Drought Vulnerability Assessment Using GIS Tools

S. Aparna and Vineetha Basil

Abstract—Drought is the most complex but least understood of all natural hazards. It is caused by shortage of rain and humidity deficit and is a recurrent meteorological phenomenon. The existence of agricultural drought early warning system can be very useful in order to improve drought preparedness and to reduce drought impacts. This study presents, a GIS based method for assessment of agricultural drought vulnerability in Palakkad district. It was identified that the key factors that define agricultural drought vulnerability are climate (precipitation), soil, land-use, geomorphology of the area and access to irrigation. Thematic maps of each factor were created using GIS software based on assigned weights. The final result was presented in a form of map and it was calculated by simple addition of the weights of all the GIS data layers. The resulting map of regional drought vulnerability can help decision makers to develop useful agricultural drought mitigation strategies. From the result map it is identified that the northern side Palakkad district is drought prone area when maps of 2010 and 2011 were compared. The effects of various factors on the drought prone area were analysed.

Keywords—Drought, GIS, Thematic Maps, Weights

I. INTRODUCTION

Of the many climatic events that influence the earth’s environmental fabric, drought is perhaps the one that is most linked with desertification. Drought is a natural hazard originating from a deficiency of precipitation that results in a water shortage for some activities or some groups and is often associated with other climatic factors (such as high temperatures, high winds and low relative humidity) that can aggravate the severity of the event. Drought differs from aridity in that the latter is restricted to low rainfall regions and is a permanent feature of the climate. Drought is a slow-onset, creeping natural hazard that is a normal part of climate for virtually all regions of the world; it results in serious economic, social, and environmental impacts. Drought severity is dependent not only on the duration, intensity and spatial extent of a specific drought episode, but also on the demands made by human activities and vegetation on a specific region’s water supply. The impacts of drought are largely nonstructural and spread over a larger geographical area than are damages from other natural hazards.

According to Dracup et al. (1980) [1], the U. S. Weather Bureau defines drought as “Lack of rainfall so great as so long continued to affect injuriously the plant and animal life of a place and to deplete water supplies both for domestic purposes and the operation of power plants especially in these regions where rainfall is normally sufficient for such purposes”. As this definition implies, drought is mainly and directly linked with lack of rainfall that causes consequences including agricultural and hydrological hazards associated with severity and duration of this lack (Dracup et al., 1980) [1]. Many authors and researchers agree on the aforementioned definition of drought (Dracup et al., 1980; Wilhite, D.A., 2000a, 2000b [2]). According to Wilhite and Glantz classification, four categories of droughts could be identified: a) meteorological drought b) hydrological drought c) agricultural drought, d) socio-economic drought. Here in this study agricultural drought for the study area is considered. By conducting this study an early warning system for assessing the agricultural drought can be established for the study area.

II. MATERIALS & METHODS

A. Study Area

Study area is Palakkad district which is one of the 14 districts of the Indian state of Kerala. It is a major Paddy growing area of the State and hence district is nicknamed "the granary of Kerala" and "rice bowl of Kerala". It is also called as the “Gateway of Kerala” due to the presence of the Palakkad Gap, in the Western Ghats. This District lies between 10°21' and 11°14' North latitude and 76°02'and 76°54’ East longitude. The city of Palakkad is the district headquarters. Palakkad is bordered on the northwest by the Malappuram District, on the southwest by the Thrissur District and on the east by Coimbatore district of Tamil Nadu. The district is 13.62% urbanised. The total geographical area of the district is 4480 sq.kms representing 11.53 % of the state’s geographical area. Fig 1 shows the location of study area.

![Location Map of the study area](image-url)

Fig. 1: Location Map of the study area
B. Methods

- Numeric Weighting Scheme and Drought vulnerability factors

The use of GIS for integrating data from different sources was found essential in many drought studies. There are numerous factors that influence drought vulnerability. Based on analysis of literature and data availability it was identified that the key factors that define agricultural drought vulnerability in the Palakkad region are climate, soil properties, land-use, geomorphology of the area and access to irrigation. Each class of vulnerability factors has been assigned a numerical weight ranging from 1 to 5, with the most significant in regard to drought vulnerability having a weight of 5 and the least significant a weight of 1. Thematic maps of each factor are created using GIS software based on assigned weights. The methodology used in this study to assess agricultural drought vulnerability is similar to approach used by Wilhelmi and Wilhite for integrated assessment of vulnerability to agricultural drought in Nebraska USA [3]. Each of the five factors considered are explained below.

- Climate (Precipitation)

Drought is a complex natural disaster that causes serious environmental, social, and economic consequences worldwide. Complex drought phenomenon is usually explained by drought index (A. Bezdan et.al [4]). In this study the Standard Index Annual Precipitation (SIAP) was used. Only rainfall data was required for the calculation. SIAP index maps for Palakkad region were prepared using GIS. Using the rainfall data of the 22 meteorological stations for the period 1980-2011 maps representing the rainfall of each year were prepared with the help of kriging tool in Arc GIS.10. For calculating SIAP index map for each year, the mean and standard deviation maps have to be prepared. It was done using the tool ‘Raster Calculator’ in GIS. The SIAP index maps for 2010 and 2011 years were prepared by the application of the equation for calculating the SIAP index in the Raster Calculator. The image classification based on the specified range of both index values was done using the ‘Interactive Supervised Classification’ tool in Image Classification toolbar. After classification, these maps were masked with the digitized study area to obtain the drought maps for each year. Yearly rainfall of 32 years for the following 22 stations were given as input to GIS. Cheerakuzhy, Chulliar, Eruthampatty, Koduvayur, Kunnamkulam, Malampuzha, Manalaroo, Mangalam Dam, Meenakara dam, Mukkali, Olavakkot, Ottapalam Parambikulam, Pazhayannur, Pokunni, Pothundy, Pudur Thrithala, Thunakadavu, Vaniampara, Vazhani and Walayar dam. The digitized study area showing the 22 meteorological stations is shown below (Fig 2).

\[
SIAP = \frac{P_i - P}{SD}
\]

Where
\[ P_i = \text{actual precipitation}, \quad P = \text{mean} \]
\[ SD = \text{Standard Deviation of precipitation}. \]

After finding the SIAP index value, the obtained values are compared with the following table (Table: 1) [5]

<table>
<thead>
<tr>
<th>Table 1: Classification criteria of SIAP index classes and description of the status indicator value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Index Descriptive</td>
</tr>
<tr>
<td>More Wet</td>
</tr>
<tr>
<td>Wet</td>
</tr>
<tr>
<td>Normal</td>
</tr>
<tr>
<td>Dry</td>
</tr>
<tr>
<td>More Dry</td>
</tr>
</tbody>
</table>

Fig. 2: Digitized Study area
Fig 3 shows the SIAP index map prepared using GIS for the year 2010 and 2011.

• **Geomorphology**

Slope gradient and slope aspects were derived from the Shuttle Radar Topography Mission digital elevation data imagery acquired by NASA. Weights were assigned to different classes of slope gradient and slope aspect with respect to their degree of significance in vulnerability to drought. These maps were then added together and reclassified again into two classes and numerical weights of 1 and 2 were assigned to them.

• **Land use**

Land use is one of the significant factors of agricultural drought vulnerability. The input map was reclassified into 3 classes regarding drought vulnerability. First class include Pastures and Heterogeneous agricultural areas (land principally occupied by agriculture, with significant areas of natural vegetation) and those areas were considered as less vulnerable to drought than arable lands so the numerical weight of 1 was assigned to this class. Second class includes arable land (does not separate irrigated and rainfed cropland) with numerical weight of 2 assigned to this class. Third class include non-agricultural land so the numerical weight of 100 was assigned to this class for masking purposes, since this class was not included in the agricultural drought vulnerability assessment.

• **Soil**

The total available water in the root zone, soil irrigability classes and soil fertility and production potential are significant agricultural drought vulnerability factors. The total available water in the root zone was calculated as difference between the water content at field capacity and wilting point in the root zone[6]. Considering vulnerability to drought total available water is classified into five and numerical weights are assigned accordingly as (less than 40 mm (5); 40 - 80 mm (4); 80 - 120 mm (3); 120 - 160 mm (2); 160 - 200 mm (1)).

Soil suitability for irrigation is divided into five classes. The classes are defined in terms of the degree of soil limitations. Soil irrigability classes are presented in Table 2 [4].

<table>
<thead>
<tr>
<th>Soil Irrigability Class</th>
<th>Description</th>
<th>Drought vulnerability weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>No limitation for sustained use under irrigation</td>
<td>1</td>
</tr>
<tr>
<td>II</td>
<td>Slight soil limitation for sustained use under irrigation</td>
<td>2</td>
</tr>
<tr>
<td>IIIa</td>
<td>Moderate soil limitation for sustained use under irrigation</td>
<td>3</td>
</tr>
<tr>
<td>IIIb</td>
<td>Severe soil limitation for sustained use under irrigation</td>
<td>4</td>
</tr>
<tr>
<td>IIIc</td>
<td>Very severe soil limitation for sustained use under irrigation</td>
<td>5</td>
</tr>
</tbody>
</table>

Soil fertility and production potential is divided into four classes, presented in Table 3.

<table>
<thead>
<tr>
<th>Soil Fertility and Production Potential Class</th>
<th>Description</th>
<th>Drought vulnerability weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>High fertility and production potential - allowing high and stable crop yields</td>
<td>1</td>
</tr>
<tr>
<td>II</td>
<td>Moderate fertility and production potential</td>
<td>2</td>
</tr>
<tr>
<td>III</td>
<td>Low fertility and production potential</td>
<td>4</td>
</tr>
<tr>
<td>IV</td>
<td>Very low fertility and production potential - suitable for pastures or forest, not for agriculture</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 2: Soil Irrigability Classes

Table 3: Soil Fertility and Production Potential Classes

The soil maps based on these three factors were then added together and reclassified.

• **Irrigation**

In the Palakkad region the variation in crop yields is strongly correlated with the amount and distribution of rain during the growing season. Numerical weight of 1 is assigned for the areas under irrigation systems while for the rest of areas; weight of 5 is assigned which indicates a significant difference in the ability to withstand the lack of precipitation.

• **Resulting drought vulnerability map**

The final result of the combination of drought vulnerability factors was calculated by simple addition of the weights GIS. Five previously created maps (drought vulnerability maps regarding climate, geomorphology, soil properties, land use and access to irrigation) were added together by using Raster calculator in ArcGIS. Geographic areas with high numeric values of sum of weights are assumed to be relatively more vulnerable to agricultural drought then areas with lower values. The resulting map was reclassified into six classes identifying areas with "low vulnerability", "low to moderate", "moderate", "high", "very high vulnerability" and "non-agricultural" areas.

C. **Data Source**

The maps used for this study were collected from the following departments as given in Table 4
### Table 4: Source of Maps

<table>
<thead>
<tr>
<th>Type of data</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRTM data</td>
<td>Kerala Forest Research Institute(KFRI)</td>
</tr>
<tr>
<td>Soil map</td>
<td>Kerala Forest Research Institute(KFRI)</td>
</tr>
<tr>
<td>Land use map</td>
<td>Kerala Forest Research Institute(KFRI)</td>
</tr>
<tr>
<td>Rainfall data</td>
<td>Hydrology Department</td>
</tr>
</tbody>
</table>

### III. RESULTS & DISCUSSION

#### A. Framework for Derivation of Drought Vulnerability Map Using Numerical Weighting Scheme

To produce an agricultural drought vulnerability map for Palakkad, climate (Fig 4), soil (Fig 5), slope (Fig 6) land use (Fig 7), and irrigated cropland (Fig 8) maps were combined in Arc GIS to determine the areal extent of combinations of classes present. A numerical weighting scheme was used to assess the drought vulnerability potential of each factor.

- **Climate map**

![Climate Map](image)

Fig. 4: Climate map for the year 2010 and 2011

- **Soil map**

![Soil Map](image)

Fig. 5: Composite map of vulnerability to drought based on soil properties

- **Geomorphology Map**

![Geomorphology Map](image)

Fig. 6: Composite map of vulnerability to drought based on geomorphology of the region.

- **Land use Map**

![Land Use Map](image)

Fig. 7: Drought vulnerability map based on land use
Irrigation Map

The final result of this study is a map created by the combination of drought vulnerability factors. It is calculated by simple addition of the weights. Five previously created maps (drought vulnerability maps regarding climate, geomorphology, soil properties, land use and irrigation) were added together using numerical weighting scheme. This was done using the tool Raster calculator in Arc GIS. Geographic areas with high numeric values of sum of weights are assumed to be relatively more vulnerable to agricultural drought than areas with lower values. The resulting map was reclassified into six classes identifying areas with "low vulnerability", "low to moderate", "moderate", "high", "very high vulnerability" and "non-agricultural" areas. This was done for both years 2010 and 2011. The climate map for the corresponding year was used in the preparation of the final map of each year. The resulting map for the years 2010 and 2011 are presented in Fig 9 and Fig 10 respectively.

Result Analysis-Effect of various factors on drought vulnerability of the study area

1) Soil - In the Northern side of Palakkad district, the soil type is clayey; with less infiltration capacity and as a result high runoff occurs. By implementing some retention structures, percolation capacity can be enhanced, thereby increasing the water availability. Some of the areas in southern side have also clayey soil type.

2) Land use - In the Northern and southern side the land use is arable (areas that do not separate irrigated and rain fed cropland). Hence Vulnerability to drought is high in these areas.

3) Irrigation - The Northern and southern side are non-irrigated areas.

4) Geomorphology - Slope in the northern and southern side is more than other areas, resulting in high runoff.

5) Climate - In the years 2010 and 2011 the rainfall was less in the northern side compared to other areas in the district.

IV. SUMMARY AND CONCLUSION

In this study, an attempt has been made to prepare the agricultural drought vulnerability map of Palakkad district using the maps of various factors affecting the drought with the help of numerical weighting scheme in GIS. Using this drought vulnerability map, the drought prone areas are identified and are classified as very high, high, moderate, low to moderate and low drought vulnerable zone. The effect of various factors on the result map was also analysed.
decision makers can utilize these maps to provide useful
drought mitigation strategies in the required area.

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