DROUGHT HAZARD ZONATION USING GIS BASED MULTI- CRITARIA EVALUATION APPROACH WITH REMOTELY SENSED DATASETS

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ABSTRACT

Drought is an intricate phenomenon governed by several atmospheric factors such as precipitation, temperature, evapotranspiration, soil moisture, vegetation cover, stream flow etc. To monitor drought hazard, several criteria and factors will need to be evaluated. The main objective of this study was to evolve a drought hazard map with the selected five main parameters viz., standardized precipitation index, land surface temperature, soil moisture, evapotranspiration and normalized difference vegetation index during the monsoon period from 2002 to 2014 employing GIS aided multi-criteria evaluation (MCE) technique. To standardized the input data layers and deciding the factors weight for the MCE, analytical hierarchy process (AHP) approach was applied. Bundelkhand region of Uttar Pradesh was selected for this study, as drought is very frequent and dominant here. The results depicted that about 55.9% and 7.5% of the total area is classified under high and extreme drought hazard zone respectively however, about 36.59% of the total area found to be the least vulnerable (moderate to low) to drought hazard. Central parts of the region namely Jhansi, Mahoba, Jalaun and Hamirpur districts are highly affected by drought condition. Based on finding of this study we recommend the use of MCE techniques for effective and precise drought hazard zonation.

KEYWORDS: Drought hazard map, GIS, Rainfall, SPI, MCE-AHP

1. INTRODUCTION

Drought is a complex phenomenon (Son *et al.*, 2012), which may limit agricultural productivity and effect human society, leading to significant losses. With climate change, droughts occur more frequent, intensified and severe in recent decades around the globe. Accurate and reliable drought monitoring would be of critical importance for drought to reduce potential impacts of drought. Currently, hundreds of indices to character drought have been proposed, and they 50 can be divided into site-based and remote sensing-based indices(Heim Jr, 2002).

Traditional methods of drought monitoring are based on the meteorological indices (MI) derived from weather stations data. A flurry of MI based on the drought-related variables, such as temperature, precipitation, evaluation and others, which have been used in many areas all over the world for drought monitoring. The new opportunities for drought characterizations from satellite remote-sensing products have been witnessed in recent decades. Satellite sensors can be used to supply some useful information and monitor drought in areas where meteorological sites are sparse or non-existent regions on large scale(Ji and Peters, 2003). The application of remote sensing data products have been expanding of drought monitoring and the prediction at the regional and global scales. This study aims to evolve a drought hazard map by remote sensing and GIS aided multi-criteria evaluation (MCE) technique.

2. STUDY AREA

The Bundelkhand region lies at the heart of India located below the Indo-Gangetic plain to the north with the undulating Vindhyan mountain range spread across the northwest to the south.The Uttar Pradesh region of Bundelkhand is worst affected drought area, lies between $24^0$00' and $26^0$05' N latitudes and $78^0$00' and $82^0$05' E longitudes(**Fig. 1**). The main rivers are the Sindh, Betwa, Ken, Bagahin, Tons, Pahuj, Dhasan and Chambal, and constitute the part of Ganga basin. The topography of the region is highly undulating, with rocky outcrops and boulder-strewn plains in a rugged landscape. The major soils include alluvial, medium black, and mixed red and black soils(Singh and Phadke, 2006).

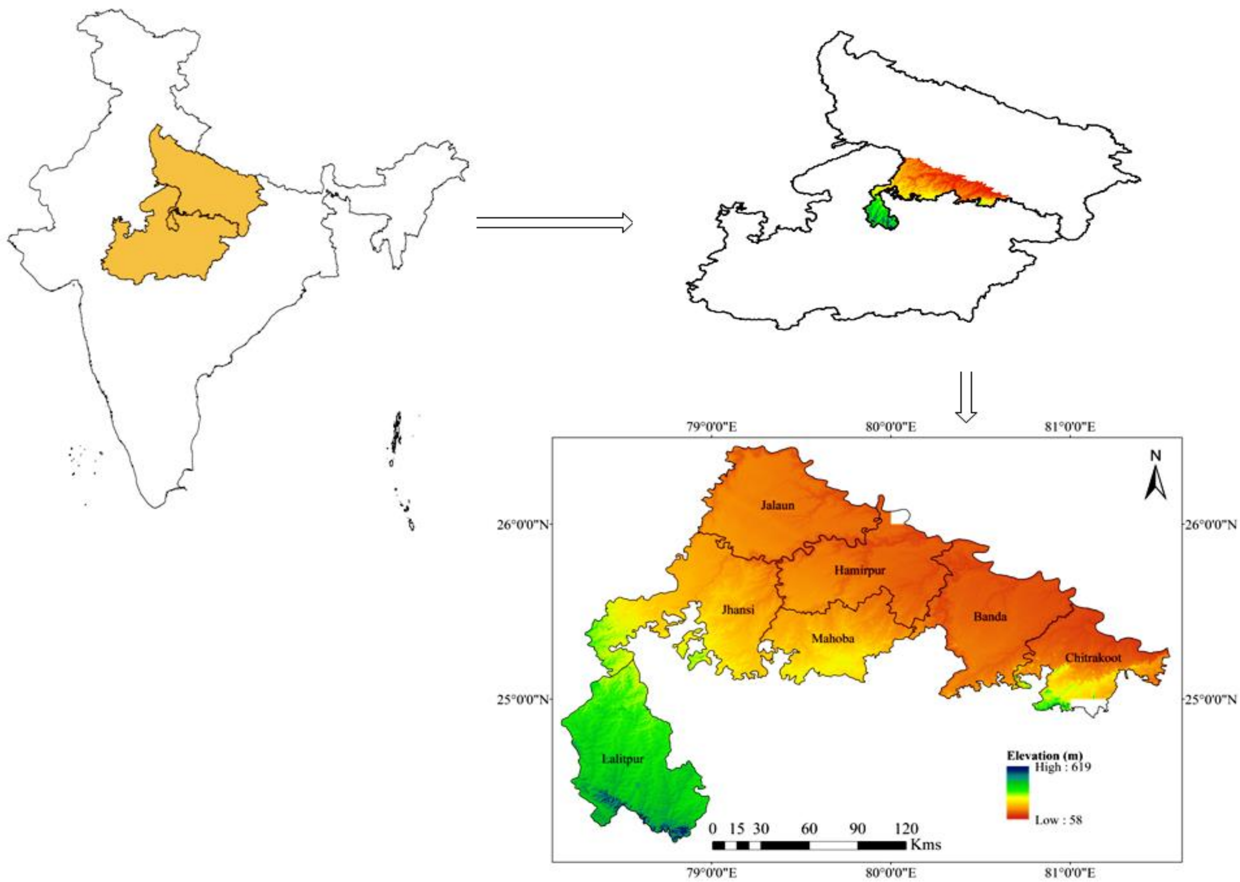

Figure 1. Location map of the Bundelkhand-UP region

3. MATERIALS AND METHODS

3.1. Data Preparation

The input thematic layers were prepared during the monsoon months (June- September) for 13 years period from 2002 to 2014 using geospatial platform for evaluation of hazard zonation map for Bundelkhand-UP region. In this paper we have use the Tropical Rainfall Measuring Mission (TRMM) 3B43 data, for computation of standardized precipitation index (SPI). Real time precipitation information of TRMM are available in 0.25^0 x 0.25^0 spatial resolution and daily temporal resolution, covering 50 degree N to 50 degree S since 1998. The other important datasets required from Moderate Resolution Imaging Spectroradiometer (MODIS) satellite. Land surface temperature climatology was prepared using MOD11B3 LST product with 0.05^0 spatial resolution. The Global MOD13A2 NDVI images are monthly available at 0.1^0 spatial resolution. In addition, MOD16A2 ET product with temporal resolution of one month and spatial resolution of 0.05^0. MODIS program make available images in 36 spectral bands. These images are downloaded from the database Land Processes Distributed Active Archive Center (LP DAAC; https:// lpdaac.usgs.gov/).

3.2. Multi-Criteria Evaluation (MCE)

The goal of achieving any objective is fulfilled by evaluation of several criteria. Such evaluation of several criteria is called Multi-Criteria Evaluation (MCE). MCE is a decisive technique that evaluates a problem by sequencing preference for multiple alternatives using several criteria that may have different units(Eastman *et al.*, 1998). It is a frequently used technique in environmental system analysis. The main objective of MCE approach is to compare and rank alternatives as well as to evaluate their consequences on the basis of established criteria.

3.3. Analytic Hierarchy Process (AHP)

The Analytical hierarchy Process (AHP) is a widely used and popular multi-criteria evaluation method, developed by Saaty (1980). The AHP is a mathematical approach, used for the analysis of multiple-criteria decision-making studies. This complex model have a hierarchy process i.e., achieving goal, having set of criteria for specification of overall goal, decomposition into sub criteria and lastly, the decision alternatives will be evaluated(de Jong, 1984). The AHP includes eigen value approach, which provides a measure for the consistency of the decision performed (consistency ratio).

4. RESULT AND DISCUSSION

SPI, climatology shown that, the years 2002, 2004-2007, 2009 and 2014 were the drought years with SPI in the range of -1.5 to -1.0. The sate-of-the-art of the ESA CCI soil moisture product is used for soil moisture climatology preparation. The soil moisture varies from 0.18 to 0.29 m^3m^{-3}. The spatial pattern of map shows soil moisture deprived northern part in the study area (not shown). The Normalized Difference vegetation Index (NDVI) seasonal climatology is other important variable for evaluation of drought hazard map as it is most suitable indicator for greenness visualization. The NDVI values ranges from +0.27 to +0.62 shows moderate NDVI values with sparse vegetation such as senescing crops or grassland **Fig 2.**

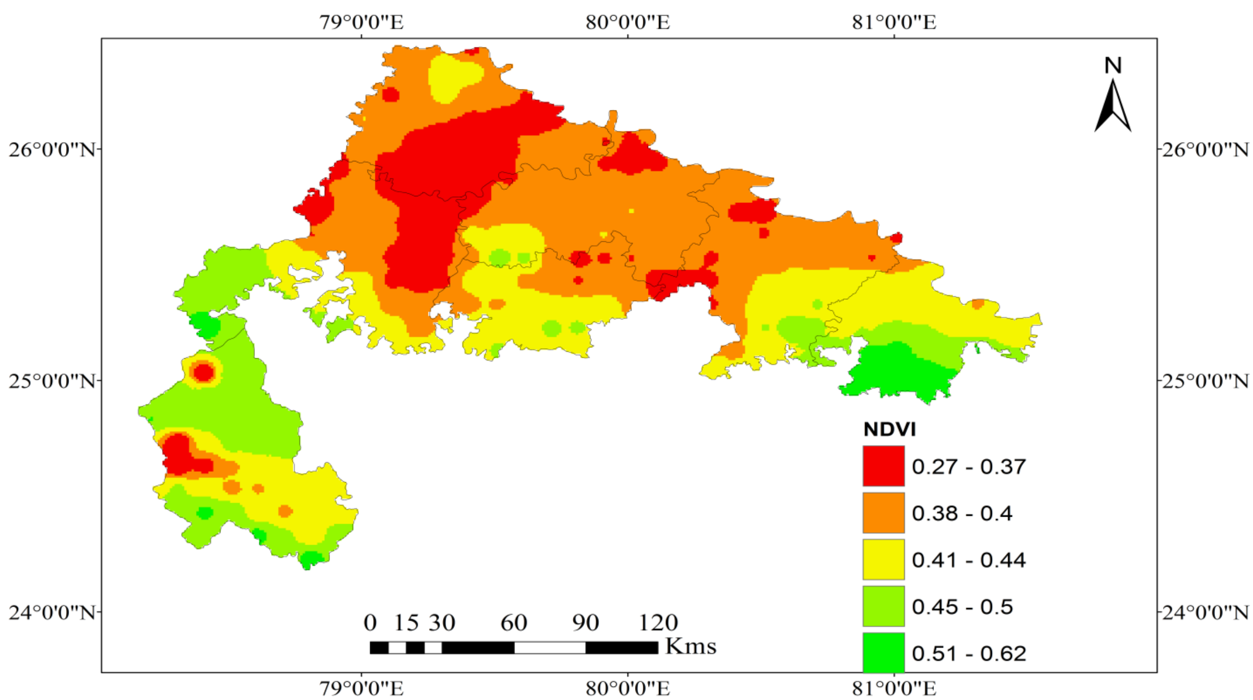

Figure 2. NDVI climatology from 2002 to 2014

Terrestrial ET reflects the evaporation from lands (wet and moist), rain water deflected by the canopy before it reaches on ground and through plant stomata. The spatial map shows higher ET (> 700 mm/season) over southern part, medium ET (600 - 700 mm/season) over southern eastern and western part and lower ET (< 600 mm/season) over central north part of the study area (not shown here). The Temperature climatology shows the random pattern with high temperature in central northern part **Fig 3.**

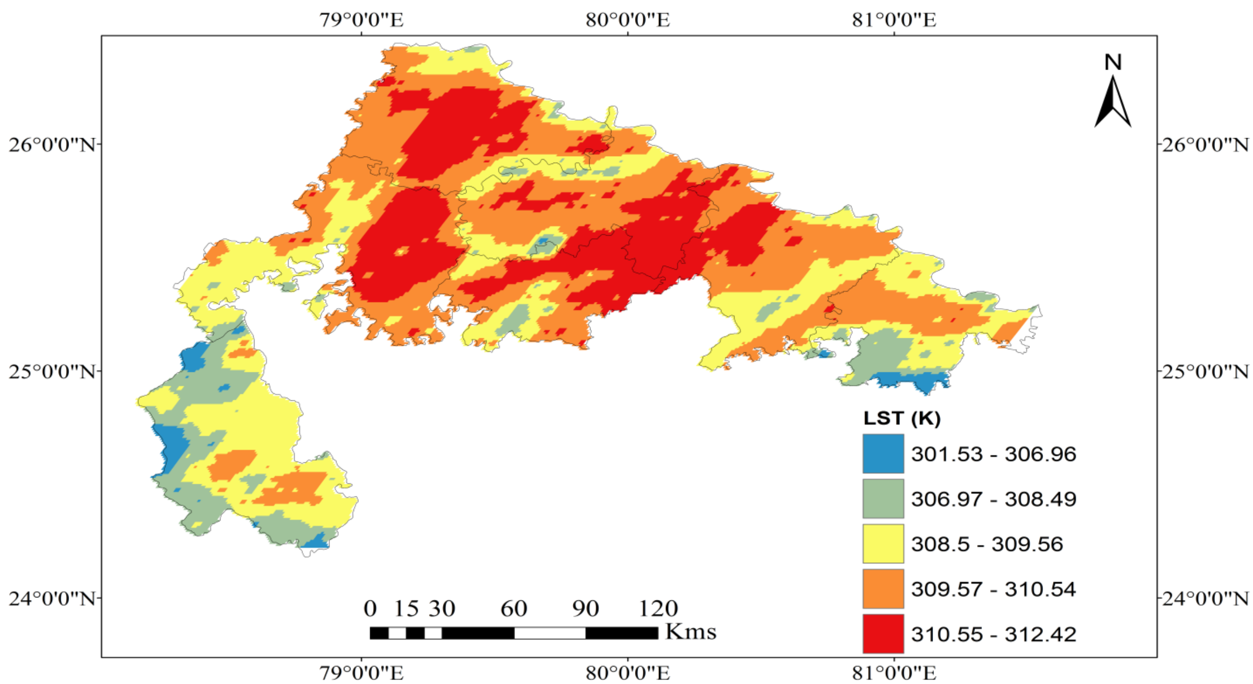

Figure 3. Land surface climatology from 2002 to 2014

4.1. Multi-Criteria Evaluation (MCE) and Weighting Assignment

The five important parameters such as Standardized Precipitation Index (SPI), Land Surface Temperature (LST), Soil Moisture (SM), Evapotranspiration (ET) and Normalized Difference Vegetation Index (NDVI) is used as input layers in a MCE-AHP technique. The previous literatures were useful for assigning a rate to the selected parameters. Rates are given from 1 to 9, where 9 indicates the maximum priority. The highest rating indicates high degree of influence on drought phenomenon. The consistency for weighting assignment is then checked in terms of CI and CR values after MCE-AHP analysis. The rating and weights, which were obtained with acceptable CR range are shown in **Table 1**.

Table 1: Pair comparison matrix of thematic layers

	SPI	LST	SM	ET	NDVI	Normalized weight
SPI	1	3	5	7	9	50.43
LST	1/3	1	3	5	7	26.09
SM	1/5	1/3	1	3	5	13.32
ET	1/7	1/5	1/3	1	3	6.72
NDVI	1/9	1/7	1/5	1/3	1	3.45

Consistency Ratio = 0.056

In this MCE-AHP approach, SPI is given the highest standardized weight of 50.43 %, followed by LST (26.09 %), soil moisture (13.32 %), evapotranspiration (6.72 %) and NDVI (3.45 %). Then reclassification and weighted overlay techniques of spatial analyst tool are significantly gives the final integrated drought hazard map using Arc GIS (version 10.1). The final map has four zones namely low moderate, high and extreme **Fig 4.**

The results depicted that about 55.9% and 7.5% of the total area is classified under high and extreme drought hazard zone respectively and about 36.59% of the total area found to be the least vulnerable to drought hazard.

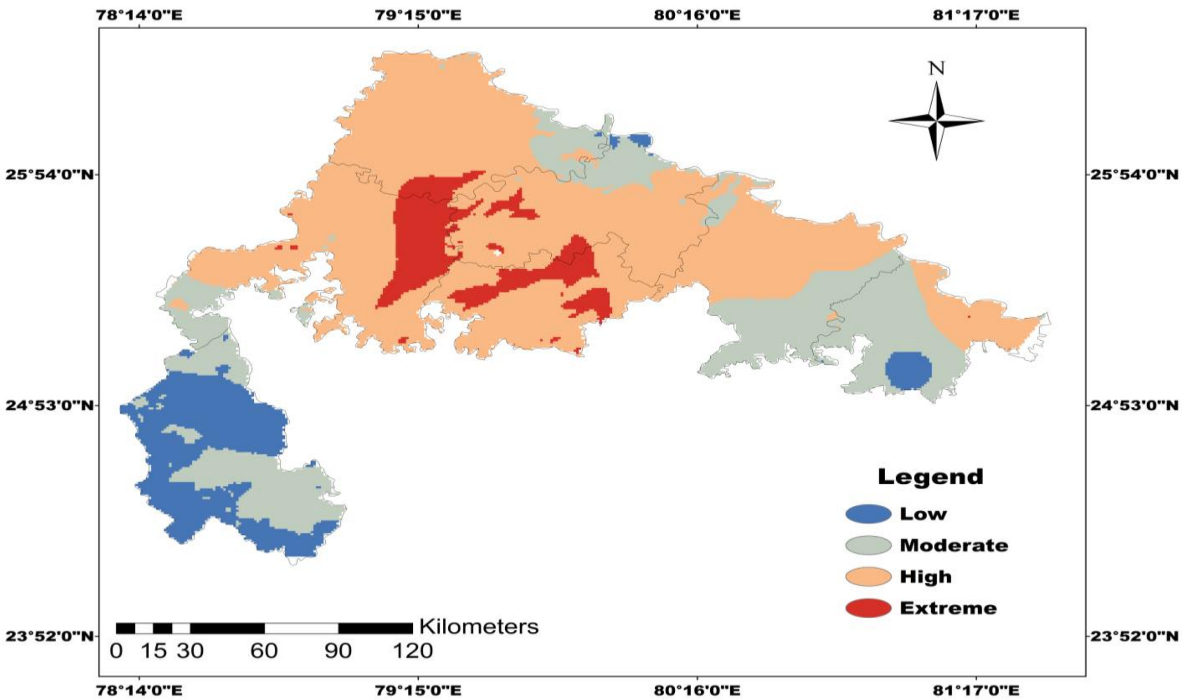

Figure 4. Drought Hazard zonation map

5. CONCLUSION

This study shows usefulness of GIS techniques through spatial analysis and integration of non-spatial data for derivation of drought hazard map. Thus far, there has been a gap of scientific studies aimed to assessing the severity, duration and risk of contemporary drought in the highly drought affected area Bundelkhand-UP region. This work showed the potential of using a satellite based precipitation product for the identification of drought hazard. Results obtained were showed that central parts of the region namely Jhansi, Mahoba, Jalaun and Hamirpur districts are highly affected by drought condition with 55.9% and 7.5% of the total area under high and extreme drought hazard zone respectively and about 36.59% under low to moderate zone. Further work will be continued to validate and improving drought identification by combing both satellite product with ground based data and by linking drought risk by means of remote sensing products to observed impact on human activities like agricultural productivity and livelihood.

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