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Assessment of Meteorological Drought Vulnerability through an Integrated Approach Using AHP and GIS in the Karnali River Basin

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Abstract
The weighted overlay analysis tool in ArcGIS was adopted in the study of the drought-prone zone region by combining all the raster layers of drought-influencing aspects of the GIS platform. By analyzing a Geographic Information System (GIS) and the Analytical Hierarchy Process (AHP), disaster monitoring is made possible. Thematic maps were created for each of the eight features, comprising precipitation, temperature, slope, aspect, drainage density, elevation band, LULC, and soil type. To generate pairwise comparison matrices and determine how each parameter is weighted, AHP was used. Using GIS, a drought severity map was prepared after eight thematic maps were examined, integrated, and combined. KRB is highly vulnerable to drought by 56.79%, moderately vulnerable by 20.63%, and very highly vulnerable by only 20.55% of drought categories. These findings were achieved utilizing the Analytical Hierarchy Process (AHP) combined with a GIS platform. The output map resulting from this process will provide insights into the severity of drought susceptibility, which is significant for meteorological drought importance and serves drought mitigation.

Keywords
Drought, AHP, GIS, Drought Vulnerability Map (DVM), Karnali River Basin (KRB)

1. Introduction

Drought is a stochastic natural hazard caused by severe and prolonged precipitation shortages, and meteorological drought is the first drought event to have an influence on agriculture and hydrology [1]. Drought is defined as meteorological (less rainfall), agricultural (reduced soil moisture), hydrological (less surface runoff), or socioeconomic (demand exceeds supply)[2]. Meteorological drought, caused by less than normal precipitation,[3] causes insufficient soil moisture for plants, which hinders plant growth and leads to agricultural drought. The majority of European nations, the United States, and several Asian nations are taking this into consideration [2]. Drought has led to challenges, particularly in rain-fed hill farming systems, where people depend on summer and winter rains for their primarily agricultural activities [4]. It has a detrimental impact on the production of groundwater, contemporary industrial products, and power. In recent years, major droughts have occurred in Nepal's Karnali River Basin. The identification or mapping of drought zones was accomplished by the integration of GIS with other multi-criteria decision-making approaches such as the Analytic Hierarchy Process (AHP) methods[5].

When considering multiple possibilities available for achieving the goal, the AHP approach formulated by Saaty [6] assists in selecting or prioritizing the selection parameters in the pairwise comparison matrix. The assessment of the identification of drought zone regions involved several variables in a pairwise comparison matrix[5]. There have been relatively few studies performed in KRB although the fact that the drought and its consequences on people's livelihoods are an important subject. A general understanding of the drought risk associated with the Karnali River Basin is provided by the theoretical approach used for creating the Drought Vulnerability Map (DVM) and implementing the AHP technique.[2] The objective of this study is to identify or map the drought prone zones through GIS and AHP methods of the Karnali River Basin. It is anticipated that decision-makers, people, and communities involved in agriculture, water resource management, and water conservation efforts will gain from and be more aware of the study's findings and the region's propensity for drought.

2. Study Area

The KRB is located in Western Nepal between latitudes 28°30'-30°30'N and longitudes 80°50'-83°50'E as shown in Figure 1. The river forms a basin area of more than 46,100 km$\hat{2}$ in size, 45 percent of which is in India. In the basin, annual precipitation averages 1,479 millimeters, with 77% of that falling during the summer monsoon season (June to September) and only 7% falling during the winter months (December to February). Pre-monsoon precipitation, which occurs between March and May, accounts for 12% of the total annual amount, while post-monsoon precipitation, which occurs between October and November, accounts for barely 4%. The temperature of the basin may vary in similar ways. The average max and min temperature range in the basin is frequently between 25°C at its peak point and barely 13°C at its lowest point.

3. Materials and Methods

Using a multi-criteria decision model with Geographic Information Systems (GIS) can generate results that are more accurate and realistic. Depending on the accessibility and

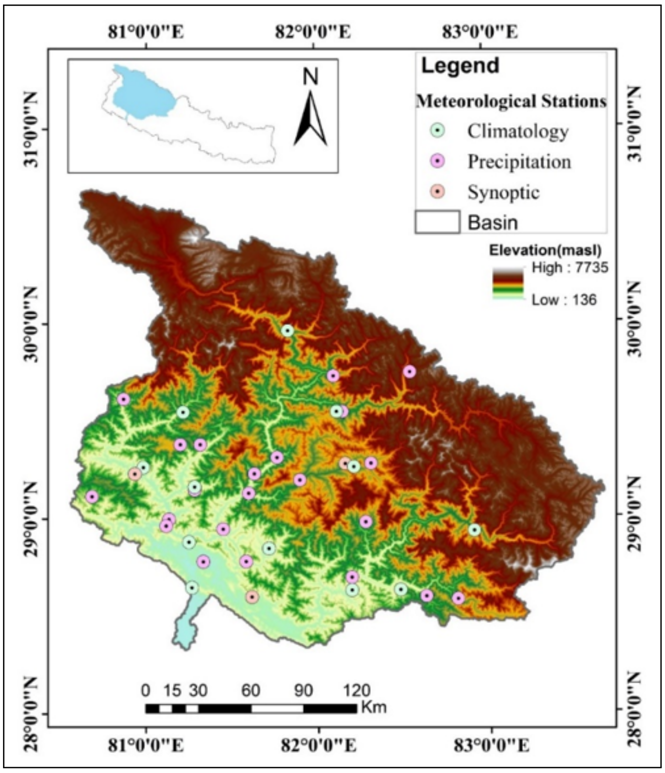

Figure 1: Karnali River Basin

accuracy of the data in various areas, these criteria may be used to map the vulnerability to meteorological drought. Effective parameters and drought sensitivity factors are identified in the current research[2]. The Analytical Hierarchy Method (AHP) was used to identify the eight conditioning factors that included precipitation, temperature, slope, aspect, drainage density, elevation band, LULC, and soil type to determine the severity of drought in the research locations. In Figure 2 , a thorough proposed technique is shown.

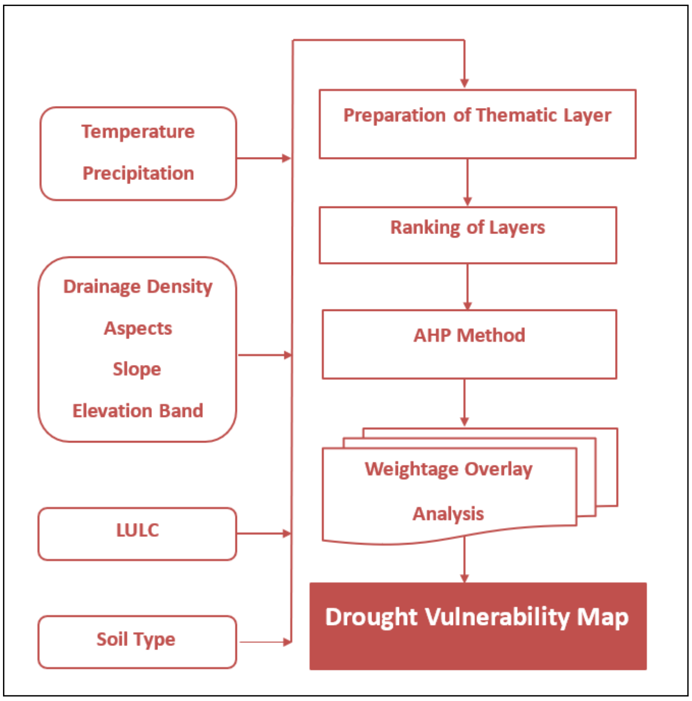

Figure 2: Flowchart depicting the adopted methodology

3.1 Selection and importance of layer data

Precipitation
The main determinant affecting the susceptibility of an area to drought is the amount of rainfall that occurs there[2]. Using the Inverse Distance Weightage (IDW) tool in ArcGIS, 29 weather station location data points were used to interpolate the surface rainfall map of the research area.The region with little precipitation is given a higher rank on a scale evaluating the impact of drought and vice versa[5].

Temperature
The temperature map of the research area has been interpolated using the IDW approach that uses 8 locations for weather stations. The research area's highest monthly temperatures typically range from 25.27°C to 37.25°C each year. The area with high temperatures is given a higher rank on the scale of how much of an impact drought has, and vice versa [5].

Drainage Density
The ratio of a region's total stream channel length to its area is termed as the drainage density. A place with a lot of drainage can carry a lot of surface runoff to various stream systems. The lowest scale of drought effect is provided to the region with low drainage.

Soil Type
In terms of plant and agricultural growth, the interaction between soil and water is crucial. The permeability and water-holding capability of a particular area are significantly influenced by the soil's texture. They are less likely to be hazardous under drought, if the soil type has a strong capacity to preserve or store water.

LULC
Five categories of landcover are identified in the study: vegetation, agricultural, built-up areas, barren areas, and waterbodies. The LULC maps are generated using supervised classification. In comparison with water bodies, snow, riverbed, (ranked from high to low sensitivity), cropland is more likely to be affected by drought.

Elevation Band
The elevation of the plain also has a significant impact on water availability. The south is mostly a low-elevation zone, high altitudes may be found in the north. The descriptive data demonstrate that the average sea level ranges from 141 to 7756 m.

Aspects
The hydrology study regions is impacted by the sun's variable levels of radiation on each aspect, which is the slope direction. (3) Five distinct classes were identified on the aspect map of the research region. The range of values for the aspects' vulnerability classes is from 1 to 5, with a higher number indicating a stronger influence on drought vulnerability [2].

Slope
Slope, a measure of the extent to which the land surface gradients from the horizontal, is another important drought risk factor.[7] Infiltration and slope of the ground surface often have a reversal relationship, with slope increasing causing infiltration to decrease and vice versa. The susceptibility to drought is more affected when the levels are higher [2].

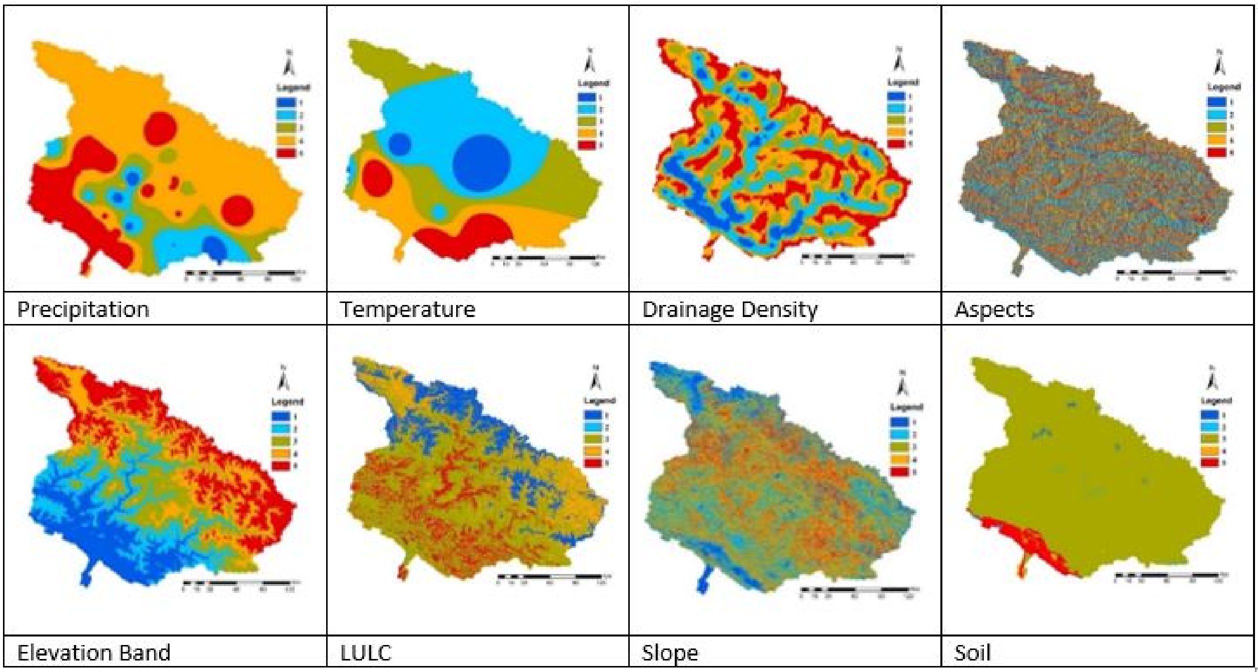

Figure 3: Different thematic layers

Table 1: Layer rank and hazard for mapping Drought prone zone

S.N	LAYER	RANK	HAZARD	S.N	LAYER	RANK	HAZARD
1	**Temperature (0.238)**			**5**	**Elevation (0.044)**		
	<27	1	very low		141 - 1522	1	Very low
	27-30	2	low		1522 - 2619	2	low
	30-33	3	moderate		2619 - 3753	3	moderate
	33-36	4	high		3753 - 4777	4	high
	>36	5	very high		4777 - 7756	5	very high
2	**Precipitation (0.32)**			**6**	**Aspects (0.036)**		
	<5	5	very high		1-68.36	1	very low
	5-10	4	high		68.36 - 141.96	3	moderate
	10-15	3	moderate		141.96 - 214.14	5	very high
	15-20	2	low		214.14 - 286.33	4	high
	>20	1	very low		286.33 - 359.93	2	low
3	**LULC (0.116)**			**7**	**Soil (0.0781)**		
	Water Body, Snow and Glacier, Riverbed	1	very low		Ice and Glacier	1	Very low
	Grassland, Forest	2	low		Sandy Clay Loam	2	low
	Build Up Area	3	moderate		Loam	3	moderate
	Bare Slope, Bare Rock	4	high		Sandy Loam	4	high
	Cropland	5	very high		Sand	5	very high
4	**Slope (0.062)**			**8**	**Drainage Density (0.106)**		
	0 - 15	1	very low		0.024- 0.30	5	very high
	15 - 25	2	low		0.30- 0.46	4	high
	25 - 35	3	moderate		0.46 - 0.63	3	moderate
	35 - 45	4	high		0.63 - 0.83	2	low
	45 - 85	5	very high		0.83 - 1.37	1	very low

3.2 Proposed Model-AHP Model

A Multi-Criteria Decision-Making (MCDM) approach is a pairwise comparison matrix of parameters used to define an objective, is a key component of the AHP technique[5]. The scale factor from 1 to 9, according to importance is shown in Table 2 and is the criterion for evaluating judgment. Through a pairwise comparison matrix and normalized weight, the methodologies were utilized to determine the weights of the various criteria used for the identification of drought-prone zones. Based on the perspectives of government officials, farmers, and local communities, as well as evaluations of the literature and specialist expertise, these weights have been determined. The final result of the drought zone in ArcGIS is determined by using these weights in the weighted overlay analysis, which additionally considers their degree of impact on the scale (1–5).

Following are the formulae that were used to determine the consistency ratio (CR) and consistency index (CI):

$$CI = \frac{\lambda_{\max} - n}{n - 1}$$

$$CR = \frac{CI}{RI}$$

Where,
λ_{max} = maximum eigen value;
n = number of parameters in matrix;
RI = random index value (for n = 7; RI = 1.32) (2)

Table 2: AHP Description

AHP Description	Intensity of importance Explanation
1	Equally Strong
3	Moderately strong
4	Strongly Strong
7	Very Strongly strong
9	Extremely strong
2,4,6,8	Intermediate values

3.2.1 Proposed Model-GIS

All eight theme maps in the present model were created using a GIS. The relevant raster maps were subjected to weights from AHP that were used in a GIS model. Using AHP, weightage aspects were developed. The integration of input data layers was done using the weighted overlay method that is provided in ArcView Model Builder. The total of the cumulative values of all parameters was utilized for the GIS-based classification of drought into several classes after each parameter's rating was multiplied by its weight.

3.2.2 Weighted overlay analysis

A quick, straightforward, and adequate method for identifying potential drought-threatened regions is the weighted overlay analysis. A drought risk zonation map of the research zone was created using eight factors. These factors were ranked numerically proportionally on a scale of 1 to 5, depending on their importance. Higher weights and ranks indicate a bigger influence on the possibility of drought. These elements were combined using the weighted overlay techniques in GIS as thematic layers to produce the drought danger zone map. The drought map was then created by combining all the parameters after multiplying them by the weights assigned to them. The values of the drought map are more significantly affected by the factors with greater weights. Drought map was categorized into five zones: very high, high, moderate, less and very less drought.

$$D = \sum_{n=1}^{\infty} (T_j \times d_i)$$

where, Tj denotes the weights of each parameter multiplied to the drought parameters (di)

4. Results and Discussion

4.1 Layers Ranking Table

The weights and rankings of each parameter utilized in the AHP are displayed in Table 1 for the weighted overlay analysis in GIS. Each subclass of the parameters is multiplied by each parameter's weights, which are then placed in order again based on how each subclass affects the parameter. Each sub-class impact is given a rank between 1 and 5, with 5 being the highest[5].

4.2 Layers Map

According to the importance of each of the parameters to the drought condition in the study area, the ranking of each layer was done from 1 to 5, 1 being least significant and 5 being more significant. Figure **??** shows the eight different thematic layers.

4.3 AHP Table

Pairwise comparisons of all eight elements were carried out after preparing AHP questionnaires that were responded to by experts. The eight parameters were compared in pairs using a numerical approach at this step, where the extreme numbers 1 and 9 represent equally and greatly favored possibilities, respectively. After thorough examination, weights associated with drought vulnerability were assigned to each of the eight layers . The value of the paired comparisons' inconsistency in this investigation was 0.1. The generated AHP matrix has lambda maximums of 7.635, 0.106, and 0.08 as well as consistency index (CI) and consistency ratio (CR) values. The given matrix is consistent and may be utilized in the analysis since CR.

4.4 Drought Vulnerability Map

The DVI map was further reclassified into five classes: identifying geographic areas as 'Very less vulnerable', 'less vulnerable', 'moderately vulnerable', 'highly vulnerable', and 'very highly vulnerable'. KRB is highly vulnerable to drought by 56.79%, moderately vulnerable by 20.63%, and very highly vulnerable by only 20.55% of drought categories. Very highly vulnerable drought occurs in the southern part of the basin, Doti, Kailali, Surkhet, Bardiya district of the study area and some scattered portion of the north eastern part (Dolpa). Moderate drought is found to be concentrated in the central part. High drought is found to dominate the majority portion of the study area. These findings were achieved utilizing the Analytical Hierarchy Process (AHP) combined with a GIS

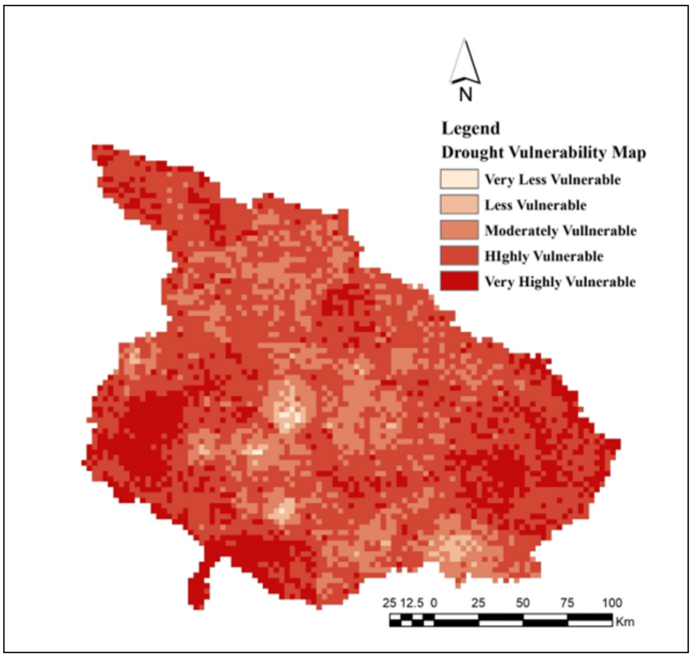

Figure 4: Drought Vulnerability Map

platform. The output map resulting from this process will provide insights into the severity of drought susceptibility, which is significant for drought importance and serves drought mitigation.

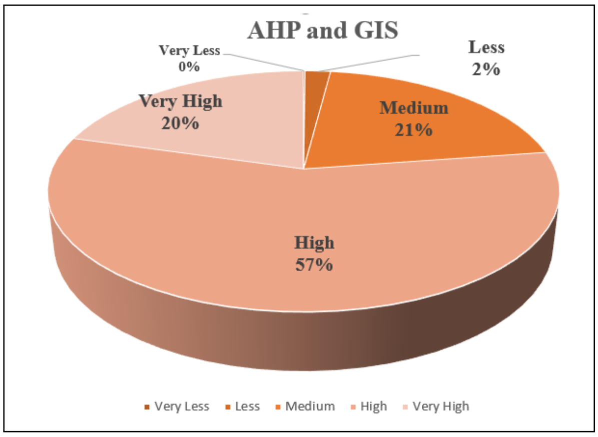

Figure 5: Drought Prone Areas in %

5. Conclusions

To determine which parts of the KRB are at risk from drought, research was conducted.Using an integrated approach of GIS and AHP technique this research attempts to provide an alternate technique of identifying drought regions when time and resources are limited. With pairwise comparison matrix among the parameters, help in ranking those parameters for the identification of drought zones, and its normalized weights, which effectively address the hierarchical relationships among the parameters, the AHP method has made it easier to assess the drought regions. The output obtained from the weighted overlay analysis in Arc GIS shows zones with very less, less, moderate, high, very high drought cover across the KRB. The majority of the regions in the Karnali River Basin can be classified as high vulnerable, referring to the meteorological vulnerability map. Only alternate and straightforward approaches for identifying the region's drought zones are highlighted in this study.

This study has demonstrated the great potential of GIS combined with the AHP approach for determining drought zones in the area. This theoretical approach, with less information and in a very short period of time, drought assessment can be done and gives acceptable result. As a result, policymakers and decision-makers can respond quickly and effectively to any drought situation.

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