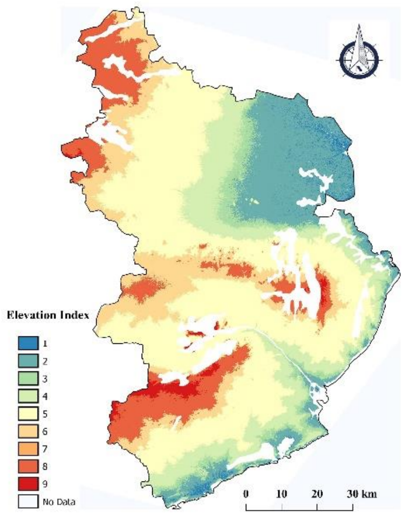

Figure 4: Elevation Index map

5.2 Soil Index

Soil is the most important factor for land degradation analysis. Soil index was integrated from several soil parameters combining soil depth, soil pH and soil texture severity using fuzzy rule-based interference system. The probability density function depicting normal, has been plotted and accordingly the risk was allotted (Figure 5). All possible unique combinations were found in the study areas under different risks of soil categories. It is witnessed that Class 3 exhibits the maximum risk in the study area as it has a steep slope on left side were as the bell shaped curve is instable in the right hand side. Finally a soil index map (Figure 6) was generated according to the risk factor into 9 major classes.

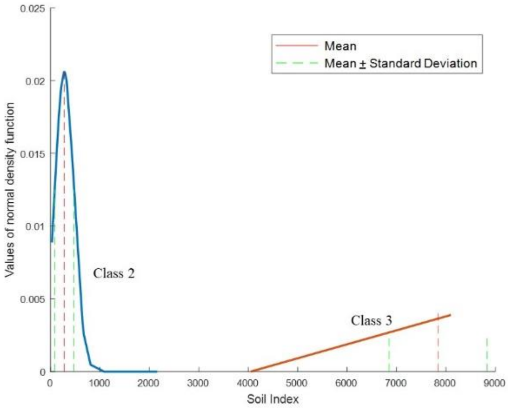

Figure 5: Normal density function of Soil classes to indicate risk categories

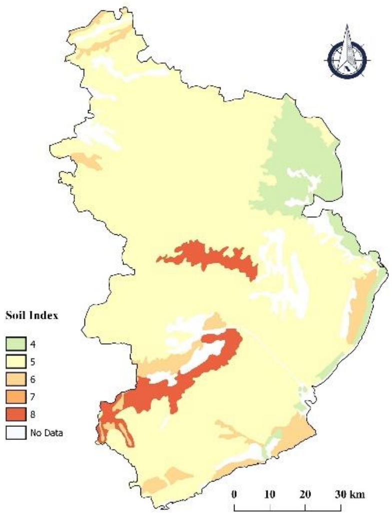

Figure 6: Soil Index map

5.3 Land use land cover Vulnerability Index

Land use/land cover was prepared using knowledge based supervised classification and maximum likelihood classifier algorithm. The results reveal that there are 9 different land use and land cover over Bhavnagar district. All the nine classes has been allotted a numerical value from 1 to 9 according to its vulnerability towards land degradation to the expert’s decision from several literature (Figure 7). The Table 2 exhibits the impact of vulnerability.

Table 2: LULC vulnerability index

LULC Class	Index Value
Deciduous Forest	1
Agricultural Land	2
Scrub/Deg. Forest	3
Scrub Land	4
Current Fallow	5
Wasteland	6
Gullied	7
Littoral swamp	8
Build up Area	9

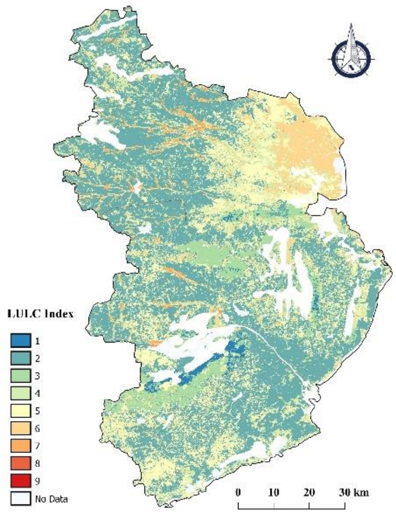

Figure 7: Land Use Land Cover Index map

5.4 Vegetation Index

The most important factor in regards to the protection of soil fertility and its productivity, is vegetation. Areas affected by desertification processes gradually lose their level of biological quality and productivity strength. Destruction of vegetation, most often by human activities accelerates soil degradation to large extent, hence leading to desertification. Therefore, higher photosynthetic activity will result in lower reflectance in the red channel and higher reflectance in the near infrared channel. This signature is uniquely identified with respect to the green plants and it also becomes reverse in case of unhealthy or water stressed vegetation. Thus, healthy vegetation absorbs most of the visible light that falls on it and reflects a large portion of the near-infrared light. Unhealthy or sparse vegetation reflects more visible light and less near-infrared light. The forest types of Bhavnagar district belong to mainly Tropical Thorn Forest which shed all their leaves in winter. Thus to get the average vegetation vigor, entire years mean was taken into consideration. Using this basic mechanisms probability distribution of NDVI values vulnerable to desertification was plotted and risk zones were calculated (Figure 8) from this risk map of vegetation index was calculated (Figure 9).

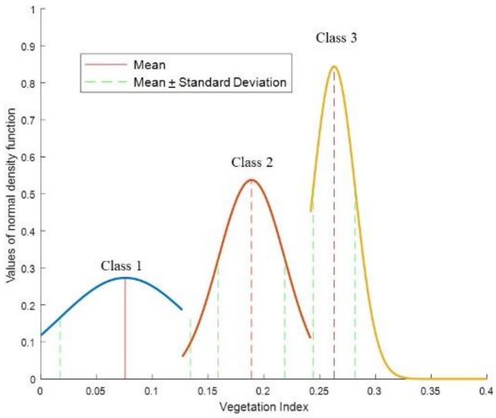

Figure 8: Normal density function of vegetation classes to indicate risk categories

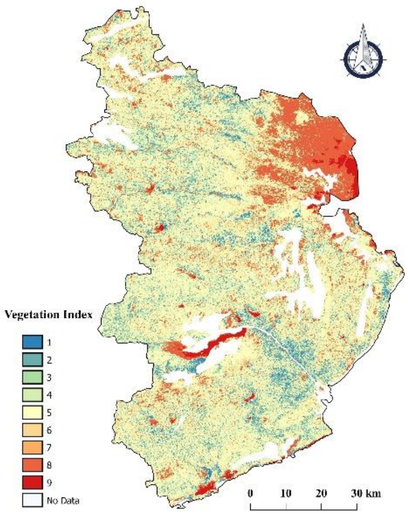

Figure 9: Vegetation Index map

vulnerability according to its probability distribution (Figure 10).

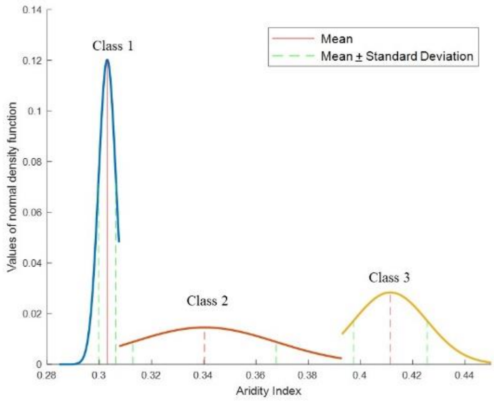

Figure 10: Normal density function of Aridity classes to indicate risk categories

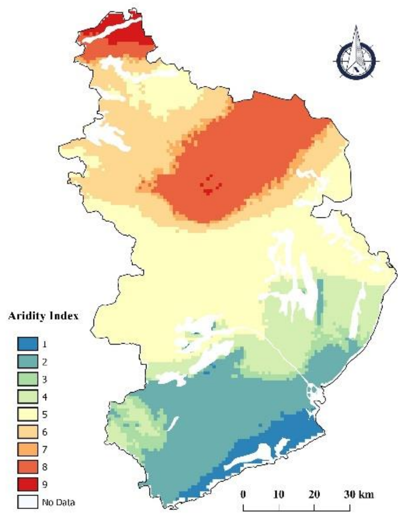

Figure 11: Aridity Index map

5.5 Climate Index

A climate Index (Figure 11) was calculated based on the level of aridity. CGIAR-CSI Global Aridity Index database was used for aridity index (Trabucco et al. 2009). The Global-Aridity is modeled using the data available from the WorldClim Global Climate Data (Hijmans et al. 2005) as input parameters, for years 1950-2000. The aridity index is ranged from 0.07 to 0.32 with the mean (μ) of 0.25 and standard deviation of 0.02 (σ). Based on aridity index, the district has been divided into nine climatic classes of

5.6 Socio Economic Index

Socio economic data sets impact land degradation to a great extent. Urban encroachment on agricultural and biodiversity land bring negative impact on the environment. Urban expansion brings more pressure on the existing natural resources, especially the agricultural land as it seeks to cope with anthropogenic demands. The study area has been subjected to a large increase in population over the years and subjected to urban activities like school colleges. Figure 12 shows the social-economic index map.

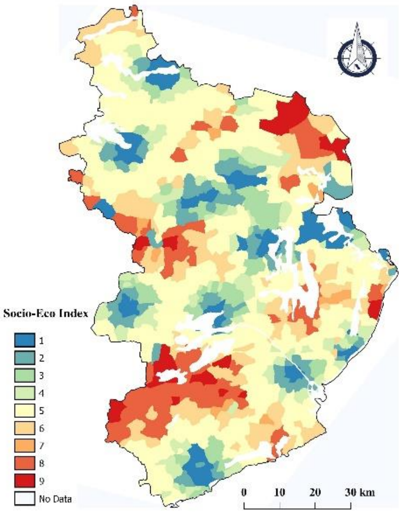

Figure 12: Socio-Economic Index map

5.7 Desertification Vulnerability Index

The above observations, as inferred from the normal density functions of individual classes of individual parameters, were represented spatially in GIS environment to know the areas under risk of desertification with their severity. The interpretation reveals that the degradation pattern of Bhavnagar district is scattered and in patches. Overall Desertification Vulnerability Index (DVI) is present in (figure 13). Mostly Bhavnagar district is under moderate vulnerability, since coastal part is mostly out of risk comparatively and high alarming areas are in patches around main urban zones.

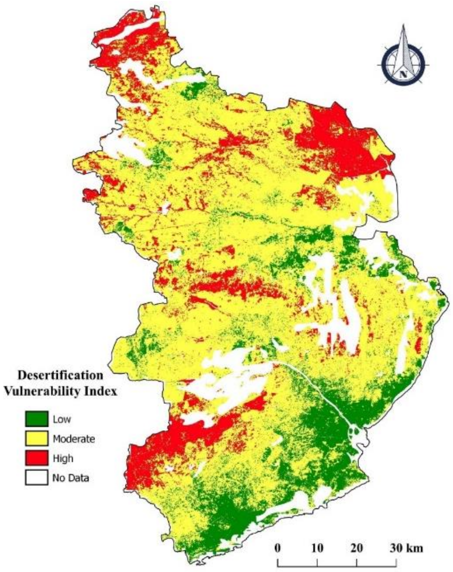

Figure 13: Desertification Vulnerability Index

Conclusion

The paper depicts that the fuzzy membership approach using geoinformatics technique in detail using natural factors and socio economic data sets secondary and primary data available. Assessing the risk of desertification by integrating all effective factors is also possible and reasonable by this model. The normal probability density function is suitable for membership analysis. The membership functions allow making out the areas representing the transitional zone in between two successive classes. Thus the model identifies the risk areas with their severity and facilitates appropriate decision making for combating and preventive methods. The future scope of the study is to predict the risk severity in future and to validate the model efficiency with future status.

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