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GIS-AHP based site selection to identify the optimum number of meteorological stations: Karasu Watershed case study

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ABSTRACT

The density of meteorological stations in most watersheds across the globe is far lower than recommended by the World Meteorological Organization (WMO). However, for some basins, including those used as pilot, an adequate quantity of weather stations is crucial for collecting high-accuracy data. This study aimed to 1) estimate the optimum number of meteorological stations and 2) demarcate the most appropriate sites for their installation considering physical and environmental factors directly and indirectly influencing both objectives, i.e. to develop a well-optimized weather station network. The Weighted Overlay method and six (6) environmental factors -- precipitation variance, slope, elevation, proximity of existing stations, land cover and land use, as well as distance from roads -- were applied to delineate the potential locations. All parameters were mapped out separately and then reclassified for scoring (0 to 100 scale) based on their significance. The Analytic Hierarchy Process (AHP) method was applied to determine the impact of each factor. Based on the analysis, the precipitation variance received 38% weight, while the distance from road was computed to reach only 3% weight. The Weighted Overlay map of the Karasu Watershed was delineated into corresponding highly suitable, moderately suitable, suitable, marginally suitable, and not suitable zones. Finally, the recommended station locations were validated using a hypsometric curve to ensure proper coverage of different elevations. The research will improve the climate change and water resource management applications by informing them with sufficient climatic data about the entire target area including all variations, as well as will help addressing the challenge of data shortage and thus increase the quality of future thematic research.

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1. Introduction

Meteorological stations are the collection of instruments with which the amount of rainfall and other climate data including temperature, humidity, wind, sunshine, etc. have been measured. The accuracy of rainfall and other climate data plays an important role in the planning and operation of water resources management. The more accurate the data, the more confidently we can plan, design and implement the water resource projects on the field. Rainfall is one of the key inputs to a hydrological model since it is an important part of the hydrological cycle (Shen et al., 2012). Despite the good quality and well-functioning meteorological station instruments, the issue of station location and optimal number adds to the importance of the topic for reliable data collecting (Saghafian et al., 2016). However, climatic data can also be measured using satellite sensors and weather radars. Ground-based meteorological stations offer precise data in the form of points, whereas weather radars and satellites observe areal rainfall and other climatic data (Tan & Yang, 2020). Therefore, it is essential to design a comprehensive scheme of meteorological stations for a region with an adequate number of stations to cover the entire area with all of its fluctuations in rainfall and other climatic parameters.

There are several methods used for selecting the optimal location and the optimum number of meteorological stations. Chang and Makkeasorn (2010) distinguish two types of modeling for optimal site selection of meteorological stations: statistically driven and simulation-driven approaches. A statistical measure of information content is employed by Pickett and Whiting (1981) to assess the effectiveness of a specific monitoring network setup in Canada. This approach is used to combine observed pollution dynamics with network data in order to assess network effectiveness. Pardo-Igúzquiza (1998) uses the simulated annealing as an algorithm of a random search for the optimal location of rainfall measurement gauges, where the double criterion of estimation accuracy and economic cost are taken into account. Also, a field observations method which is supported by satellite images is used by Saghafian et al. (2016) to select a proper site for installing the meteorological stations. The composing method of kriging and entropy is used by Chen et al. (2008); Xu et al. (2018); Yeh et al. (2011) for the determination of the location and number of raingauge stations in the optimal rainfall network. Moreover, the Geographic Information System GIS with the integration of remote sensing is used by Chang and Makkeasorn (2010) to pinpoint the most critical locations collectively for the deployment of monitoring stations in a vast watershed as a case study in south Texas. Despite the studies mentioned above and the suggestions of various methods for optimizing a meteorological network, the use of GIS-AHP approach is the novel and pioneer part of this work.

Weighted Overlay is a multi-criteria analysis technique for site selection and suitability models. Many studies have been done using Weighted Overlay techniques in a variety of fields, including suitability analysis of agricultural land in Azad Kashmir (Hassan et al., 2020), identifying potential landslide areas (Awawdeh et al., 2018; Basharat et al., 2016; Shit et al., 2016), assessment of groundwater recharge zones in different areas (Iqbal et al., 2020; Kaliraj et al., 2015; Nagarajan & Singh, 2009), and so many other multi-criteria decision-making fields. To evaluate natural systems, Analytic Hierarchy Process (AHP); a multiple-criteria decision-making (MCDM), has been most widely used alongside the Weighted Overlay techniques of GIS (Hassan et al., 2020; Jabbar et al., 2019; Mandal & Mondal, 2019; Pani et al., 2016).

Karasu watershed is one of the important watersheds in Turkey where many studies on water resources management have already been conducted (Ahady et al., 2022; Ertas et al., 2016; Şensoy et al., 2006; Şorman et al., 2019). According to the data from the General Directory of Meteorology of Turkey, currently, there are only three meteorological stations (Erzincan, Tercan, and Erzurum Havalimani) which are spatially distributed across the watershed with an area of 10283 square kilometers controlled by the stream gauge station of Kemah at the outlet point of the watershed. Based on the recommendations for establishing the network of raingauge stations of the Bureau of Indian Standards (Marg, 1994), for the hilly and mountainous region, there should be at least one raingauge station per 130 square kilometers area. Therefore, the current number is a much smaller number of stations than would be necessary to adequately cover a hilly and mountainous watershed with all of its fluctuations of climatic factors. In this study, the Weighted Overlay technique is used to select suitable sites for new meteorological stations to be installed in the Karasu watershed. The primary objectives of this study are (i) to determine the optimum number of meteorological stations to be spatially distributed across the Karasu watershed. (ii) to locate the additional number of meteorological stations throughout the watershed while considering the various physical and environmental factors that have a direct and indirect influence on the optimal number and location of a well-optimized network of meteorological stations. Implementing this research will benefit climate change and water resource management applications by supplying them with adequate climatic data covering the entire region with all of its variations, as well as contributing to the quality of future works affected by data shortages.

2. Geographical and Environmental settings of the study area

The Karasu watershed, considered in this study is one of the headwater watersheds of the Euphrates basin located in northeastern Turkey. In terms of geographical coordinates, the Karasu watershed is located between 39° 30’ 00»N and 40° 15’ 00»N, and 38° 45’ 00»E and 41° 30’ 00»E (Fig. 1), with elevations ranging from 1122 to 3538 meters (Fig 2). Based on the norms of optimum numbers of meteorological stations , like many other watersheds throughout the world, the Karasu watershed also countered the shortage of meteorological stations for collecting enough climatic data to be considered for further research on water resources. There are only three existing meteorological stations (Erzincan, Tercan, and Erzurum Havalimani) in the watershed with 10283 square kilometers of the area controlled by the stream gauge station of Kemah at the outlet point of the watershed (Fig 2). Moreover, variation in the amount of precipitation is another important factor that plays a vital role in the number of meteorological stations in a watershed (Shaghaghian & Abedini, 2013), the precipitation varies from less than 500 mm to above 900 mm throughout a typical year in the Karasu watershed, necessitating a higher number of meteorological stations to measure the precipitation data with all its fluctuations.

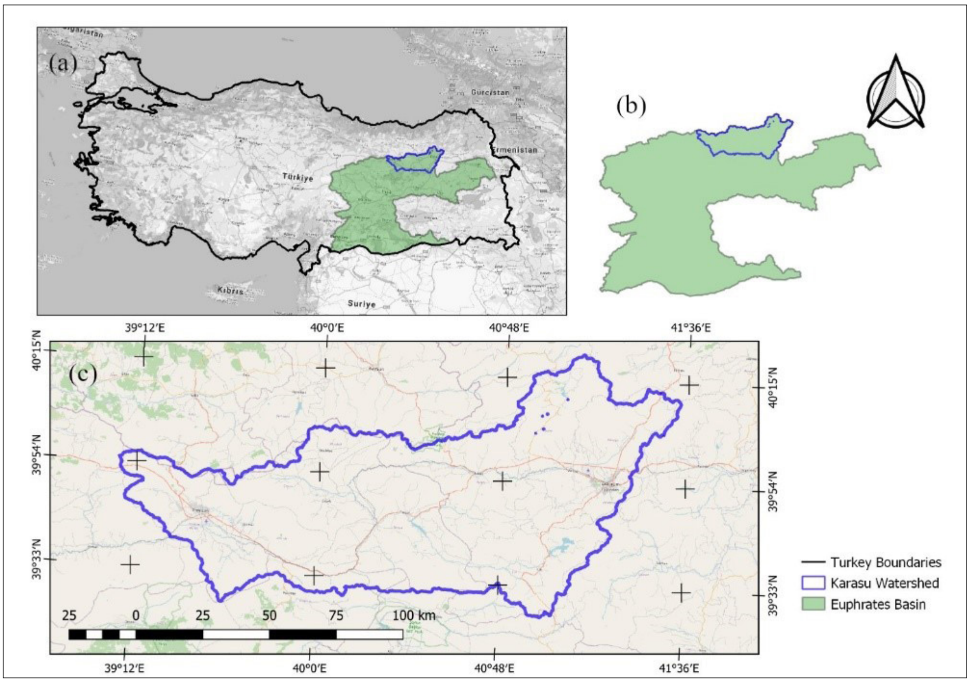

Figure 1. Study area location map: (a) Turkey map, (b) Euphrates basin, and (c) Karasu watershed.

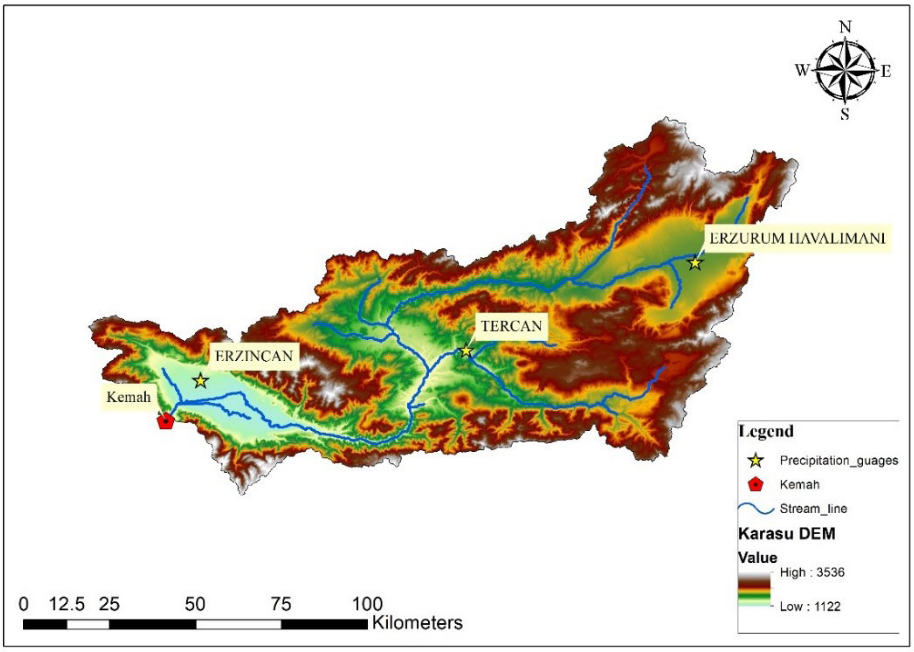

Figure 2. Elevation map and station locations in the Karasu watershed.

3. Materials and Methods

3.1. Data used

The required data to carry out this research consists of both satellite-based data and informative data about the current dominant network of meteorological stations, which is tabulated in Table 1. The DEM is downloaded as SRTM 1 Arc-Second Global elevation data at a resolution of 1 arc-second (30 meters) from the Earth Explorer website in the form of GeoTIFF file format to be utilized in ArcGIS software. The latest land cover map is downloaded from the CORINE Land Cover website, it consists of an inventory of land cover in 44 different classes. Corine Land Cover uses a Minimum Mapping Unit (MMU) of 25 hectares for areal phenomena and minimum width of 100-meter for linear phenomena. Moreover, the accumulative precipitation for the year 2018 is downloaded in GeoTIFF format from (https://giovanni.gsfc.nasa.gov/giovanni/), a web-based application that provides a simple and intuitive way to visualize, analyze, and access vast amounts of Earth science remote sensing data without having to download the data (although data downloads are also supported). The shapefile for the main roads in Turkey is downloaded from the MapCruzin website and then clipped with the Karasu watershed shapefile for extraction of the main roads in the Karasu watershed. To assess the demand for the optimal number of meteorological stations, we must first understand the existing network of meteorological stations, therefore, the data about the available number of stations in the watershed are collected from the General Directory of Meteorology of Turkey.

Table I. Type and source of the data.

Type of data	Source of the data
DEM	https://earthexplorer.usgs.gov/
Precipitation	https://giovanni.gsfc.nasa.gov/giovanni/
Land Use & Land Cover	https://land.copernicus.eu/pan-european/co-rine-land-cover
Road Map	https://extract.bbbike.org/
Existing Stations	General Directory of Meteorology of Turkey

The Karasu watershed is delineated with Hydrology tools in ArcMap 10.8 using the Digital Elevation Model (DEM) of 30-meter resolution provided by USGS. The data sources are digitally converted and geographically referenced to UTM-WGS 84 projection, and the coordinate system WGS 1984 UTM Zone 37N is selected based on the location of the area.

Figure 3 represents the overall flow of the work.

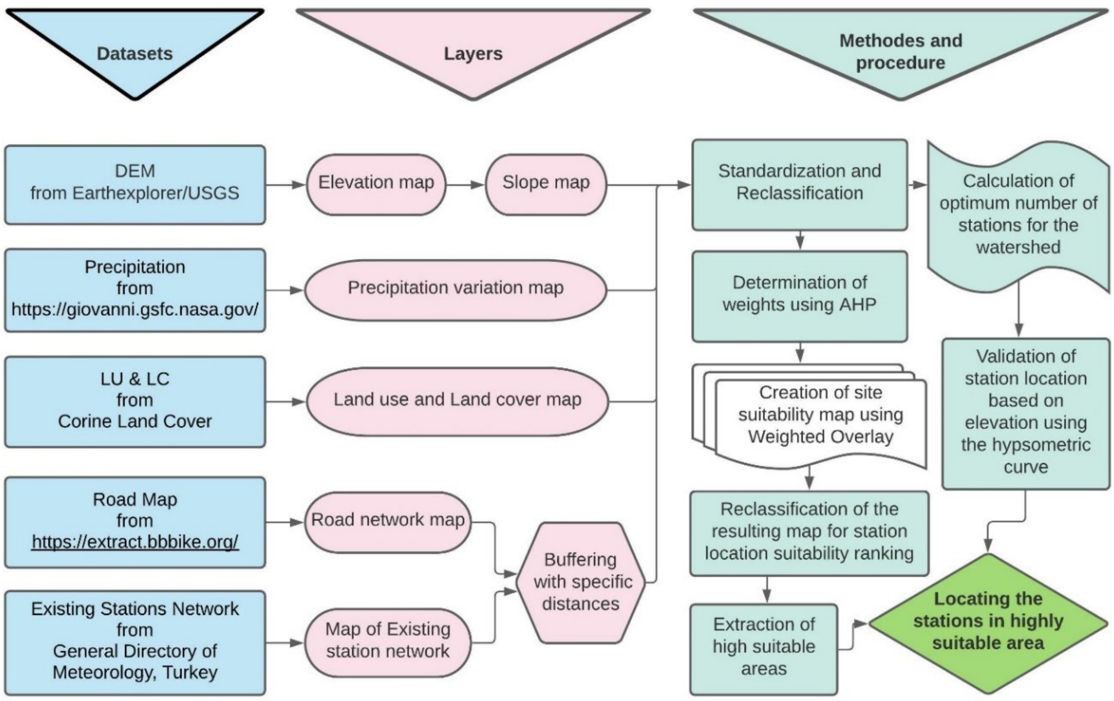

Figure 3. Methodology working flow chart

3.2. The optimal number of meteorological stations

The first step in this study is to determine the number of meteorological stations required for collecting the climate data across the entire watershed. Second, an appropriate site for the newly added meteorological stations must be selected. The number of meteorological stations depends on various factors at a watershed level. Precipitation is one of those key factors, as well as one of the most important inputs in hydrological modeling and forecasting. For more precise rainfall-runoff simulations, accurate estimates of the areal precipitation are necessary since the hydrological process of the surface run-off is determined using representative precipitation.

However, a raingauge station estimates the amount of rainfall in one point over a region or catchment. On the one hand, economic considerations frequently limit the density and number of meteorological stations for a specific region or catchment, on the other hand, the accuracy of rainfall and other climate parameters is dependent on the density of the meteorological station network (Hong et al., 2016). The number of stations should be sufficient to be able to collect the amount of rainfall of all intensities and variations. Therefore, for the Karasu watershed, we want to compute the optimum number of meteorological stations before deciding on a suitable location for the stations, subsequently, the suitable locations will be demarcated for each of the stations.

In the literature, some of the studies have recommended raingauge density ranges based on the elevation of the region from the sea level (Table II), while there are some numerical methods as well to calculate the number of raingauges for a specific region.

Table II. Rainfall stations density based on the elevation of the region

Area	Meteorological stations density
Plains	1 in 520 Square kilometers
Elevated regions	1 in 260 – 390 Square kilometers
Hilly and very heavy	1 in 130 Square kilometers

Source: (Hong et al., 2016)

When the arithmetical average of precipitation is available for a region, the optimum number of raingauges is calculated using the following equation (Marg, 1994):

$$N=\left(\frac{C_v}{P}\right)^2$$

Where:

N – is the optimum number of raingauge stations,

«C», «v» – Coefficient of variation of the rainfall values of the existing raingauge stations,

«P» – the desired degree of percentage error in the estimate of basin mean rainfall.

For the Karasu watershed, we have three pre-existed raingauge stations, the amount of annual mean precipitation is given in Table III for all three stations. With this number of stations, the desired degree of percentage error in the estimate of mean rainfall is equal to 10%, which is in the acceptable range based on the World Meteorological Organization (WMO) recommendations (Marg, 1994). But the Karasu watershed is located above 1 km from the sea level and is a mountainous watershed with an area of more than 10000 square kilometers, in addition, it is a pilot area for conducting research on water resources and snow (Ahady et al., 2022; Ertas et al., 2016; Şensoy et al., 2006; Şorman et al., 2019). So, three meteorological stations are not enough to collect accurate climatic data from the watershed for future use. With the aforementioned considerations in mind, the permissible degree of error in the calculation of the mean rainfall is set at 4%, and the number of stations is estimated.

Table III. Existing stations

Stations	Annual average precipitation (mm)
Erzincan	675.20
Tercan	926.00
Erzurum Havalimani	751.53

$$C_v = \frac{\text{Average of precipitation for stations}}{\text{Standard Deviation}} = \frac{784.24}{128.56} \cdot 100 = 16.4\ \%$$

$$N = \left(\frac{16.4}{4}\right)^2 = 16.8 \cong 17$$

In total, 17 meteorological stations are required for the Karasu watershed, three of which have already been installed and 14 more should be added.

3.3. Site selection for meteorological stations

3.3.1. Weighted overlay analysis:

The weighted overlay analysis is a helpful tool for making multiple criteria-based decisions. In this work, we have integrated multiple climate and environmental factors to identify the proper and suitable sites for meteorological stations using raster weighted-overlay analysis in the Karasu watershed. The feature class of each parameter is already assigned weights depending on its level of suitability to the appropriate site for the meteorological station. To avoid the inaccuracy of combining characteristics from different layers into a single layer, in the raster overlay, each cell of each layer must reference the same geographic location (Malczewski, 2006). In this study, numeric weight values are assigned to the pixels (cells) of feature classes in certain thematic layers, which are then combined mathematically to give a new value for the corresponding pixels in the output layer. To create an output layer, the weighted overlay analysis applies a common scale value to the multiple thematic layers. For this work, we defined the scale weight for each class within the range of 1 to 100. In which the feature with maximum potential magnitude having on the results has been assigned to higher weight value as 100, the lower weight value as 1 has assigned the feature classes with minimum influence. The total weighted index values were then determined using the raster calculator tool by multiplying the scale weight with the percentage of influencing weight value (percent of influence weight) of the corresponding parameter, in which, each parameter is assigned a percentage of influencing weight values based on its direct or indirect influence on the site selection of meteorological stations. In the weighted overlay analysis, the total percentage of influencing weight values for all parameters must equal 100 percent. To generate a weighted raster layer, the different layers were given scale weight values based on their relevant importance. Preference values are allocated not only to feature classes inside a layer but also to layers that have similar effects across all levels. For example, a feature class with more influence within a layer is given a higher scale weight value. Similarly, a greater scale weight number represents a more influential feature class in another layer. The subsequently higher value of the percentage of influencing weight is assigned to the primary contributing layer among all other layers (Carver, 1991). To get the results, the multiple thematic layers have been analyzed with the Weighted Overlay analysis algorithm using the ArcGIS environment.

3.3.2. Assigning weights and Weights Overlay analysis:

A geo-database of feature classes within a layer was created to assign the acceptable scale weight based on its influences to the proper site of meteorological stations. Following that, each of the theme layers is allocated a weight based on their contribution to the site selection of meteorological stations. Also, the appropriate scale weight and percentage of influencing weight are allocated to different parameters and their related feature classes depending on the potential magnitude of site selection of the stations. The highest scale weight value (100) is given to the feature class that contributes the most to the site selection of meteorological stations, while the lowest scale weight value is given to the feature class that has a poor influence on it (Awadh et al., 2021; Krishnamurthy & Srinivas, 1995). On this basis, each of a thematic layer's feature classes is given a unique scale weight value based on its potential magnitude for the site selection decision. Following that, a proportion of influencing weight value is assigned to each theme layer based on direct or indirect effects on the site selection process. The assigned scale weight and percentage allocated for each feature class and thematic layer are shown in Table IX. The feature layer (vector) is transformed to a raster grid format using a weighted overlay analysis based on its scale weights and percentage of influencing weight. In the end, based on the suitability of the site for locating the metrological stations, the output map is divided into five zones: highly suitable, moderately suitable, suitable, marginally suitable, and not suitable.

3.4. Prioritization of parameters using multiple criteria decision-making tools

The process of prioritizing parameters that effect a system is highly confusing and complicated. Decision-making processes involve a series of steps starting from identifying the problems, constructing the preferences, evaluating the alternatives, and selecting the best alternatives among them (Tzeng & Huang, 2011). There are several proposed multi-criterion decision-making methods to utilize to achieve our goals by selecting the best alternative, one of which is the Analytic Hierarchy Process (AHP) (Erdogan et al., 2017; Özdağoğlu & Özdağoğlu, 2007; Ozdemir & Sahin, 2018; Velasquez & Hester, 2013). AHP is a process of producing numerical values to rank each decision alternative according to the degree to which it meets the requirements of the decision-maker (Baltalar, 2021).

In this study, elevation, slope, precipitation variation, land cover and land use, distance from existing stations, and distance from the main road network are the parameters that determine meteorological station site on a spatial distribution basis (Bankanza, 2011; Basher & Zheng, 1998; Johnson & Hanson, 1995; Joly & Gillet, 2017; Joly et al., 2003). To address the question, «Which factor has the most impact on the location of a meteorological station?» we utilize the AHP multi-criterion decision-making approach to prioritize them.

Based on the literature on the Karasu watershed, all of the aforementioned factors are ranked from least to most important in terms of their influence on meteorological station site selection (Table IV), and then scored based on the relative importance of each factor, with the least important factor being “distance from the roads” and the most important factor being “precipitation variation”.

The pair-wise matrix of preference of factors influencing the site selection of meteorological stations has been created in Table IV.

Table IV. Pair-wise matrix of preference of the influencing factors.

No	Factors	Distance from Road	LC & LU	Station Loca-tion	Elevation	Slope	Precipitation variation
1	Distance from Road	1.0	0.20	0.17	0.14	0.13	0.11
2	Land cover	5.0	1.0	0.50	0.33	0.25	0.20

3	Station location	6.0	2.0	1.0	0.50	0.33	0.25
4	Elevation	7.0	3.0	2.0	1.0	0.50	0.33
5	Slope	8.0	4.0	3.0	2.0	1.0	0.50
6	Precipitation variation	9.0	5.0	4.0	3.0	2.0	1.0
	Total	**36.00**	**15.20**	**10.67**	**6.98**	**4.21**	**2.39**

The sum of the same column is divided by the values earned in the previous matrix. In the newly emerged matrix, the sum of each column will be equal to 1. Table V.

Table V. Matrix of divided values by the sum.

No	Factors	Distance from Road	LC & LU	Station Location	Elevation	Slope	Precipitation variation
1	Distance from Road	0.03	0.01	0.02	0.02	0.03	0.05
2	Land cover	0.14	0.07	0.05	0.05	0.06	0.08
3	Station location	0.17	0.13	0.09	0.07	0.08	0.10
4	Elevation	0.19	0.20	0.19	0.14	0.12	0.14
5	Slope	0.22	0.26	0.28	0.29	0.24	0.21
6	Precipitation variation	0.25	0.33	0.38	0.43	0.48	0.42
	Total	**1**	**1**	**1**	**1**	**1**	**1**

Now, the average of all the values for each row will be calculated, and subsequently, the percentage of the average is being determined. To convert it to applicable values for weighted overly in GIS, we round it off to the natural numbers (Table VI).

Table VI. Influence percentage of parameters.

No	Factors	average	Percentage of influence	Percentage of influence
1	Distance from Road	0.026	2.55	3
2	Land cover	0.074	7.37	7

3	Station location	0.108	10.79	11
4	Elevation	0.163	16.34	16
5	Slope	0.250	25.00	25
6	Precipitation variation	0.379	37.95	38
	Total	**1**	**100**	**100**

The percentage of influence of each parameter for Weighted Overlay analysis of meteorological stations site selection in the Karasu watershed is shown as a graph in Figure 4.

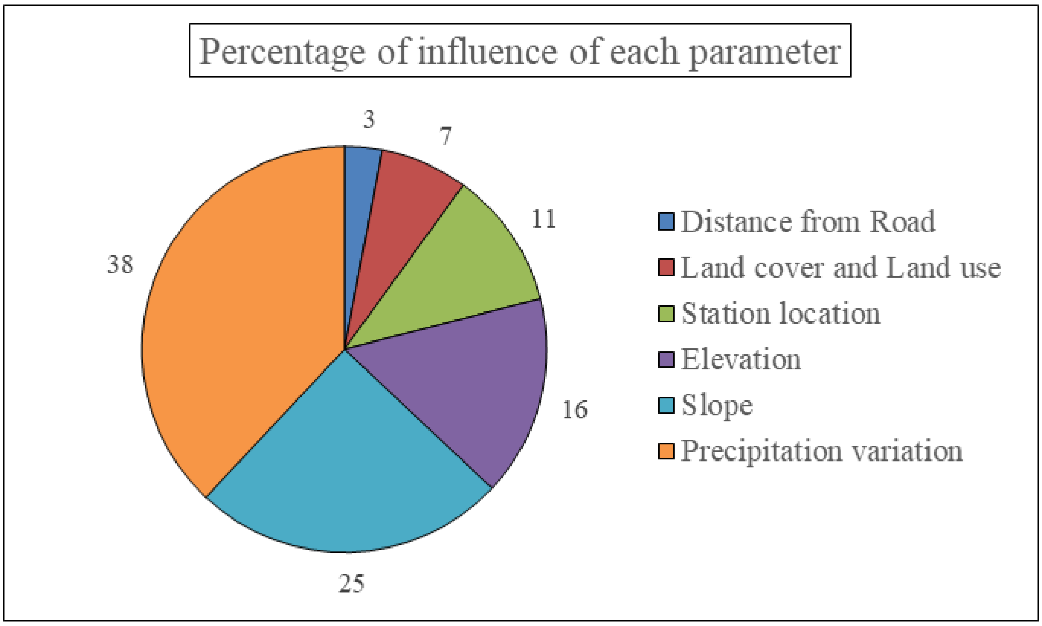

Figure 4. Percentage of influence of each parameter considered in the site-selection procedure of meteorological stations in the Karasu watershed.

3.5. Reclassification:

The six parameters that influence the decision-making process of site selection for meteorological stations, both directly and indirectly, are categorized into a relevant range of values for each parameter. Subsequently, each of the thematic layers is reclassified with their allocated weight based on their contribution to the site selection of meteorological stations. Each of the themes is described below:

3.6. Elevation:

The elevation map of the study area is prepared using the Digital Elevation Model (DEM) of 30-meter resolution as SRTM 1 Arc-Second Global elevation raster data. The given raster is classified into five different ranges of elevations, considering the need for meteorological stations existing in each range of elevations (Table VII). The first-class ranges in elevation from 1122 to 1550 meters and encompasses a total area of 1359.13 square kilometers, with two meteorological stations currently in place there. Therefore, it is assigned with the lower weight value as the less appropriate option among the other features. The feature class with an elevation range of 1900 to 2500 meters, on the other hand, is weighted 100 since it has a large area and no pre-installed meteorological station within this range of elevation.

Table VII. Number of existing meteorological stations based on different elevations

No	Parameter	range	Area (km^2)	Existing Stations
1	Elevation	1122 - 1550	1359.135	2
		1550 - 1900	3063.635	1
		1900 - 2500	4717.5	0
		2500 - 2800	924.2278	0
		2800 - 3538	314.3085	0

3.7. Slope:

Another factor to consider while choosing the location for a meteorological station is the slope. A standard meteorological ground plan requires an area of at least 24 feet by 24 feet (7.13 m X 7.13 m) (Finklin, 1990), with a minimum possible slope. First, we created a slope map of the Karasu watershed using the DEM of the area with the help of the Slope command in ArcGIS 3D Analyst Tools. The watershed was then divided into five classes to assess the minimum slope for the location of a meteorological station The steep slope of 20 to 75 degrees was assigned the lowest weight value as the less optimal site for the stations, while the 0 to 5-degree slope was assigned the highest 100 scores as a more appropriate site (Table IX).

3.8. Precipitation variation:

The accuracy of the rainfall data depends on rainguage network coverage of the region with all its rainfall variabilities. However, due to economic constraints, meteorological stations cannot be installed at all locations in a catchment. Therefore, the identification of points of rainfall variability in the catchment is essential to capture all high and low amounts of rainfall with all its fluctuations in the catchment. To reach this purpose, the isohyet precipitation variation map is prepared using the precipitation amounts for 10 areal stations using NASA data from (https://giovanni.gsfc.nasa.gov/giovanni/) website. It is a monthly precipitation product called GPM-IMERG, in the IMERG Version 6 algorithm, the information is combined from the Tropical Rainfall Measuring Mission (TRMM), which is available from 2000 to 2015, and from the Global Precipitation Measurement (GPM), available from 2014 to the present. The GPM-IMERG provides valuable global rainfall estimates (Huffman et al., 2015). Rainfall ranges from 611 to 907 mm in the Karasu watershed, and the watershed is classified into five classes based on rainfall variability. Based on the variation of rainfall depth and the presence of meteorological stations in the watershed, each class is weighted with different values ranging from 0 to 100 (Table VIII).

Table VIII. Number of existing stations based on different elevations

No	Parameter	Range mm	Area (km²)	Existing Stations
3	Precipitation variation	611-700	977.4	1
		700-750	1081.6	0
		750-800	2450.4	1
		800-880	5131	1
		880-907	737.6	0

3.9. Current available meteorological stations (Existing stations network):

The optimal number of meteorological stations is the total number of stations required to cover the entire area of the catchment and should take into account the variability of mean monthly and annual rainfall in the catchment (Marg, 1994). To calculate the required number of meteorological stations in a catchment, it is needed to gain knowledge about the currently available network of meteorological stations. For the Karasu watershed, there are three pre-existing meteorological stations (Erzincan, Tercan, and Erzurum Havalimani), to which the required number of stations will be added. According to the Marg (1994) guideline, for watersheds in moderately elevated areas with an average height of one kilometer above sea level, the network density should be one raingauge per 250 to 400 square kilometers, with a radius of 9 to 11 kilometers around the stations. With this in mind, we create the buffers around the stations and divide them into four categories, with the closest distance to the stations being weighted lower, and the furthest areas being weighted higher, with values ranging from 0 to 100 for the furthest areas (Table IX).

3.10. Land cover:

It is critical to locate a meteorological station in an area free of disturbances and obstacles so that the station can collect actual climate data. For example, to limit the effects of trees on wind speed and rainfall volume, the stations should be placed at a specific distance from trees. Therefore, it is essential to consider the type of the landcover while locating the stations. For this work, the latest land cover map is downloaded from the CORINE Land Cover website for 2018. It consists of an inventory of land cover in 44 different classes. In general, five major classes encompass all 44 classes (Brown et al., 2002). Since it is not feasible to assign weights to all 44 classes, we grouped all 44 classes into five main classes based on their similarities in characteristics: urban areas, agricultural areas, forest and pasture, bare lands, and water bodies. Then, the class of water bodies is assigned a lower weight, while the class of bare land, which is the most suitable for the location of the meteorological station, is assigned a higher weight in the analysis (Table IX).

3.11. Distance from the main roads:

The accessibility of the meteorological station site is also one of the important factors that should be taken into account when planning the network of meteorological stations in a watershed. The closer the station is to the road, the easier it will be to access and maintain. Therefore, in the Karasu watershed, the entire area is covered with buffers at four different distances from the main road network, providing the highest weight of 100 to the areas closest to the road and the least weight to the areas farthest from the road network (Table IX).

Table IX. Assigning of scale weights and percentage of influence to feature classes of different parameters.

No	Factors	Feature class	Station locating potentiality	% of influence	Scale weight
1	Elevation	1122 - 1550	Low	16	60
		1550 - 1900	Moderate		80
		1900 - 2500	High		90
		2500 - 2800	Moderate		70
		2800 - 3538	Very high		100
2	Slope	0 to 5	Very high	25	100
		5 to 10	High		90
		10 to 15	Moderate		40
		15 to 20	Low		10
		Higher than 20	Very low		0
3	Precipitation variation	611-700	Moderate	38	80
		700-750	High		90
		750-800	Low		70
		800-880	Moderate		75
		880-907	Very high		100
4	Station location	250 sq. km	Very low	11	0
		500 sq. km	Low		40
		2000 sq. km	High		90
		higher than 2000 km2	Very high		100

5	Land cover and Land use	Urban	Low	7	10
		Agriculture	High		90
		Forest and Pasture	Low		5
		Bare land	Very high		100
		Water	Very low		0
6	Distance from Road	5 km	Very high	3	100
		10 km	High		90
		15 km	Moderate		80
		40 km	Low		20

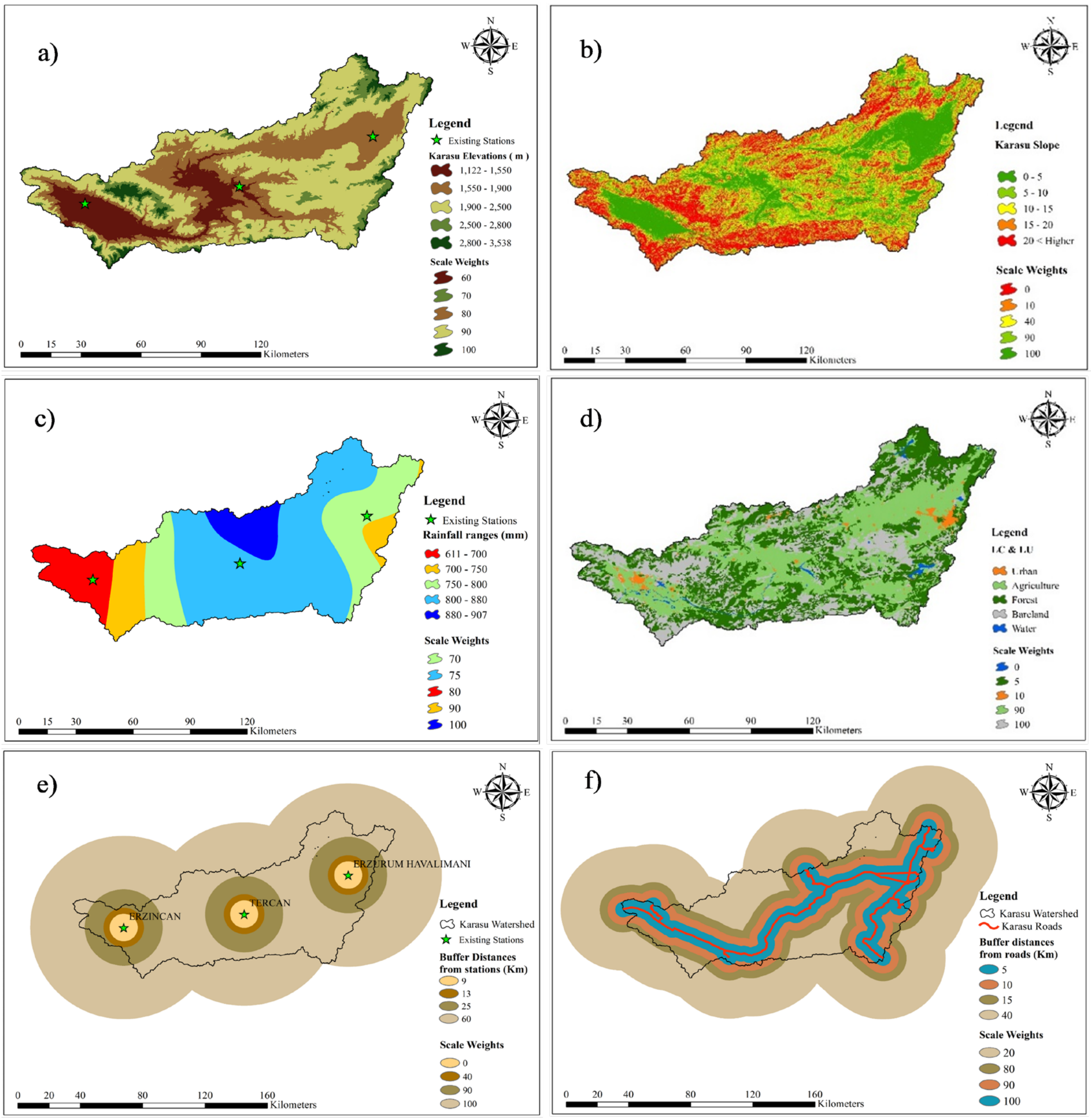

Figure 5. Thematic maps of the layers proposed for site selection of meteorological stations, (a) elevation map, (b) slope map, (c) rainfall variation map, (d) Landcover map, (e) existing station network map, and (d) Road network map.

4. Results and discussion

Finally, the Weighted Overlay results are derived using the multiple environmental factors in ArcGIS software (Fig 7). The weighted overlay map is classified into five classes from highly suitable to not suitable areas to demarcate the areas for the installation of meteorological stations (Table X). As can be seen from the weighted overlay map in Fig 7, there are sufficient targeted sites for the installation of meteorological stations throughout the watershed, thus it is essential to pick the locations that have a high suitability ranking for locating the stations. An area of 24 feet by 24 feet (7.13 m x 7.13 m) (Finklin, 1990) or, according to the literature, an area of (10x10) meters is required to install the necessary instruments of a meteorological station. Since each pixel of the map in Fig 7 represents an area of (30x30) meters, thus, if one pixel has been ranked as high ranking, it is large enough for the construction of a meteorological station. As could be seen, most of the pixels in the central parts of the Karasu watershed are ranked as highly suitable sites for placing the meteorological stations, but the goal is to place the meteorological stations throughout the watershed to cover all parts of the watershed, and we can achieve our goal since there are many pixels all over the watershed where we can place the stations.

Table X. Meteorological stations site suitability ranking

Ranking	Scale weights
Not suitable	38 - 60
Marginally suitable	60 - 70
Suitable	70 - 80
Moderately suitable	80 - 88
Highly suitable	88 - 99

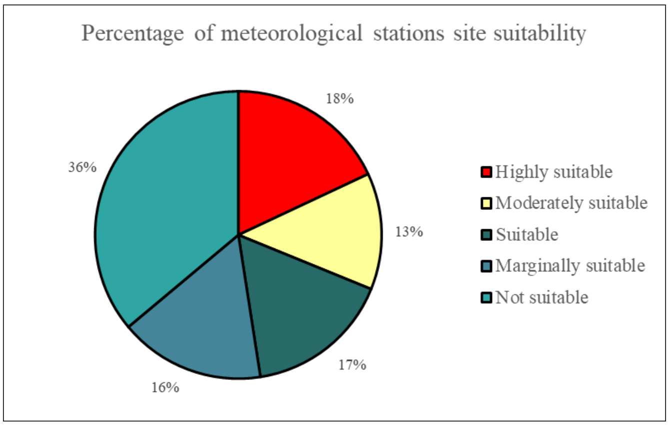

Figure 6. Percentage of meteorological stations site suitability.

To add the 14 additional meteorological stations (Table XI) to the existing station network on the map, we extract the highly suitable locations in a separate shapefile and place the 14 stations based on the distance between each station, site elevation, and precipitation variation (Fig 8). The locations of the newly added meteorological stations are then checked to see if they could cover the entire Karasu watershed, taking into account the rainfall variations at different elevations on the field.

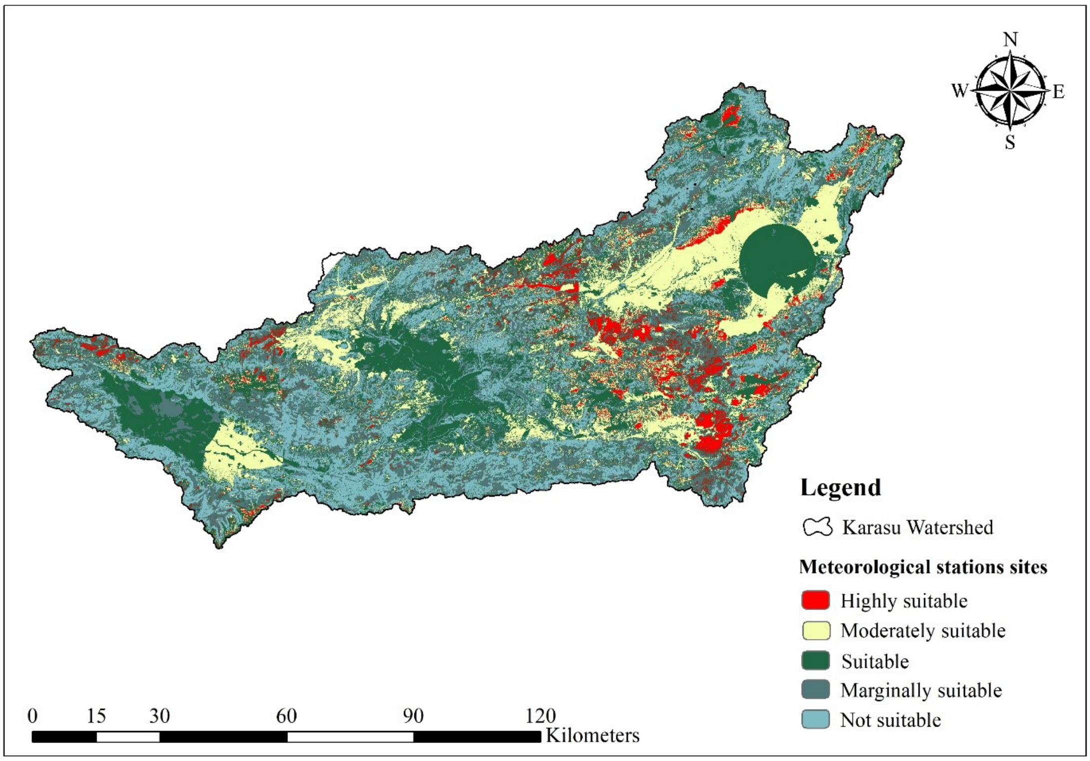

Figure 7. Sites ranking map of meteorological stations derived from weighted overlay method.

Table XI. Location of newly added meteorological stations

No of station	Longitude	Latitude	Elevation
1	41.546075	40.1555	2914
2	41.069306	40.18403	2249
3	40.955529	40.03917	2157
4	41.294771	39.80946	2925
5	41.126744	39.68222	2179
6	40.867028	39.73215	2295
7	40.693533	39.52866	2285
8	40.277306	39.55142	1933

9	40.351391	40.02209	2914
10	40.013614	39.95695	1957
11	39.941882	39.69493	2854
12	39.756755	39.78455	3430
13	39.639683	39.47828	2854
14	39.308522	39.87737	1971

Table XII. Pre-existing meteorological stations in the Karasu watershed

Station	**Longitude**	**Latitude**	**Elevation**
Erzincan	39.7523	39.4868	1216
Tercan	39.7769	40.3906	1429
Erzurum Hav.	39.9529	41.1897	1758

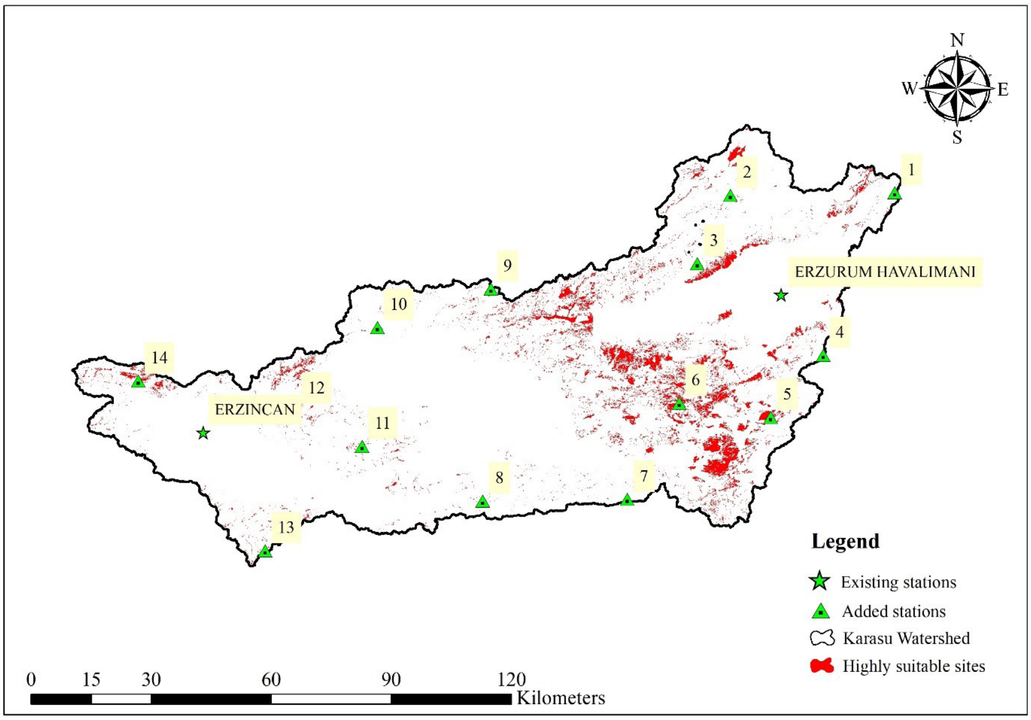

Figure 8. Meteorological station locations are ranked as highly suitable.

5. Validation

The very suitable zones are validated across the watershed to check if the stations can cover different areas with various elevations and all of the rainfall fluctuations. The hypsometric curve of the Karasu watershed was used to ensure that existing and newly added meteorological stations can cover all elevations from low to high, the results were then checked on the map in Fig 10a to confirm that the stations are well distributed across the watershed. As shown in Fig 9, the pre-existing stations of Erzincan, Tercan, and Erzurum are installed in the lower elevations of the watershed, which covers an elevation range of 1216 to 1758 meters, but the upper elevation of the watershed has no pre-installed stations. The locations of the newly added 14 stations can be seen from the hypsometric curve (Fig 8) that spans the missing portion of the watershed with the recommended positions 1 through 14. Moreover, the same locations of meteorological stations were then checked to verify if they encompass the Karasu watershed, including all rainfall patterns. The locations of the stations, as shown in Fig 10b, indicate that all of the areas with varying quantities of precipitation in proportion to the amount of area covered by each pattern of rainfall. There are 7 stations located in the largest proportion of the watershed with an area of 2450.4 square kilometers, while one station is located in the highest part of the watershed with the smallest amount of 737.6 square kilometers area.

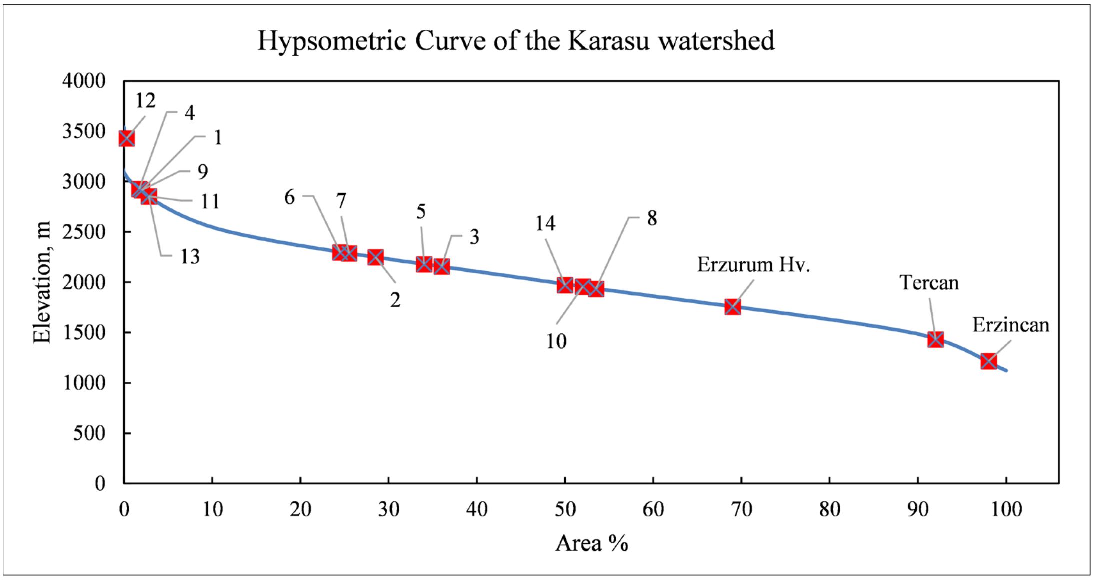

Figure 9. Hypsometric curve of the Karasu watershed.

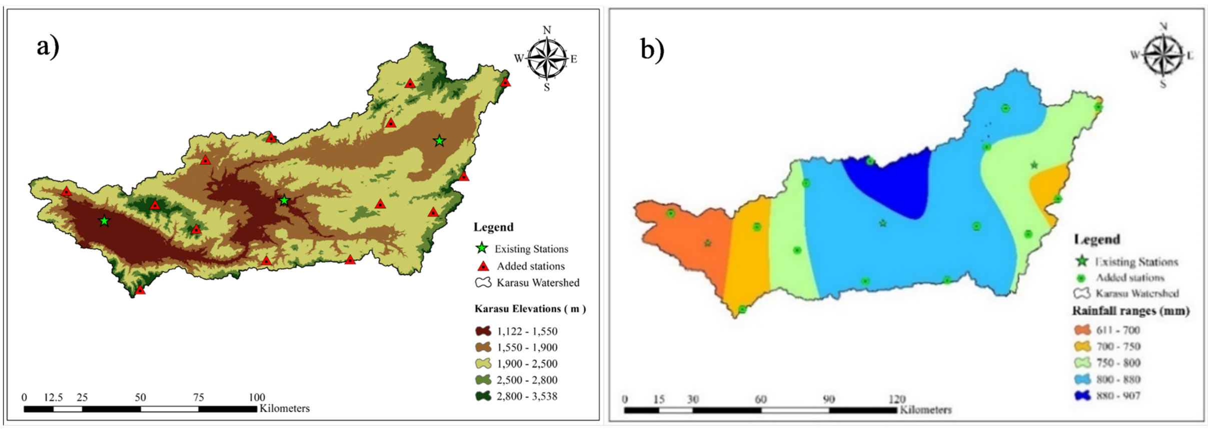

Figure 10. Meteorological station locations validation map, (a) elevation map, (b) precipitation variation map.

6. Conclusion

Site selection and the optimal number of meteorological stations are two interrelated issues for a region that must be addressed to collect sufficient climatic data for watershed management and climate change analysis. In this study, we identify the parameters affecting the location of the meteorological stations and suggest new weighting factors for each of the parameters using AHP analysis to evaluate their percentage of influence. Following that, the «Weighted Overlay» method, which is one of the most commonly used GIS tools for multicriteria problem solving, is used to assess the suitability of the location for 14 additional meteorological stations in the Karasu watershed.

The result map reveals that there are enough suitable sites that have been weighted as highly suitable rank spatially distributed all over the watershed, a little dense in the center, and scattered at both ends of the watershed. With sufficient space as a highly suitable ranking, the remaining four parts of the watershed with lower rankings would not be a viable option for the installation of meteorological stations. Therefore, 14 additional stations were placed in highly suitable locations throughout the watershed in order to cover the entire watershed and provide sufficient climatic data. Thus, the interpretations derived from the outputs of the study could be used as firsthand information by decision-makers to contribute to wise decision-making regarding the most appropriate location for the placement of meteorological stations.

However, this approach has been used for many other purposes, such as groundwater potential zone mapping (Awadh et al., 2021; Iqbal et al., 2020; Pani et al., 2016), land suitability for agriculture (Hassan et al., 2020), fire risk assessment (Eskandari, 2017), landslide hazard assessment (Awawdeh et al., 2018; Mandal & Mondal, 2019) and so on, but it is a new approach for meteorological station site selection and can be replicated to other regions of interest for collecting sufficient climate data.

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