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Abstract

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Keywords

drought vulnerability assessment, AHP, GIS, Remote sensing (RS), drought vulnerability factors

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RESEARCH ARTICLE

Drought vulnerability modeling over Mandawa watershed, northern Iraq, using GIS-AHP techniques

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ABSTRACT

Drought is among the most severe natural calamities induced by lack of water, having a negative implication on water resources and agriculture in the affected area. Drought types and severity vary by location, so understanding the spatial distribution can aid in developing measures to overcome this natural hazard. In this study, the areas vulnerable to droughts in the Mandawa watershed in the Kurdistan region of Iraq were determined by employing seven associated factors: rainfall, temperature, LULC, surface slope, soil texture, elevation, and distance to rivers. Satellite imagery of Landsat 8 OLI for 2021 was employed to create the Land Use and Land Cover (LULC) and distance to rivers maps. The elevation and surface slope maps have been generated from the Digital Elevation Model at 30 m resolution, soil texture map was extracted from The FAO Digital Soil Map of the World and the inverse distance weighting method was utilized to interpolate the rainfall and temperature throughout the watershed. Analytical Hierarchy Process (AHP) was used to create a pairwise compression matrix to obtain the weight of each parameter. In the Geographic Information System (GIS) environment, the combined impact of affecting factors was utilized to create the area's drought zonation map. The results indicated that only 5.2% and 13.8% of the study area is vulnerable to extreme and severe droughts, respectively. While more than 35% of the watershed is hardly vulnerable to droughts.

Key Words: **drought vulnerability assessment, AHP, GIS, Remote sensing (RS), drought vulnerability factors**

INTRODUCTION

Drought is considered one of nature's most destructive forces, involving a variety of natural and human factors that influence drought risk and vulnerability. Drought vulnerability is a function of exposure components, adaptive capacity and sensitivity, and it determines how vulnerable a region is to drought. Drought vulnerability indicators are used to illustrate these components, which describe physical, infrastructural, and socioeconomic factors. Droughts have been classified into four types: meteorological, hydrological, agricultural, and socioeconomic drought (Wilhite and Glantz, 1985). The most important type of drought is meteorological drought, which causes other types of drought by reducing mean long rainfall (Nasrollahi et al., 2018). A period of insufficient surface and subsurface water resources for the defined water usage of a specified water management system is referred to as a hydrological drought (Mishra and Singh, 2010). Agricultural drought is a significant failure in crop production brought on by insufficient soil moisture (Singh et al., 2019). Socioeconomic arises mostly when the need for an economic good exceeds its availability as a result of a weather-related shortfall in water supplies (Bayissa et al., 2018).

The catchment's response to a lack of precipitation varies and is largely determined by the catchment's physio-geographic characteristics such as permeability, topography, land use, land cover, climatic conditions and water regulation (Van Loon and Laaha, 2015). As a result, developing strategies will aid in drought relief measures, providing security to the study area.

Remote sensing is considered one of the most effective monitoring methods; it provides more dependable disaster information over large geographic regions than traditional measurements. (Chopra, 2006). There are numerous remote sensing-based methods for mapping, quantifying, monitoring, and forecasting droughts in a region. Alshaikh (2015) has observed a study between 1990 and 2013 to evaluate and monitor drought conditions in north Kingdom of Saudi Arabia (KSA). The Water Supplying Vegetation Index (WSVI) which was obtained from Landsat 5. Landsat 8 was used in this study to evaluate drought. The researchers summarized that satellite remote sensing data can be utilized to assess drought conditions in Kingdom of Saudi Arabia (KSA). Gaznayee and Al-Quraishi (2019) used RS data to assess drought severity and impact maps in Erbil province, Kurdistan, between 1998 and 2017. Temperature Condition Index (TCI) and Normalized Difference Vegetation Index (NDVI) were extracted from 20 Landsat mosaic images. According to the study's findings, the capital city witnessed severe to extreme drought.

GIS aids in the identification of multiple data sources required for disaster monitoring, as well as the ability to analyze and integrate different kinds of data sets for bigger regions (Zagade and Umrikar, 2021). According to recent research, remote sensing combined with GIS provides a better solution technique for drought monitoring than other traditional means. Fadhil (2011) conducted a study in Kurdistan region using RS and GIS techniques to map the drought, that hit some parts of country in 2007-2008. Normalized Difference Water Index (NDWI), NDVI, Land Surface Temperature (LST), Tasseled Cap Transformation Wetness, and Bare Soil Index have been employed. The results illustrated that 29.9% of soil wetness, 56.7% of vegetation cover, and 32.5% of the surface area of Dokan Lake have been decreased when it is compared to 2007.

Multi-Criteria Decision Analysis (MCDA) is a technique and procedure for structuring decision problems, designing, evaluating, and ranking alternative decisions. One of the most extensively utilized MCDA techniques is Analytical Hierarchy Process (AHP) which has been established by (Saaty, 1977).

A growing trend was observed in the use of RS-GIS and multi-criteria decision methods for mapping different natural hazards in different disciplines (Pereira and Duckstein, 1993, Yalcin and Bulut, 2007, Pogarčić et al., 2008, Stefanidis and Stathis, 2013). However, only a few studies on drought risk assessment have been published. Palchaudhuri and Biswas (2016) carried out a study in India, to prepare drought severity map using 14 different parameters utilizing GIS and AHP techniques. According to the findings, 70% of Puruliya district's total area is under severe drought, affecting nearly 14 blocks.

This research looks into the possibilities of using remote sensing data in conjunction with geospatial analysis to map drought vulnerability in Mandawa watershed with land surface area of (3542.46 km^2) in Kurdistan region of Iraq. To create the Drought Vulnerability Assessment (DVA) map, a multiple of variables and aggregated drought measures (elevation, slope, precipitation, LULC, soil texture, temperature, and distance to rivers) are assessed, weighted, and overlaid in GIS using AHP techniques. Data was obtained from various sources such as meteorological stations, Landsat 8 image, and digital elevation model (DEM). Till now, no such drought susceptibility research from this region has been reported; thus, this will indeed be the pioneering effort required for sectorial drought preparation.

MATERIALS AND METHODS

Research Area

The research area is in Iraq's Kurdistan Region, in the country's north-eastern part. It is administratively part of both the governorates of Erbil and Duhok. The physical area is considered as a portion of Greater Zab River basin, extending from Bekhma Dam location in North to Aski-Kalak in South. The region spans 36° 51' 28" to 36° 11' 24.16" North latitude and 43° 36' 36.49" to 44° 31' 16.42" East longitude, and has a land surface area of (3542.46 km^2). Mountains and extensive plateaus characterize the area, which has an average elevation of nearly 691 m above sea level (ASL). The research area has a semi-arid continental climate. The average annual precipitation in the study area ranges from 552 to 1330 mm, and the average temperature ranges between 18.2 to 21.05 C^o (KRG, 2021), depending upon climatic data from six selected stations in and around the research area. Fig. 1 illustrates the study area's location**.**

Data Collection

Drought vulnerability is important to assess the damage induced by droughts. In this regard, the use of GIS and AHP can provide more realistic and accurate results. In general, the factors that contribute to drought vulnerability are diverse. The use of these factors for mapping drought vulnerability is dependent on the reliability and availability of data in various regions. Effective parameters were identified in this study. Then, seven main parameters (elevation, slope, precipitation, LULC, soil texture, temperature, and distance to rivers) were specified from meteorological stations, Landsat 8 images and Digital Elevation Model (DEM). Table 1 shows the data types and their sources in detail.

Table 1: The data type and their sources in detail

Data	*Description*	*Source*	*Date*
Elevation and Slope	Obtained from DEM (30-m resolution)	USGS Earth Explorer	2014
Precipitation and Temperature	Obtained from meteorological data	Meteorological departments	2002-2021
LULC and Distance to rivers	Obtained from Landsat (8) image (30-m resolution)	USGS Earth Explorer	2021
Soil texture	Extracted from world soil map (1:5000000)	FAO Digital Soil Map of the World	2002

Table 2: Geographic and climatic characteristics of stations and data

Station name	*Latitude (N)*	*Longitude (E)*	*Elevation (m)*	*Mean rainfall (mm)*	*Mean annual temperature*
Salahaddin	36° 23'	44° 13'	1088	1026.5	18.24
Shaqlawa	36° 24'	44° 19'	980	1331	18.39
Soran	36° 39'	44° 32'	680	1176.5	18.36
Akre	36° 44'	43° 54'	636	1134.5	20.5
Ainkawa	36° 13'	44° 01'	436	676.5	21.1
Khabat	36° 16'	44° 39'	252	551.6	21.05

Generation of Thematic Layers

Rainfall and Temperature Layers

Drought vulnerability is influenced by precipitation and temperature. Drought is more likely in low-precipitation areas than it is in high-precipitation areas. Furthermore, high-temperature areas are more susceptible to drought than low-temperature areas. In this study, monthly precipitation and temperature data from the Meteorological Department of the Ministry of Agriculture and Water Resources, Kurdistan Region Government (KRG), Iraq, were used to create annual precipitation and temperature maps that interpolated 6 stations namely (Pirmam, Soran, Akre, Erbil, Khabat, Ainkawa) located in and around the study area using the Inverse Distance Weighting (IDW) method for 19 years, from 2002 to 2021. Table 2 shows geographic and climatic characteristics of stations and data, and Fig. 1 depicts the locations of the stations.

LULC

One of the most important aspects for determining the impact of droughts is LULC. Droughts are expected to have the most impact on agricultural areas, followed by residential areas. In terms of land cover, high vegetation cover areas are more susceptible to droughts than low vegetation cover areas. In this study, ERDAS IMAGINE 2014 was used to apply supervised classification methods with maximum likelihood grouping to the (Landsat 8 OLI) for 2021 with 30-m resolution for the study area to create the LULC layer.

Slope

Slope gradient is inversely correlated with Surface water infiltration in a given area. Thus, as the catchment's slope increases, infiltration and concentration time decrease, resulting in less infiltration and higher runoff rates. As a result, areas with lower slopes are thought to be less susceptible to drought than areas with moderate or higher slopes (Zagade and Umrikar, 2021). In this study, the slope layer was created from the projected DEM layer by using the surface function (slope) from the spatial analyst tool in ArcGIS software.

Distance to Rivers

River distance is regarded as one of the most important variables in evaluating the possible distribution of drought-affected regions. Access to water decreases as one moves away from the river, increasing vulnerability to drought occurrences (Kalura et al., 2021). In order to create the distance from rivers map, the shapefile of the main river (portion of the Greater Zab River) was extracted from the LULC layer utilizing the extraction tool in ArcGIS software in the first step. Following that, the distance from the river map was calculated using the distance tool of the spatial analyst extension tool of ArcGIS.

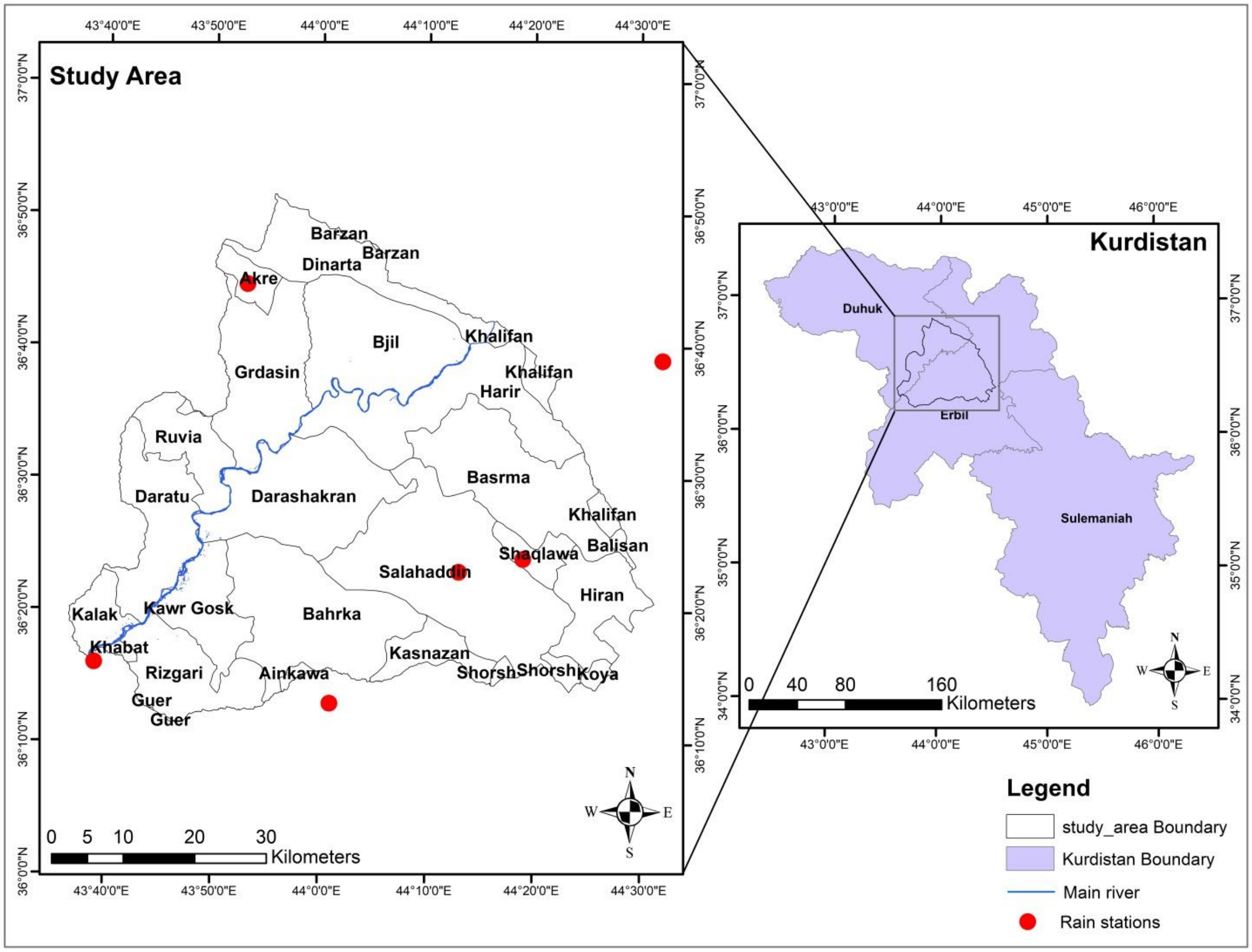

Fig. 1: The study area's location

Soil Texture

Because of the property of water retention abilities, soil type is regarded a contributing component in drought vulnerability assessments (Swain et al., 2022). Water retention capacity varies according to soil type, particularly the texture of the constituent elements. Finer-grained soils can hold more water than coarser-grained soils (Swain et al., 2022). The soil texture map for the study area was created by extracting a study area soil map from The FAO Digital Soil Map of the World with scale (1:5000000).

Elevation

Water availability can be correlated with the elevation of areas within a basin. The higher the elevation, the less water is available. Higher elevation zones, as opposed to lower elevation zones, have more undulating terrain with steeper slopes and streams of first and second-order. Within those regions, stream flow fluctuates throughout the year. As a result, higher elevation zones are more vulnerable to drought than lower elevation zones (Hoque et al., 2021). Elevation data have been acquired for this study by the DEM of the NASA Space Shuttle Radar Topography Mission (SRTM) utilizing InSAR with 1 Arc spatial resolution which is equivalent to 30-meter resolution.

Hierarchy Process (AHP)

The AHP is a math and psychology-based method for organizing and analyzing complicated decisions. This method, developed by (Saaty, 1977), is one of the most widely utilized multi-criteria decision making techniques. It has been utilized in a variety of sectors to solve unstructured problems (Zarei et al., 2021). The process for solving spatial multi-criteria decision - making problems entails creating a value structure of assessment criteria in which the objectives and the respective alternatives are arranged in a hierarchy. The hierarchy structure was created to account for the different influencing parameters, which include precipitation, slope, LULC, temperature, texture of soil, elevation, and distance to rivers. The weight and rank of each criterion must be determined after constructing a hierarchical structure of decision-making elements (Mokarram and Zarei, 2018). A pairwise comparison method has been used in this method to determine the layer weights. In AHP method, the factors are compared and weighed corresponding to each other in pairs. The element comparisons and weights are documented in a (n * n) matrix using an excel sheet in Microsoft Excel 2010. Parallel comparison is performed by valuing the row element relative to the column element and evaluating it using a distance scale ranging from 1 to 9 (Table 3), with 1 indicating the least contribution and 9 indicating the greatest contribution (Pandey and Srivastava, 2018). After the pairwise comparison matrix has been compiled, the normalized pairwise comparison matrix must be calculated which its value is calculated by dividing the matrix values of each cell by the sum of the matrix values of each column in the pairwise comparison matrix value, then averaging the row values of the normalized pairwise comparison matrix to get weights of each factor. In addition, the Consistency Ratio (CR) was utilized to determine the accuracy of the AHP method.

Consistency Ratio (CR)

The weight of each parameter influences the outcome of the drought vulnerability assessment. AHP is useful for tracking the accuracy of decisions after the matrix has been compared. As a result, for robust and reliable results, the consistency ratio (CR) for checking is required, and is computed using Equation 1:

$$CR = \frac{CI}{RI} \quad (1)$$

In which, RI is random index depends on the number of effected factors and its values are obtained in Table 4, while CI is consistency index Equation 2 has been utilized to find its value:

$$CI = \frac{\lambda_{max} - \mathrm{N}}{\mathrm{N} - 1} \quad (2)$$

In which, N is the order of matrix, and λ_{max} is the greatest eigenvalue and is calculated by first creating a consistency measure values by multiplication between calculated weights and a pair wise comparison matrix values, and then averaging the division of these values and the calculated weight of the parameter. The consistency between factors in the comparison matrix is acceptable if the value of consistency ratio is less than 0.1 (Saaty, 1977). Otherwise, the pairwise comparison matrix should be revised, and the relative importance of variables should be reevaluated.

Finally, to determine drought vulnerability map various layers were aggregated and integrated in ArcGIS using weighted overlay tool in spatial analyst tools, as shown in Equation 3:

$$DV = \sum_{i=1}^{n} w_i * x_i \quad (3)$$

In which, DV is drought vulnerability, n is number of factors, w_i is weight of the criteria and x_i is the priority rating of the factor.

Table 3: Comparison matrix scale (Saaty, 1977)

Intensity of importance	Definitions
1	Equal
3	Moderate
5	Strong
7	Very strong
9	Extreme
2,4,6,8	For compromises between the above

Table 4: Values of RI (Saaty, 1977)

N	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

RESULTS AND DISCUSSION

Rainfall and Temperature

Temperature and rainfall are considered as core criteria in determining the drought vulnerability in a region. Drought vulnerability increases as temperature increases, therefore higher temperature areas will have a higher weight value, at the same time, drought vulnerability increases as precipitation decreases, so areas with the lowest rainfall received the highest weight value, while areas with the highest rainfall received the lowest weight value. Fig. 2 illustrates distribution of rainfall and temperature in the watershed.

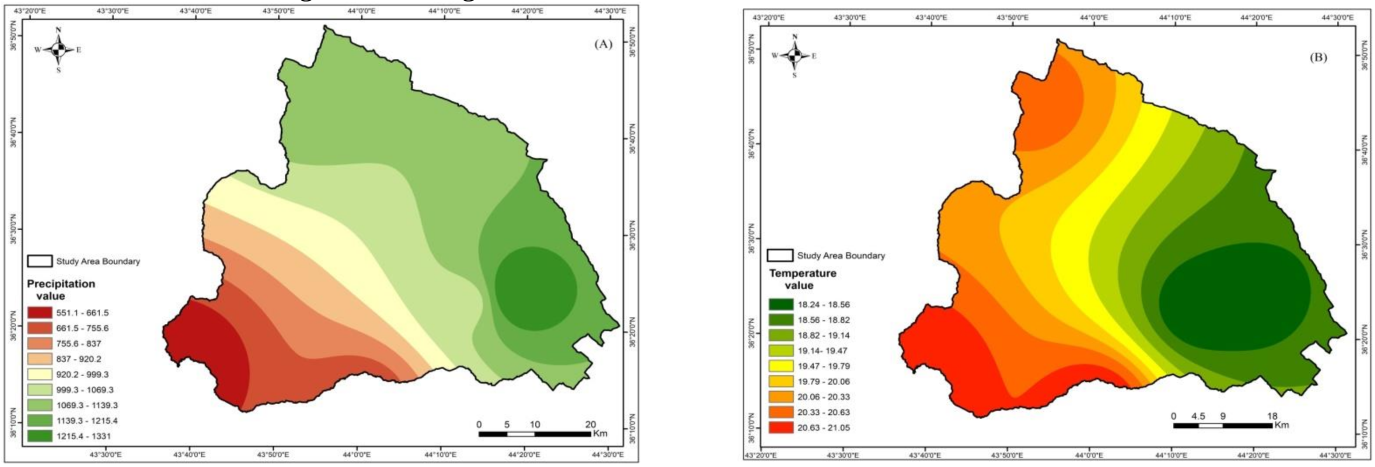

Fig. 2: Distributions of (A) rainfall and (B) temperature in watershed

LULC

Fig. 3 depicts the LULC classification of the watershed. Barren land, vegetation cover, water bodies, agricultural land and settlement are five LULC classes found throughout the basin, with increasing weightage given to drought vulnerability. Table 5 shows the weights and percentages of basin area assigned to each class.

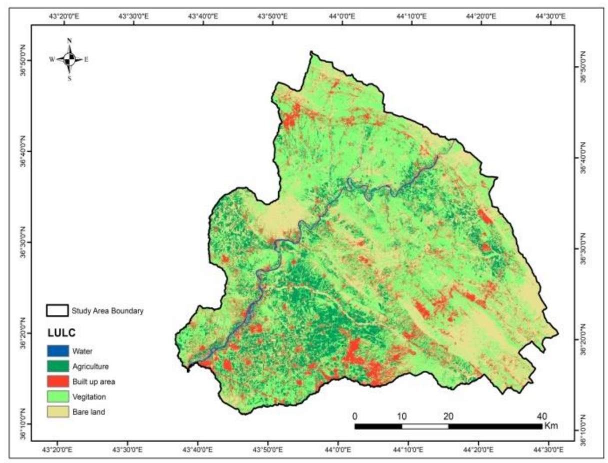

Fig. 3: LULC classification over the watershed. Created from (Landsat 8 OLI, 2021)

Surface Slope

The slope of the area has been categorized into five classes, i.e. < 5, 5–11, 11–19, 19–30 and > 30%, in descending order of vulnerability to droughts. So the highest ranks were given to the steepest slopes. The spatial distribution of the slope over the watershed is shown in Fig. 4.

Soil Texture

Fig. 5 depicts a categorized soil map of the study area. Over the region, there are three soil types: clayey, loamy clay, loamy with increasing weightage toward the drought vulnerability.

Distance to Rivers

In the current study, the watershed area is divided into five distance classifications from the portion of Grater Zab River reach, as shown in Fig. 6, namely 0-5 km, 5-10 km, 10-15km, 15-20 km, and greater than 20 km. The regions with a distance of more than 20 km got the highest rankings.

Elevation

Elevation and drought vulnerability are frequently shown to have a direct relationship. The land elevation of this study is divided into 5 classes: (243-458), (458-559), (559-901), (901-1203), and (1203-1954) as shown in Fig.7 High elevation zones are given a higher ranking, and vice versa as indicated in Table 5.

AHP Approach

Weighting is essential when evaluating multiple criteria to determine drought vulnerability. In the current study, the seven factors were evaluated and compared in pairs (Table 6) to determine the relative significance of each factor to the drought condition in the study region, as defined by natural resources experts, which can then be utilized to create the normalized pairwise comparison matrix by dividing the values of each column by its total value, then averaging the row values to get the weight of each factor as shown in (Table 6) Climatic factors are considered the most significant in determining the areas vulnerable to drought. As a result, the highest weights were assigned to precipitation (0.34) and temperature (0.24), while the lowest value was given to elevation (0.03). The multiplication of (Table 6) values and weighted sum generated consistency measure (CM) values as shown in Table 7, the average deviation of these values from the weighted sum was obtained to get λ_{max} (7.229). Following that, Equation 1, Equation 2 and Table 4 were used to determine consistency among factors. The results revealed that CR is 0.03 which is less than 0.1 so the weights are acceptable.

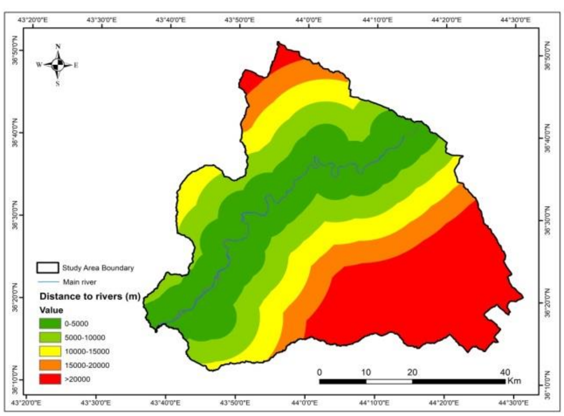

Fig. 6: Distance to river classification over the watershed

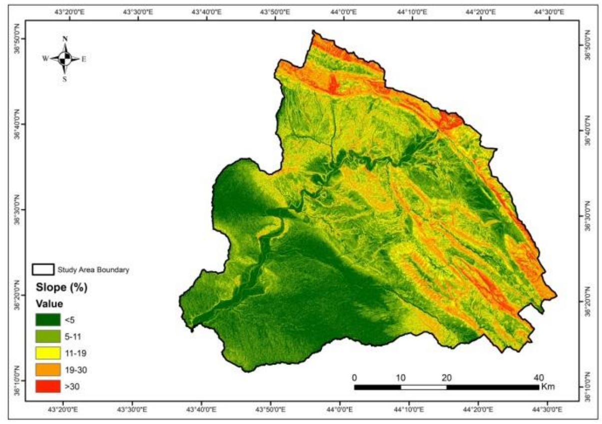

Fig. 4: Slope classification over the watershed

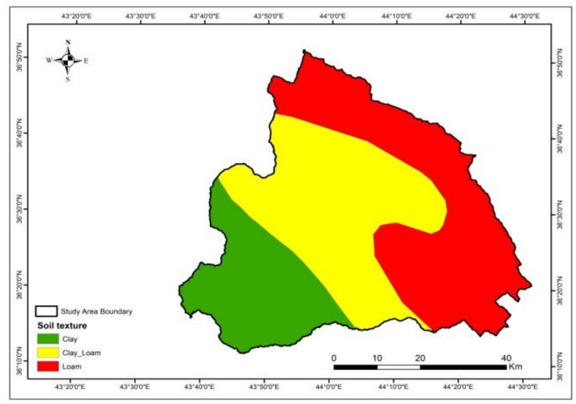

Fig. 5: Soil texture classification over the watershed. Adapted from (The FAO Digital Soil Map of the World)

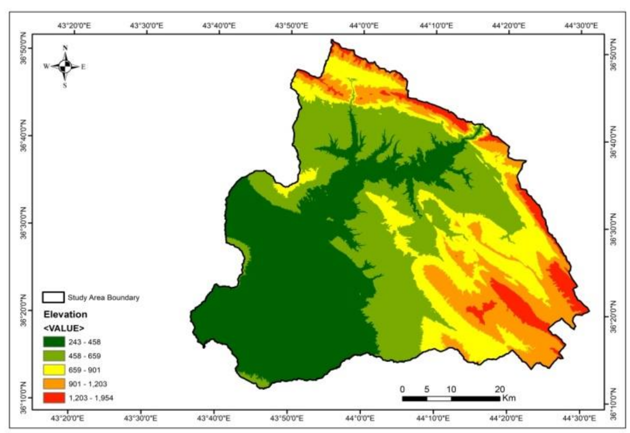

Fig. 7: Elevation classification over the watershed. Adapted from (USGS Earth Explorer)

Table 5: Weights and ranks of different factors that contribute to drought vulnerability

NO.	Parameters	Range of value	Ranks	AHP weight (%)	Area (%)[1]
1	Rainfall (mm)	551.9-661.5	9	35	4.88
		661.5-755.8	8		11.16
		755.85-837	7		31.16
		837-920.2	6		15.64
		920.2-999.3	5		9.77
		999.3-1069.3	4		7.77
		1069.3-1139.3	3		6.9
		1139.3-1215.4	2		7.73
		1215.4-1331	1		5.00
2	Temperature (Cº)	18.24-18.56	1	24	13.19
		18.56-18.82	2		15.31
		18.82-19.14	3		9.22
		19.14-19.47	4		7.81
		19.47-19.79	5		8.31
		19.79-20.06	6		10.43
		20.06-20.33	7		14.47
		20.33-20.63	8		11.83
		20.63-21.05	9		9.43
3	LULC	Agriculture	9	16	14.12
		Buildup area	7		11.98
		Vegetation	5		45.76
		Bare land	2		27.19
		Water	1		0.95
4	Surface slope (%)	<5	1	5	29.41
		5-11	2		36.55
		11-19	3		17.78
		19-30	4		13.71
		>30	5		2.54
5	Soil texture	Clay	1	10	22.07
		Clay loam	2		38.50
		Loam	3		39.43
6	Distance to rivers (km)	0-5	1	7	27.93
		5-10	2		19.92
		10-15	3		15.42
		15-20	4		11.06
		>20	5		25.68
7	Elevation (m)	243-458	1	3	37.17
		458-559	2		28.6
		559-901	3		16.79
		901-1203	4		12.97
		1203-1954	5		4.47

Table 6: The normalized pairwise compression matrix

[1] The area of each layer has been calculated using ArcGIS.

Criteria	Rainfall	Temperature	LULC	Soil texture	Distance to rivers	Surface slope	Elevation	Weights sum (w_i)
Rainfall	0.4	0.45	0.41	0.36	0.32	0.3	0.23	0.35
Temperature	0.2	0.22	0.27	0.27	0.25	0.26	0.19	0.24
LULC	0.1	0.11	0.14	0.18	0.19	0.17	0.19	0.16
Soil texture	0.1	0.07	0.07	0.09	0.13	0.13	0.15	0.1
Distance to rivers	0.08	0.06	0.05	0.05	0.06	0.09	0.12	0.07
Surface slope	0.06	0.04	0.03	0.03	0.03	0.04	0.08	0.05
Elevation	0.07	0.04	0.03	0.02	0.02	0.02	0.04	0.03

Table 7: Consistency measure values

	Rainfall	*Temperature*	*LULC*	*Soil texture*	*Distance to rivers*	*Surface slope*	*Elevation*
CM	2.58	1.76	1.13	0.76	0.5	0.31	0.24
CM/w_i	7.34	7.38	7.34	7.2	7.09	7.06	7.05
λ_{max} =7.229		CI=0.0345		RI=1.32		CR=0.03	

Drought Vulnerability Assessment

The map of drought vulnerability was created by analyzing factor layers, using GIS and MCDM approach. Fig. 8 depicts the map of drought vulnerability in the watershed. The drought vulnerability map was reclassified into five classes, very low drought vulnerability, mild drought vulnerability, moderate drought vulnerability, severe drought vulnerability and extreme drought vulnerability. Depending on the selected factors, the map of the drought vulnerability depicts that the majority of the watershed falls under the very low vulnerable class (35.7%), followed by mild vulnerable (29.1%), moderate vulnerable (16.2%), sever vulnerable (13.8%), and extreme (5.2%) classes. As illustrated in Table 8.

Table 8: Area of drought vulnerability classes

NO.	*Drought vulnerability class*	*Area (Km^2)*	*Area (%)*
1	Very low drought vulnerability	1265.6	35.72
2	Mild drought vulnerability	1031.04	29.1
3	Moderate drought vulnerability	575.632	16.25
4	Severe drought vulnerability	488.43	13.79
5	Extreme drought vulnerability	182.463	5.15

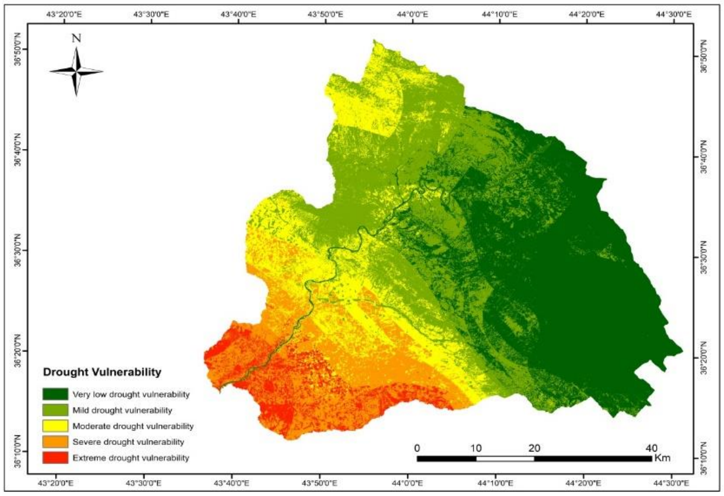

Fig 8: Drought vulnerability map of the watershed

CONCLUSIONS

The following conclusions were summarized from this study:

- The geographical distribution and properties of drought has been evaluated using GIS, RS and AHP techniques.
- Weights for each parameter (rainfall, temperature, LULC, slope, soil texture, elevation and distance to rivers) were evaluated using pairwise comparison matrix. Rainfall and elevation are considered the most and least important, respectively.
- Severe drought is found to be happen in the south of the research region, even that the area is plain with clay soil but the average amount of rainfall is much less than other locations, while the north of the study area is under very low or mild drought vulnerable classes.
- The study may have some limitations because of the method used. Because AHP is a knowledge-driven process, it may have prevented some errors in its prediction.
- Lack of data has limited the selection of associated parameters to drought vulnerability and verification of the results in the study area.

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