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Micro-level Drought Vulnerability Assessment in Peddavagu basin, a Tributary of Krishna River, Andhra Pradesh, India

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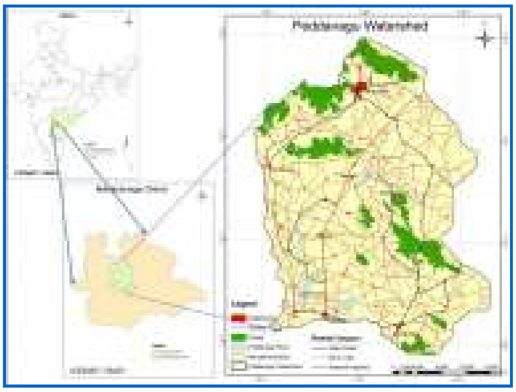

Figure 1. Location of Peddavagu basin, a tributary of Krishna River basin

Abstract — Agriculture in India, or "gambling with monsoons," as it's often called, is dependent on such weather. A monsoon failure leads to droughts and the rural Indian farmers are the worst affected, making drought identification, monitoring and characterization at the village level crucial for drought proofing in rural areas. The Mahabubnagar region of Andhra Pradesh State, in South Central India, is prone to recurrent droughts and has frequently been in the news due to the suicide attempts of the farmers in this region. If droughts could be predicted, or at least monitored and assessed scientifically, attempts could be made to mitigate the ill effects and plan for ample food and drinking water. Other relief measures could help minimize the disastrous consequences of drought, thereby minimizing the plight of farmers. A study assessed the micro-level spatial drought vulnerability with the expectation this will assist in drought-coping measures in the region. Different thematic maps including rainfall, elevation, drainage density, soils and surface water area were integrated and analyzed using the weighted overlay analysis in GIS to derive the village level drought vulnerability map.

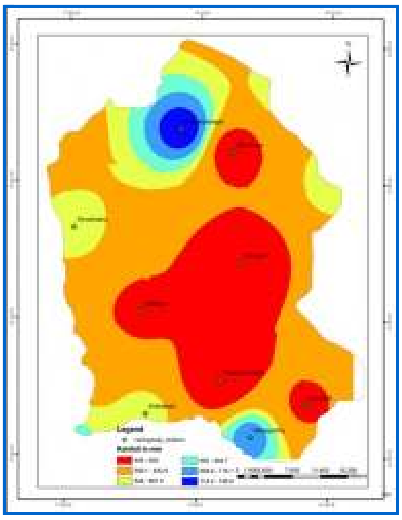

Figure 2. Spatial Variation of Ten Years Average Annual Rainfall of the Peddavagu Basin, a tributary of Krishna River basin

I. INTRODUCTION

Drought is a serious problem that significantly affects millions of people in the Semi Arid Tropics (SAT), which receives an average annual rainfall of less than 1,000 millimeters. Drought varies with regard to the time of occurrence, duration, intensity and extent of the area affected ([12], [16]). Drought starts with an extended period of reduced precipitation, although it may propagate throughout the hydrologic cycle at different temporal and spatial scales [14]. Drought is defined from the hydrological point of view as a sustained and regional extensive occurrence of below-average natural water availability ([1], [12]).

Drought is further classified into meteorological drought, agricultural drought, hydrological drought and socio-economic drought, based on water deficiency in a specific part of the hydrologic cycle. There is an element of connection between different droughts as drought in one stage can lead to a drought in another stage. Meteorological drought occurs when the precipitation is less than the normal amount of precipitation over a region. Agricultural drought occurs when the soil water content is low and not sufficient to support plant growth [1]. Hydrological drought occurs when there is a depletion of water in surface water bodies including irrigation tanks, streams, reservoirs, lakes and also a depletion of the groundwater level, and is further classified into stream-flow droughts and groundwater droughts [12]. The plight of the farmer has always been a matter of concern in India, and is only further reinforced by the recurrence of the droughts that cause untold hardships. Identification, monitoring and characterization of droughts in villages have been the topic of much research at the national and international levels.

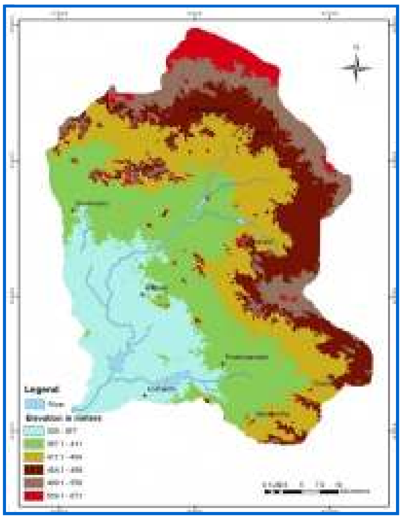

Figure 3. Digital Elevation Model of Peddavagu basin, a tributary of Krishna River basin

Several indices and methods have been developed to identify and monitor droughts at various spatial and temporal scales. Most of the drought assessments are based on the analysis of single variables like stream flow, rainfall or crop yield over a large area or region ([15], [19]). Low flow analysis index, surface water supply index (SWSI), Palmer Drought Severity Index (PDSI), reclamation drought index (RDI), deciles [19], and the Standardized Precipitation Index (SPI) [4] are a few of the ground-based indices used in drought assessment. Several satellite-based indices used for drought assessment by monitoring the vegetative stress include Normalized difference vegetation index (NDVI), Vegetation condition index (VCI), Enhanced vegetation index (EVI)[2], and the Temperature condition index (TCI) [5]. Shin and Salas [8] developed a method to analyze and quantify spatial and temporal meteorological droughts using annual precipitation data. By employing a nonparametric spatial analysis neural network algorithm, they determined the posterior probabilities of drought severity at any point. Furthermore, they assigned a Bayesian Drought Severity Index for constructing drought severity maps that display the spatial variability of drought severity on a yearly basis. Clausen and Pearson [3] studied the spatial and temporal variability of droughts by a regional frequency analysis of annual minimum stream flows. While such assessments hold good at the regional level, drought vulnerability assessment at the micro or individual village level requires a detailed assessment of all parameters that can influence drought. Drought at the regional level is governed by a number of climatic and hydrological variables, such as precipitation that depends on the season, evapotranspiration, stream flow, soil moisture, moisture content in the air, groundwater levels, surface water, orographic factors, characteristics of the Earth's surface and other similar variables ([8] , [17]). An integrated approach using various parameters that influence drought at the village level is of great importance in vulnerability assessment to support micro-level planning. Because of this, a micro-level drought vulnerability assessment framework was developed and a study was conducted to assess the vulnerability of villages to drought ([6], [7]).

Rank	Rainfall (mm)	Digital Elevation Model (m)	Drainage density (km/sq km)	Soil type	Land use/ land cover
1	[illegible]	[illegible]	[illegible]	Water Body	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	Fallow
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 1. Ranking assigned to different Choropleth Maps accruing to their vulnerability to Drought

The main objective of this study was to perform an in-depth analysis of drought parameters to assess the micro-level spatial drought vulnerability to support rural communities in decision making using Geographic Information Systems (GIS) and remote sensing techniques.

II. STUDY AREA

The Peddavagu basin, a tributary of Krishna River basin is located in the southern Telangana agri-climatic zone of the Mahabubnagar district of Andhra Pradesh (Fig. 1), which has been prone to recurrent droughts in the last two decades. The basin is 1,611 square kilometers, and lies between 77o 48' 44.7" E to 78o 13' 31.55" E longitudes and 16o 19' 31.55" N to 16o 50' 22.1" N latitudes. The basin's topography is mostly flat with granitic hills in the upstream, and its climate transitions from a tropical to a subtropical climate. The climate of the study area is semi-arid with an average annual rainfall of 622 millimeters, received mainly during the monsoon period from June to October. Summers, which last from March to May, are hot, with temperatures ranging from 27 to 41.5 Celsius. The winter, which spans from November to January, has temperatures ranging from 16.9 to 19.1 Celsius. The main livelihood opportunities for rural communities in the Mahabubnagar district are agriculture and livestock rearing. This region has two major cropping seasons, viz, June-October (kharif) and November to March (rabi). The most important crop in the basin is rice during kharif and groundnut in rabi seasons. Other regularly cultivated crops include sorghum, pearl millet, finger millet, maize, groundnut, castor, sunflower, pigeon pea and vegetables. Cultivation in kharif is mostly dependent on rainfall, while groundwater is used in rabi. Levels of the groundwater aquifer level have been falling over the years because of exploitation and a lack of groundwater recharge. Most bore wells run dry after a bad monsoon year and only those boreholes near drainage tanks and river streams yield water.

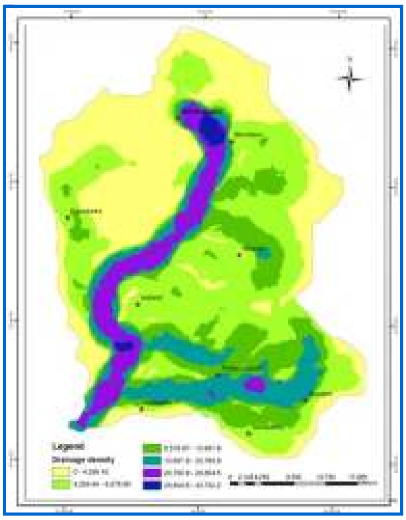

Figure 4. Drainage density map of Peddavagu Basin, a tributary of Krishna River basin

III. METHODOLOGY

A GIS-based framework developed by the Indian Institute of Technology, Bombay was tested on a pilot basis at Adakkal Mandal, Mahabubnagar to assess the micro-level drought vulnerability [6]. Based on this method, an integrated approach was developed to analyze various parameters that influence the drought. Rainfall, elevation, soils, drainage density and surface water availability were considered to be the most important parameters influencing the water availability in a village in this study.

Thematic maps showing the spatial variations of each of these parameters were prepared using remote sensing data and GIS. Spatial variation of annual rainfall over the basin was prepared using the Inverse Distance Weighting (IDW) interpolation technique. IDW makes interpolated estimates based on values at nearby locations weighted only by distance from the interpolation location [18]. The average rainfall data of the 10 meteorological stations were spatially interpolated to understand its variation over the entire study area. The rainfall varied between 626 to 749 millimeters, which was further divided into six classes and the class with the highest rainfall was given the highest rank, the subsequent class ranges and associated ranks can be seen in Table 1. The spatially interpolated rainfall map was classified into six color bands as shown in spatial variation of the ten-year average annual rainfall Map (Fig. 2).

Figure 5. Soil Map of Peddavagu basin, a tributary of Krishna River basin

The elevation map was prepared by using the Advance Spaceborne Thermal Emission and Reflection Radiometer (ASTER), a digital elevation model downloaded from Global Land Cover Facility (GLCF) website. The digital elevation map prepared from ASTER remote sensing data has the highest and lowest elevations of 671 meters and 305 meters, respectively. It was further divided into six classes as shown in the digital elevation map (Fig. 3).

The drainage map was prepared by digitizing the drainage network from the geo-referenced topographic map of the Survey of India on a 1-to-50000 scale. Further, the drainage density map was prepared using the drainage map in Arc GIS 9.2 software. From the drainage density map, it was found that the drainage lines were sparsely distributed in the upstream portion of the watershed, leading to water scarcity conditions. The drainage density values were again divided into six classes and ranked accordingly. The drainage density of the study area varied between 0 and 43.75 meters per square meter (Fig. 4).

A soil map was prepared by digitizing the geo-referenced soil map obtained from the National Bureau of Soil Survey and Land Use Planning (NBSS andLUP) in GIS environment. The predominant soils in the basin include clay, cracking clay, gravelly clay , gravelly loam and loamy soils. The information about the soil type, structure, texture and water holding capacity was gathered using the NBSS soil maps at the village level. The water holding capacity of a soil has a direct relationship to the amount of water required for crop growth, and these soils were ranked according to their water holding capacity. The soil map overlaid with village boundaries is shown in Fig 5.

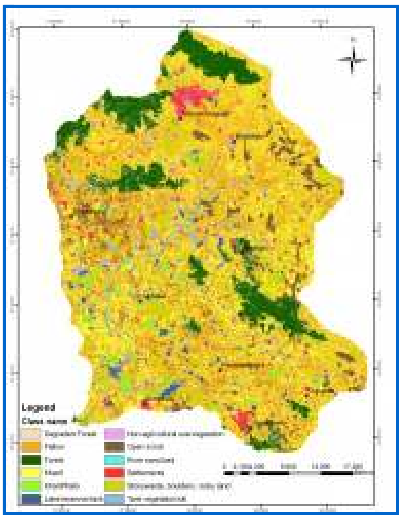

Figure 6. Landuse/land cover map of Peddavagu Watershed, a tributary of Krishna River basin

A. Land use

The land use-land cover map was prepared using the Landsat Enhanced Thematic Mapper (ETM) Imagery, 30 meter spatial resolution, was obtained from GLCF. The Landsat ETM and TM data, were classified using unsupervised and supervised classification techniques in the Earth Resource Data Analysis System (ERDAS) Imagine 8.6 Software package. A hierarchical classification system based on an Anderson classification scheme [9] was adopted for the classification.

In this study, the unsupervised classification technique along with visual interpretation was employed using limited ground truth data, topographic maps and Google Earth imagery. The unsupervised classification followed by progressive generalization [10] was used to derive the land use-land cover classes. Landsat imagery was classified using the ISODATA k-means cluster algorithm — the pixels cluster together based on the similarity of digital numbers into natural groups within a multispectral imagery. The image was initially classified into 30 classes, with a threshold value of 0.98 and a maximum of 30 iterations. The threshold value was set to 0.98 in order to force the ISODATA algorithm to run as much iteration as possible until 98 percent of the image remains unchanged. The initial 30 classes were merged by progressive generalization using ground truth data and Google Earth imagery. Ground truthing was done during April and August of 2010, so the investigation would coincide with the crop growth and development period of both rabi and kharif. Field surveys were conducted to collect the ground truth data using the Global Positioning System (GPS) Unit in Universal Transverse Mercator (UTM) and latitude and longitude coordinate system with WGS 84 datum. The ground truth data was used to identify and classify the image and for the accuracy assessment. Five to 20 samples were collected for each class, and class identification and labels were assigned based on ground truth data and Google Earth imagery. The gross cultivable land from the classified image was separated and used to mask out the agricultural area from kharif and rabi season satellite imagery. These masked out images were reclassified using the ISODATA algorithm to classify the kharif and rabi cropped areas. The study area was classified into 12 classes (Fig. 6) and the percentage of each class in the basin was estimated.

Sl. No.	Land use land cover class names	Area in percentage of total Area (%)	Area in Km2
1	Lake/reservoir/tank	0.82	23
2	Kharif	28.55	460
3	Fallow	16.75	182
4	Open scrub	7.88	127
5	Kharif Rabi	2.17	35
6	River sand bed	0.50	8
7	Non-agricultural use/vegetation	1.35	22
8	Stony waste, boulders, rocks	4.90	79
9	Settlements	2.42	39
10	Forest	9.75	157
11	Degraded Forest	1.24	20
12	Tank vegetation/silt infilled tank	2.73	44
		100	1611 Km2

Table 2. Land use/land cover classes of Peddavagu basin.

B. Drought Vulnerability Assessment

All the classes of the above generated five choropleth maps, which were ranked according to the vulnerability of each class to drought as mentioned in Table 1. Using these thematic layers, a weighed overlay analysis was carried out to prepare a drought vulnerability map. The weighted overlay technique was applied to integrate the diverse and dissimilar thematic maps to create an integrated analysis to derive the drought vulnerability map. The drought vulnerability of each thematic map was evaluated by considering the influence of each parameter on water availability and scarcity. The drought vulnerability of the study area was classified into five vulnerable classes. Village boundaries were digitized from geo-referenced cadastral maps obtained from the land survey office, Hyderabad. The village boundary map was then overlapped over the drought vulnerability map to show the degree of vulnerability of each village to drought. The drought vulnerability of each village was color-coded in red, orange, yellow, light green and green for easy understanding.

IV. RESULTS AND DISCUSSION

The 10 years average annual rainfall variation map was presented in Figure 2. It is evident from the figure that the regions around Wanaparty and Mahabubnagar have better rainfall, while other regions around Bhoothpur, Addakal, Ghanpur, Peddamandadi and Gopalpet received very low rainfall. The Devarkadra and Kothakota regions received moderate rainfall.

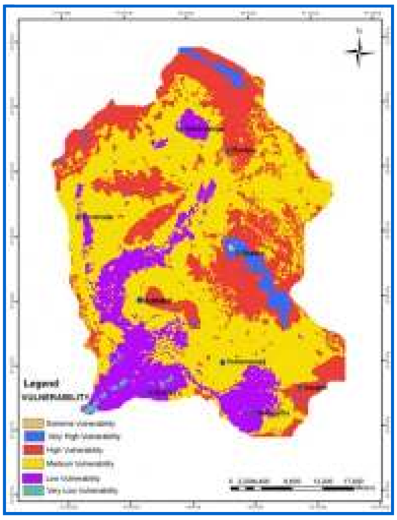

Figure 7. Final drought vulnerability map of Peddavagu basin, a tributary of Krishna River basin

A. Land use

The integrated unsupervised and supervised classification carried out on the Landsat imagery had 12 generalized classes (Figure 6). The different land use/ land cover classes and their area in percentage of the total area of watershed in square kilometers were shown in Table 2. Agriculture is primarily rain-fed with a kharif area cultivation of 28.55% of the basin. More than one third of the basin is left fallow (36.75 %) during kharif due to lack of rainfall.

B. Drought Vulnerability

Thematic maps of rainfall variability, soil, drainage density, topography and land use or land cover were analyzed using weighted overlay analysis to demarcate the drought vulnerability of the study area. The study area was classified into five vulnerable classes from very highly vulnerable, highly vulnerable, medium vulnerable, low vulnerable to very low vulnerable regions (Fig. 7).

The figure revealed that Addakal, Ghanpur, Peddamandadi, Gopalpet and Bhootpur regions are very highly or extremely vulnerable to drought, primarily due to very low rainfall occurrence, lack of surface water storage, poor soils having low water holding capacity, high elevated topography and very sparse drainage. The Kothakota and Devarkadra regions experienced high-to-moderate drought vulnerability, with moderate rainfall, and comparatively better surface water storage, having gravelly loam soils. Open scrub, stone waste, and boulders are highly vulnerable whereas fallow lands with loamy soils are regions that are moderately vulnerable to drought. The Mahabubnagar and Wanaparthy regions receive relatively good rainfall, having very low or low vulnerability to drought with good surface water storage and water holding soils like cracking clay, and clayey soils. The regions with extremely high risk to drought, concentrated in the north, north-west, north-east and center part of the basin, corresponded very well, with kharif fallow lands that were not cultivated primarily due to lack of rainfall. Satellite imagery and ground truth information has also shown the surface water bodies in the red colored villages were either dry or infested with vegetation and accumulated with silt. The basin is dominated by fallow lands and kharif crop cultivation with 36.75% and 28.55%, respectively.

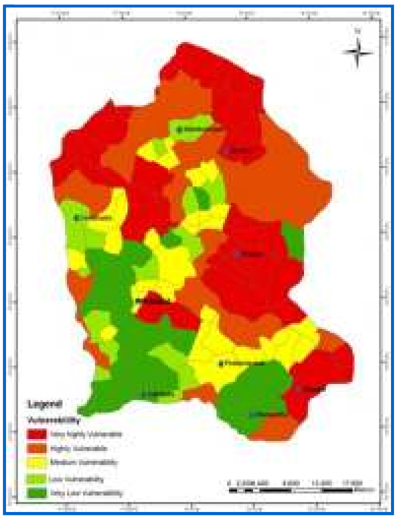

Figure 8. Drought vulnerability map of villages in the Peddavagu basin, a tributary of Krishna River basin

Further, the vulnerability of each village to drought (Fig. 8) was determined by overlaying the village map on the drought vulnerability map prepared using the weighted overlay analysis. This map was developed so farmers could easily understand the meaning of the color code. Red- and orange-colored villages indicate very high and high vulnerability to drought. These villages receive much less rainfall and do not have enough surface water storage and soil moisture for agriculture. These villages require constant drought monitoring and, in the worst situation, external water. Yellow-colored villages indicate less vulnerability to drought compared to red- and orange-colored villages but still need to be constantly monitored. Light green- and green- colored villages can sustain a drought situation with proper management measures as they have better rainfall, surface water storage, drainage density and soils. The major outcome of this study is the drought vulnerability map showing the vulnerability of a village to drought, and it is anticipated it will be useful to different stakeholders in drought management, and to village-level administrators and agricultural officials involved in decision making.

V. CONCLUSION

Drought preparedness is a priority of the disaster management authority of India, and implementation of drought preparedness programs at the micro-level require the assessment of a village's vulnerability to drought. It is hoped this study will guide disaster management authorities to better water management and augmentation of water supplies to reduce risk. This study can be improved by incorporating a water balance model on village-level water supply and demand, and by considering groundwater recharge as an additional source of supply during scarce water conditions.

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Construction Begins on Atlantis' Permanent Home

With space shuttle Atlantis' 25-year spaceflight career now in the history books, its next mission -- to inform and inspire generations of visitors to the Kennedy Space Center Visitor Complex in Florida -- is one step closer to reality. A groundbreaking ceremony Jan. 18 officially launched construction of a new 65,000-square-foot exhibit at the complex's Space Shuttle Plaza, where NASA's fourth space-rated orbiter will be the main attraction. This artist rendering reveals a full-scale external tank and twin solid rocket booster replicas standing at the exhibit entrance. Image Credit: NASA/PGAV Destinations for Delaware North Parks & Resorts

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