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Mapping Distribution of Precipitation, Temperature and Evaporation in Seydisuyu Basin with the Help of Distance Related Estimation Methods

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Abstract

In this research, distributions of precipitation, temperature and evaporation in Seydisuyu basin were analyzed with the help of inverse distance weighted (IDW) method. Because real meteorological data of the basin (precipitation, temperature and evaporation) do not have normal distribution, precipitation, temperature and evaporation distribution maps are drawn after normalization process. The number of meteorological stations, in other words the number of samples, is low, so only IDW method is used in this research. In addition to the research, reliability of the results obtained with the help of inverse distance weighting method was examined with accuracy analysis. The purpose of this study, the spatial distribution of meteorological data on a basin or areas is to demonstrate the applicability of the statistical basis.

Keywords

Inverse Distance Weighted (IDW), Geographic Information Systems (GIS), Meteorology, Seydisuyu-Basin

1. Introduction

It is necessary to manage water resources on the basin basis and together with other natural resources, in accor-

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dance with sustainable development law. The basic tool to meet these requirements is an updatable and adaptable basin information system. Basin information system concept and philosophy haven't become widespread in Turkey yet. Consequently, there is a significant deficiency in basin management even in the beginning [1]. Main goal in basin management is to protect natural resources, enable environment to renew itself, and manage them sustainably. Geographic Information Systems (GIS) are considered as a technological and indispensable tool in order to provide the environments, which are necessary to collect, store basin data, and examine them in a way, which will enable spatial analysis, for such a planning insight [2].

In basin management plans, areal distribution of the climatic data can be produced in different layers by using punctuate observation values with the help of GIS. This makes GIS usage indispensable. It is possible to see a lot of methods while defining the areal distributions of climatic parameters and producing related climatic layers. However, a convenient method for a region does not fit to another region. Therefore, it is necessary to apply the similar researches to each region with different methods, depending on the regional characteristics and the structure of available data [3]. Under these conditions, defining a more suitable method for a region or basin poses a problem.

Evaporation, temperature and precipitation data are observed punctually in meteorological observation stations. Because these data are obtained in this way, they have punctuate characteristics. Consequently, it is needed to produce are all distributions in different layers, in GIS environment by using climatic data, which have punctuate observation values. Thus, it is possible to study and investigate the relations between data layers. Average areal precipitation depth on a specific region is used in researches, which aim to develop water resources, instead of punctuate precipitation values [4].

2. Materials and Methods

The main materials used in this study are raster maps, vector maps and meteorological data of Seydisuyu river Basin. 54 scanned and rectified, 1/25000-scale raster maps and 54 coordinated vector maps (UTM 36N zone and European Datum 1950-ED50-coordinate system) of Seydisuyu River Basin and other neighbour basins were provided fromState Hydraulic Works (DSI).These maps cover Seydisuyu basin and the neighboring basins.

For the spatial analysis performed within the Seydisuyu River Basin, GIS software ArcGIS 9.3.1 was utilized. ThenDigital Elevation Model (DEM) of the basin was obtained from these maps by using GIS software 9.3 versions. The data required to determine the long term, covers monthly average values between 1991 and 2011 (20 years records), meteorological characteristics of the basin (precipitation, temperature, evaporation, relative humidity, wind, snow, etc.) were provided from State Meteorological Organisation (DMI) [5]. The necessary missing meteorological data of some years were generated by the method ofstatistical correlations.

In order to determine the hydrological basin borders of Seydisuyu River Basins, 1/25,000-scale digitised vector maps were utilized to produce the Digital Elevation Model (DEM) of the basin. Then, DEM was cut in accordance with the basin borders. During this process, ArcInfo 9.3.1 was used.

Using the DEM produced with the GIS software, sub-basins of the basin were determined and spatial analyses were made to produce topographic, slope, aspect and 3-dimensional (3D) maps of the study area. DEM was also used to determine the drainage area and sub-basinboundaries of the basin. ArcHydro Tools 9, an interface program of ArcInfo, was utilized to detect the flow direction. Thus, the synthetic drainage network andarea, which is formed as a result of the precipitations in the sub-basins, as well as the main streamof each sub-basin were also determined.

Meteorological Data was analyzed and organized in Microsoft Excel by taking the data of MGS of each province. Coordinates of MGS of each province were transferred into GIS software.

In order to make a correct estimation with a data set, it must have normal distribution. Obtained meteorological data From DMİ was analyzed, and it was found out that they didn't have normal distribution statistically. In order to have normal distribution for a data set, coefficient of Skewness must be close to zero (0), coefficient of Kurtosismust be close to three (3). Average and median values must be close to each other, too. In order to normalize data set for a correct estimation, some conversions like logarithm (Log), Natural logarithm (ln), Sine (sin), Cosine (Cos), tangent (tan) and square root were applied.

The conversion, which approached the data to the normal distribution, was used as a base, and those values were used in the estimation process. However, there was not a suitable conversion for normal distribution on temperature data, so a different method was used. Annual temperature data were degraded from the elevation of observation stations into sea level elevation, and data were arranged as the temperature values on sea level. Normal distribution was obtained with this method, and estimation process began. It was aimed to make a comparison by using the two distance related methods (Inverse Distance Weighted-IDW and Kriging), but Kriging method wasn't used in the estimation process because of inadequate number of samples. In this research, spatial estimation with IDW method was done by using meteorological data (evaporation, temperature, precipitation) in and around Seydisuyu River Basin.

3. Study Area

The research area is Seydisuyu basin, which is a sub-basin of the Sakarya River. Seydisuyu basin is in the Central Anatolian Region, between 38˚85' - 39˚36' north latitudes and 30˚16' - 31˚07' east longitudes. Waters of the basin are discharged into the Sakarya River by the Seydisuyu River. Seydisuyu basin is surrounded by Sakarya-Sarisu, Porsuk-Sarisungur, Porsuk-Kalabak in the east, by Buyuk Menderes, Gediz and Porsuk-Sarisungur in the south-west, and by Sakarya-Bardakci and Akarcaybasins in the south-east. As the hydrologic basin border, a great part of the basin is in the provincial borders of Eskisehir, and the remaining parts are in the provincial borders of Afyon and Kutahya. Seyitgazi, Mahmudiye districts of Eskisehir, Kirka town and 51 villages are in the basin. Seydisuyu basin covers an area of 1816.1 km^2 and it covers almost 13% of surface area of Eskisehir. Geographical position of the basin in Turkey is in **Figure 1**.

4. Defining Hydrologic Basin Borders of Seydisuyu Using Geographic Information Systems (GIS)

To estimate the hydro-electricity potential of Seydisuyu basin, it is necessary to know its hydrologic borders and to make its surface analysis. With this aim, basin characteristics were defined with the help of digitized maps. Digital elevation model (DEM) of the basin is formed by using 1/25,000 scaled digitized vector maps. Digital Elevation

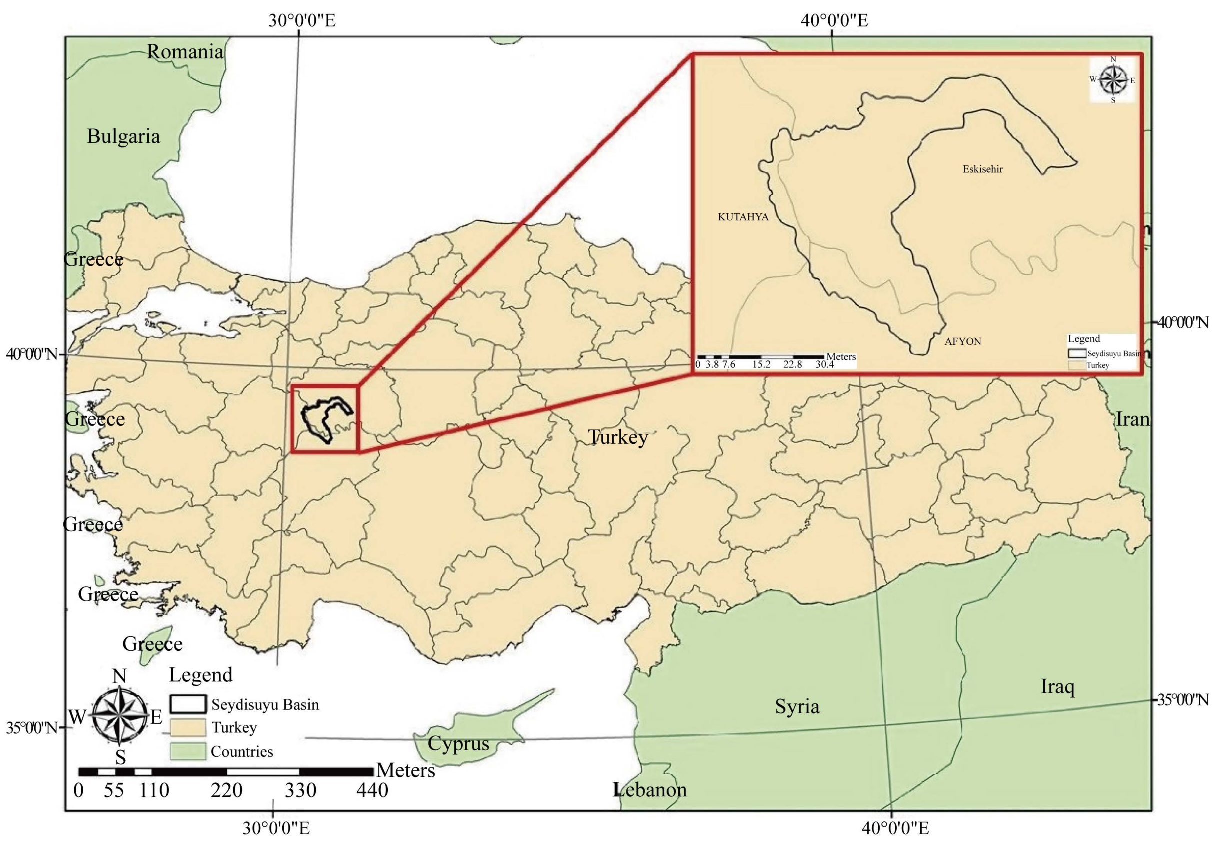


Figure 1. Position of Seydisuyu basin in Turkey.

Model was clipped and analyzed for hydrologic borders of the basin. Digital elevation model of Seydisuyu basin and sub-basins are presented in **Figure 2(a)** and **Figure 2(b)**.

4.1. Sub-Basins of Seydisuyu Basin and Definition of the Drainage Areas of These Basins

Sub-basins, which form the main basin, were drawn with hydrologic analysis on digital elevation model. In addition, slope index map, exposure map, elevation map, and three-dimensional map of the basin were created in GIS environment by using digital elevation model. Drainage area of the basin, borders of sub-basins and flow direction were found. Thus, drainage network and area, which was formed by precipitation in each sub-basin, were obtained and presented in **Figure 2(b)**. In addition, main stream of each sub-basin were found. Main stream length is 121.84 kilometers.

In this research, significant data such as the number of the main stream and the other brooks**,** total length of the brooks, and the slope of each brook were also found out. Longitudinal sections of the main streams were found. Total hydrologic area of Seydisuyu basin is 1816.1 km^2. Seydisuyu basin has mainly 5 sub-basins. The biggest basin is the number 5, which covers an area of 733.36 km^2. Total area of Seydisuyu basin and areas of each basin is presented in **Table 1**.

4.2. Spatial Characteristics of the Whole Seydisuyu Basin

Spatial characteristics of the basin were found out when the height map, slope index map, exposure map, shady relief map, and lots of data and maps were obtained by using the Digital Elevation Model of the basin. Each unit of this data means significant information in dam planning. Spatial characteristics of the basin was classified with geo-statistics method and presented in **Figures 3(a)-(d)**.

When the topographic maps of Seydisuyu basin are analyzed, it can be seen that height is between 850 and 1825

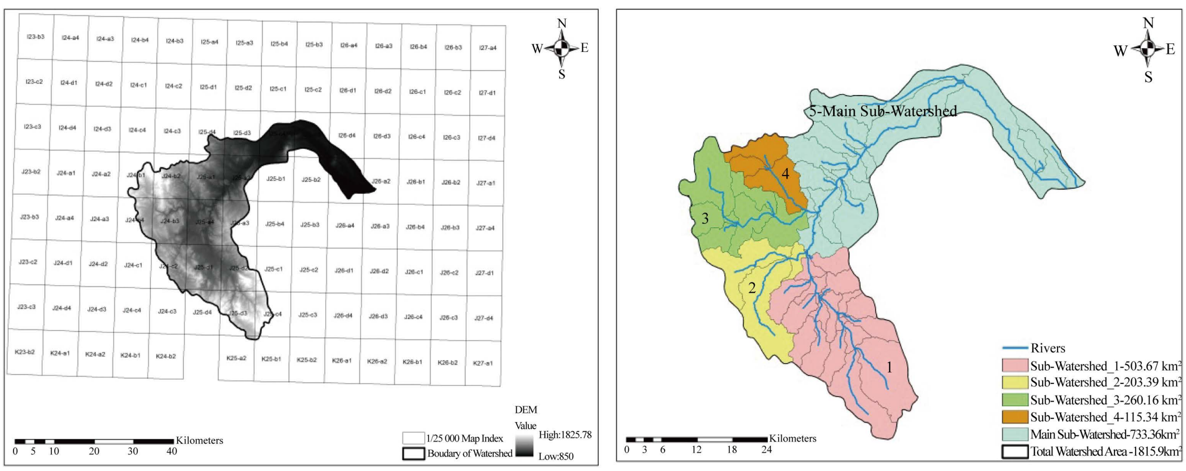


Figure 2. Digital elevation model of Seydisuyu basin and drainage network of the sub-basins.

Table 1. Areas of Seydisuyu basin and the sub-basins.

Sub-basin number	Area of the sub-basin (km^2)
1	503.67
2	203.39
3	260.16
4	115.34
5-main stream	733.36
Total	1816.1

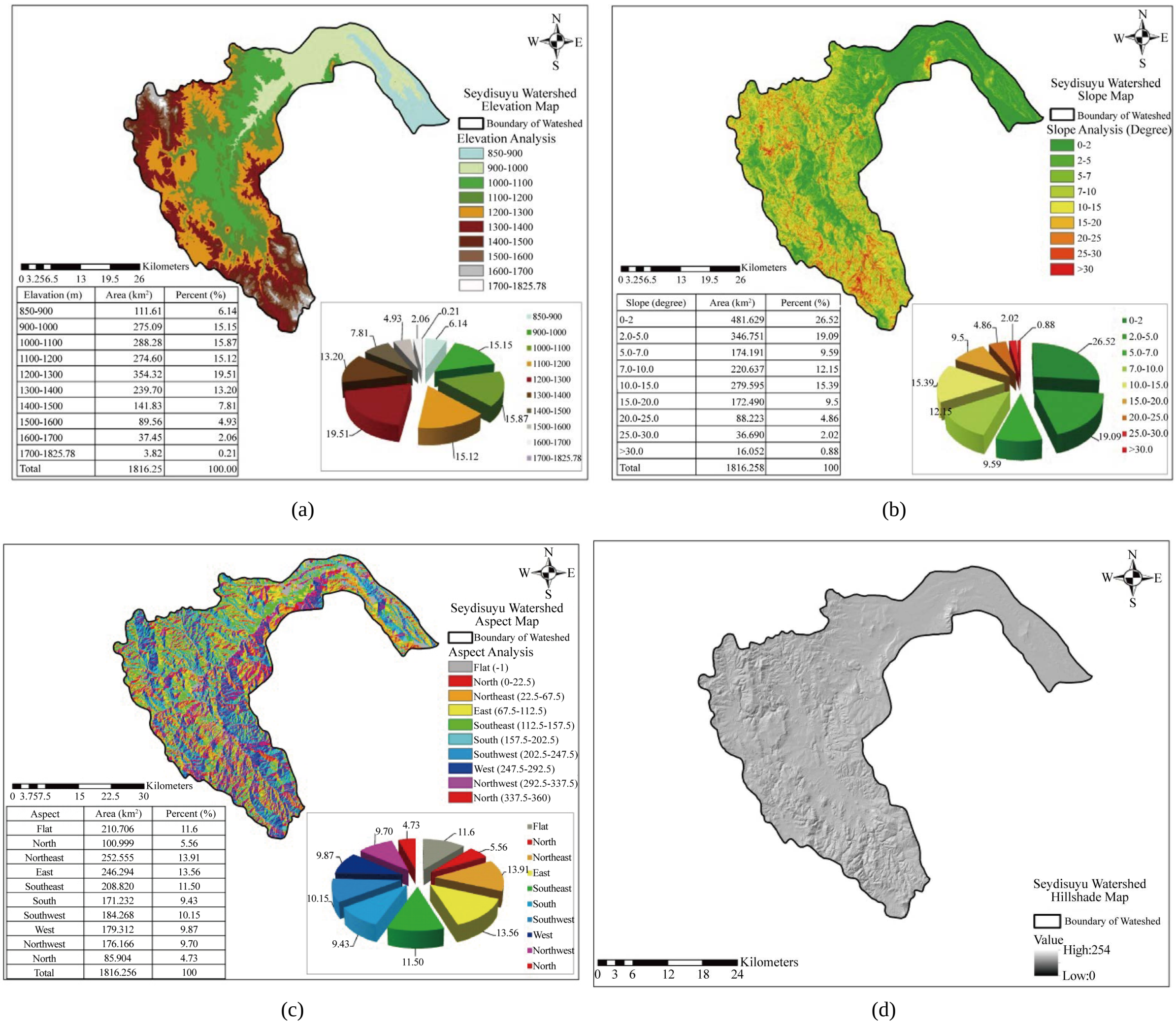


Figure 3. Spatial Maps of Seydisuyu Basin. (a) Elevation (Topographic) map; (b) Slope map; (c) Aspect map; (d) Hillshade map.

meters. Area of the basin between 1000 and 1300 meters covers 50.5% (917.2 km^2) of the total area (**Figure 3(a)**). The slope of the basin is 67.37% (1223.08 km^2) between 0 and 10 degrees and plains occupy a large part of the basin. Higher areas are on the west parts of the basin. Rate of the areas in the basin with a slope of 30 degrees or more is 0.88% (16.052 km^2), and it is a small part of the basin (**Figure 3(b)**). Exposure analysis is the geographic angle of the surface to the north. Almost 25.06% (455.114 km^2) consists of eastward and south-eastward hills (**Figure 3(c)**). It is possible to see the general structure and plains clearly in the shady relief map in **Figure 3(d)**.

5. Defining Meteorological Characteristics of the Basin

Seydisuyu basin reflects the climate characteristics of the Central Anatolian Region. However, it slightly reflects the climate characteristics of the Aegean Region, too. There are climatic differences between the western and eastern parts of the basin. Seydisuyu basin is dry and hot in summer while it is cold and wet in winter. Meteorological data of the basin are measured by Meteorology Observation Stations in Eskisehir, Kutahya, Afyon, Bilecik and Ankara. Measured data such as precipitation (mm), temperature (˚C) and evaporation (mm) are long-term monthly average data, and they were obtained from General Directorate of Meteorology for years between 1991 and 2010 (19 years). These raw data were organized and monthly average, minimum and maximum meteorological data was found out.

Statistical Evaluation of Meteorological Data

Distribution parameters of the data sets were investigated statistically. After that, distribution maps were drawn with distance related estimation methods by using the data obtained from General Directorate of Meteorology. In order to make reliable estimation, it is necessary for a data set to have normal distribution. Estimations, which are made with the data sets which don't have normal distribution, will not give reliable results. Therefore, distribution parameters of precipitation, temperature and evaporation data sets were evaluated statistically. This evaluation is presented in **Table 2**.

When the distribution parameters in **Table 2** are examined, it can be seen that data do not havea statistically normal distribution. In order to have normal distribution for a data set, coefficients of Skewness must be close to zero (0), and coefficients of stickiness must be close to three (3). Average and median values must be close to each other, too. In order to normalize data set for a correct estimation, some conversions like log, ln, sin, cos, tan and square root were applied (**Figure 4**). The conversion, which approached the data to the normal distribution, was used as a base, and those values were used in the estimation process. It was observed that in conversion for evaporation and log conversion for precipitation approached the values to the normal distribution. However, temperature values didn't have a normal distribution despite those conversions. Therefore, they were evaluated with another method. As is known, spatial characteristics, such as elevation, slope and exposure, of a measurement station affect temperature values. A measurement station on high slope topography cannot get the sunrays straightly; so temperature values will be low. When exposure (the state of geographical formations' being exposed to Sun) is considered, geographical formations on the northern and eastern hills will get the sunlight for a shorter time. This will cause temperature values to be low. Elevation is one of the factors that affect temperature most. While the temperature decreases 0.5 degrees Celcius at every 100 meters when we go up from the sea level, it increases 0.5 degrees Celcius when we go down to the sea level. When the fact that these factors affect temperature is considered, it is clear that each measurement station could come up with different results because of their spatial characteristics (elevation, slope, exposure). Therefore, temperature values were reduced to sea level with the method in Equation (1).

$$T_d = T_i + \left(h_i \times 0.005\right) \tag{1}$$

T_d: Temperature (Reduced to sea level); T_i: Average temperature of the station; h_i: Elevation of the station.

Temperature values, which are reduced to sea level, were processed in GIS database. After that, whether distribution parameters of these processed values suit the normal distribution was checked.

When **Table 2** and **Table 3** are examined, it can be seen that the coefficient of skewness is close to zero (0), and the coefficient of stickiness is close to three (3). It is not possible to have a perfect normal distribution as data do not have a spatially homogenous distribution, and there are a few point measurement stations. The closest distribution parameters to the normal distribution were obtained by making the necessary conversions.

6. Spatial Estimation Methods

Estimation is defined as the mathematical method, which was developed to estimate the deficient data in a series

Table 2. Distribution parameters of meteorological data.

Parameters	Evaporation (mm)	Temperature (˚C)	Precipitation (mm)
Number of Stations	14	34	20
Standard Deviation	31.451	1.17	196.92
Minimum	111.14	7.19	430.51
Maximum	226.15	13.29	1299.9
Average	154.81	11.64	751.2
Median	151.61	11.66	713.23
Coefficient of Skewness	0.90966	-1.52	0.89
Coefficient of Stickiness	3.2108	7.18	4.19

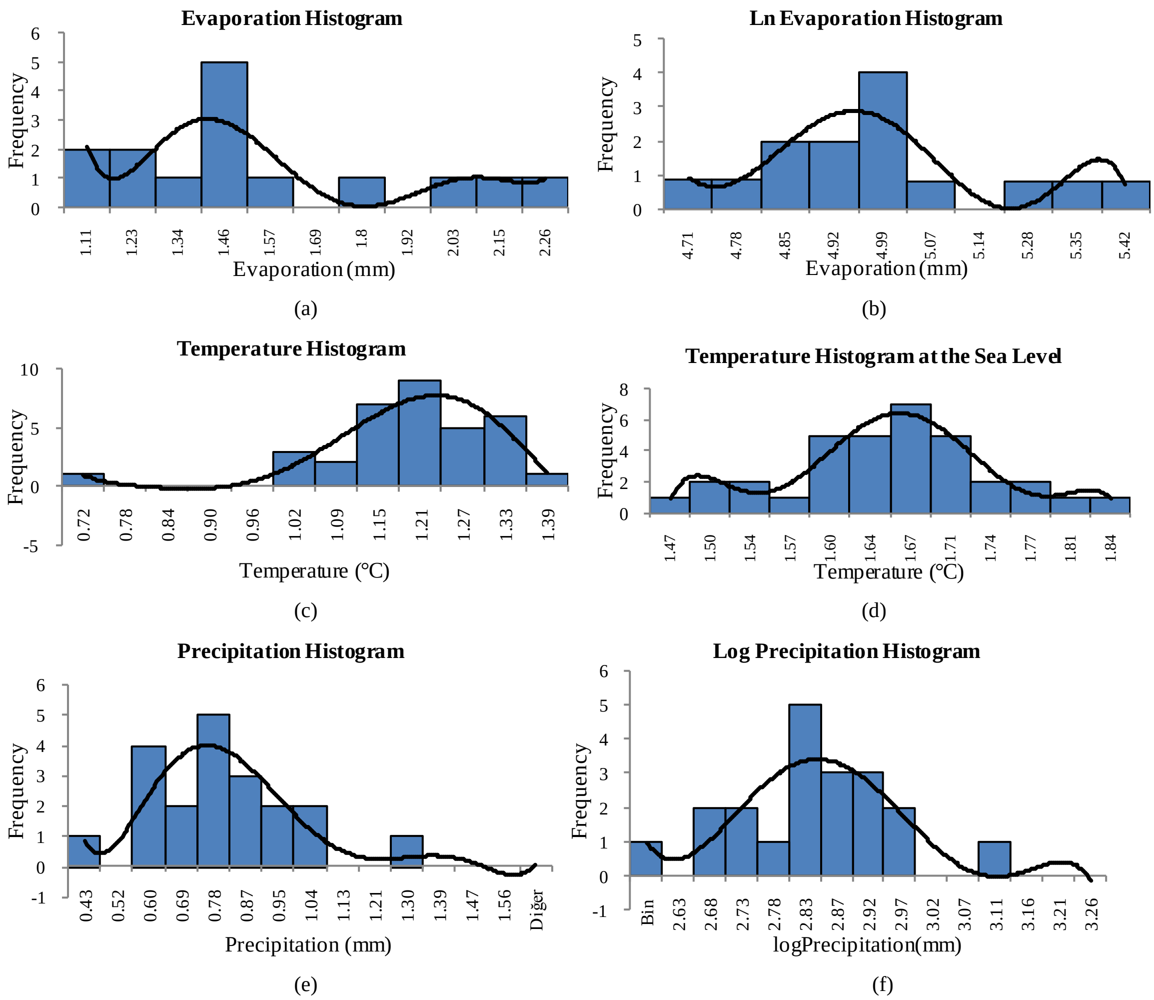


Figure 4. Raw and organized histograms of the meteorological data of Seydisuyu basin. (a) Yearly evaporation histogram; (b) Ln transformed yearly evaporation histogram; (c) Yearly temperature histogram; (d) Yearly temperature histogram which reduced to sea level; (e) Yearly precipitation histogram; (f) Log transformed yearly precipitation histogram.

Table 3. After the statistical analysis of the data, distribution parameters approaching to the normal distribution.

Parameters	Ln Evaporation (mm)	Temperature (˚C)	Log Precipitation (mm)
Number of Stations	14	34	20
Standard Deviation	0.19	0.83	0.11
Minimum	4.71	14.70	2.63
Maximum	5.42	18.07	3.11
Average	5.02	16.37	2.86
Median	5.02	16.49	2.85
Coefficient of Skewness	0.50	−0.12	0.08
Coefficient of Stickiness	2.78	2.74	3.08

[6]. Estimation, which helps new data to be created with calculation operation by using the data in specific places, is the calculation process of function, which is necessary for this calculation [7] [8]. Today, distance related spatial estimation methods are used to express the data, which is collected from specific points, coordinates of which are

known in GIS applications, spatially – in other words, from spatially referenced specific points. As a result of estimation, raster surfaces are calculated with vector data, which are identified on point geometry. Position related and distance related estimation methods (IDW, Natural Neighbors, Spline, Kriging, etc.) try to guess the values of places with unknown values [9]. Estimation methods, which are chosen according to the modeled data types, give better models. In this research, applicability of IDW method to the data was investigated, obtained raster surfaces were clipped for the basin borders, and precipitation, temperature and evaporation distribution maps of the basin were modeled.

Inverse Distance Weighted (IDW) Method

Inverse distance weighting is an estimation method, which assigns higher weight value to nearby points than more distant points, and takes all sample points into account [10]. Each sample point gets inverse proportional weight value according to their distance to the point, value of which will be estimated. Estimated value at x_0 point is calculated as it is shown in Equation (3).

$$W_i = \frac{\frac{1}{d_i^p(x_i)}}{\sum_{i=1}^{n} \frac{1}{d_i^p(x_i)}} \quad (2)$$

$$Z^*(x_0) = \sum W_i \cdot Z(x_i) \quad (3)$$

$Z^*(x_0)$ shows estimated value of x_0 point, and $Z(x_i)$ shows the value of sample point at x_i point. W_i shows the inverse distance weight of the sample at x_i from x_0, and d shows the distance between sample point and the point, which will be estimated. p shows exponential value, and n shows the number of sample points.

7. Modeling Distribution Maps of Meteorological Data in Seydisuyu Basin

7.1. Modeling of Meteorological Data in the Basin by Using IDW Method

Geographical locations of the stations, where meteorological data (precipitation, temperature, evaporation) are measured, are shown in **Figures 5(a)-(c)**.

Conversions were made in order to normalize the raw data in **Figure 4** as they didn't have a statistically normal distribution, and they were converted into a normal distribution. Histograms of the converted data were created, and they were reevaluated statistically. After that, distribution maps in the basin were modeled by using inverse distance weighting method. Modeling results are presented in **Figures 6(a)-(c)**.

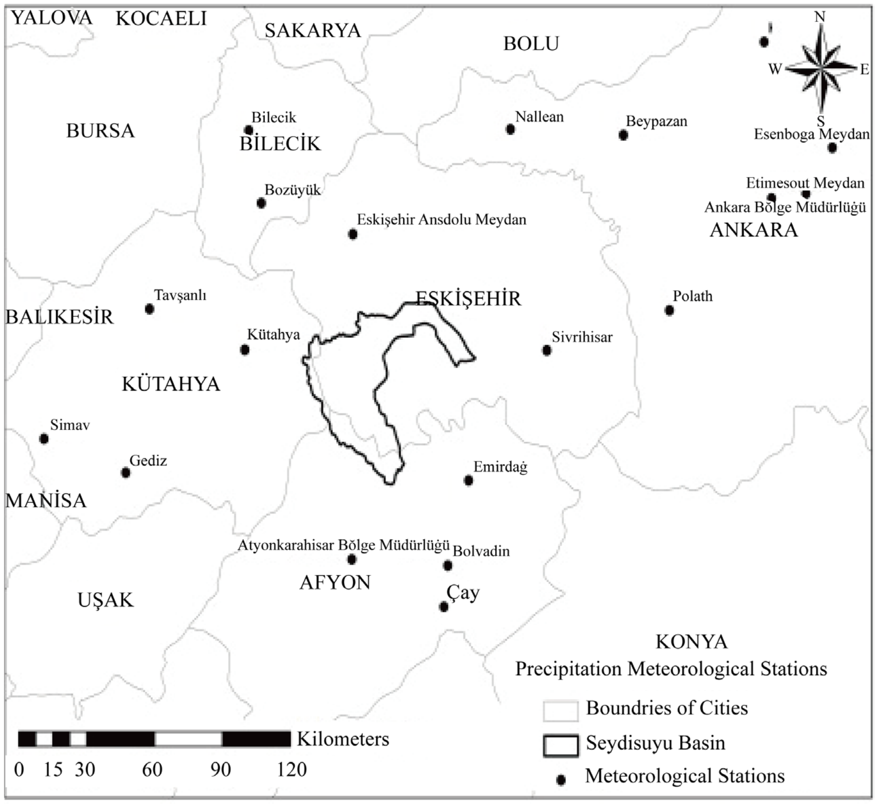
Maps, which were drawn after estimation process, were drawn with converted data, so they need to be converted into real values. Therefore, values of precipitation and evaporation data were converted into real meteorological values by using raster calculator. Data of temperature distribution were processed with the digital elevation model of the region while they were being reconverted. In this method, data of digital elevation model were reclassified in terms of temperature values at intervals of 100 meters, and temperature map, which shows real temperature values, was drawn by subtracting data of digital elevation from sea level temperature values (**Figures 7(a)-(c)**).

7.2. Accuracy Analysis

In order to make certain of estimations, three meteorological observation stations, which have proper spatial dispersion, were chosen as the control point, and precipitation, temperature and evaporation distributions were applied without these data by using IDW interpolation method.

Surface values, which were calculated by using the previously converted data for normal distribution, instead of real values of control stations, were compared with calculated values, and accuracy of estimations were analyzed by calculating root mean square errors (RMSE) in this scope (**Tables 4-6**).

Accuracy of estimations depends on the location of control stations chosen for accuracy analysis and the position of measurement value in that station among general data group as well as the dispersion of data source points. If control station data include the highest or the lowest value of data group or position of the station is close to the borders of the research area, evaluating the value of this station with high accuracy by using the values of other


YALOVA
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Etimesout Meydan
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ANKARA
Eskişehir Ansdolu Meydan
Tavşanlı
BALIKESİR
ESKİŞEHİR
Polath
Kütahya
Sivrihisar
KÜTAHYA
Simav
Gediz
Emirdağ
MANİSA
Atyonkarahisar Bölge Müdürlüğü
Bolvadin
AFYON
UŞAK
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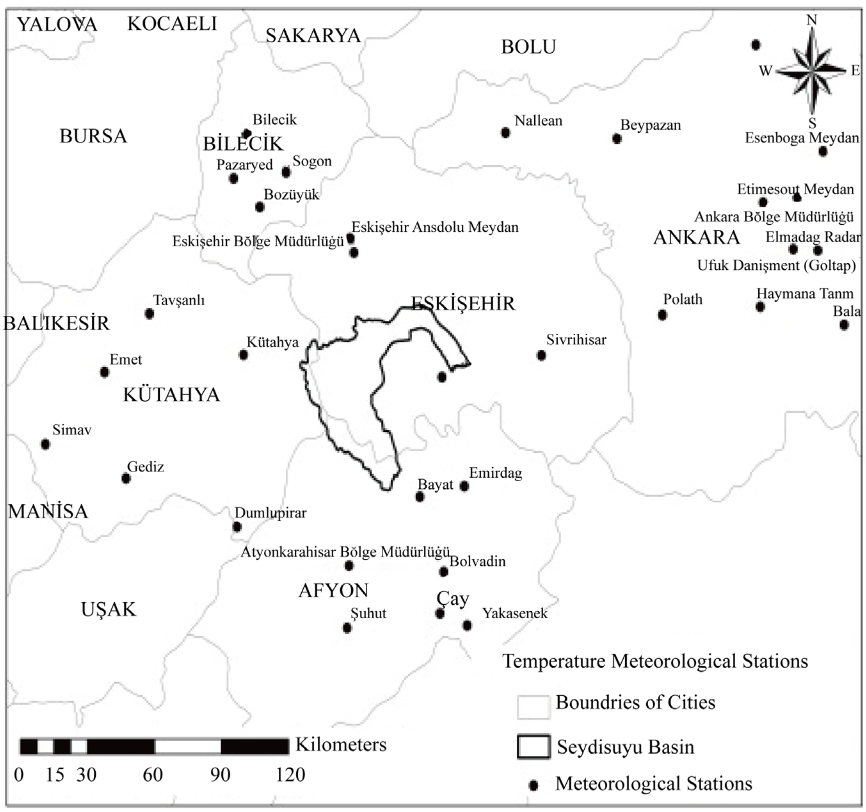
Precipitation Meteorological Stations
Boundries of Cities
Seydisuyu Basin
Meteorological Stations
Kilometers
0 15 30 60 90 120

(a)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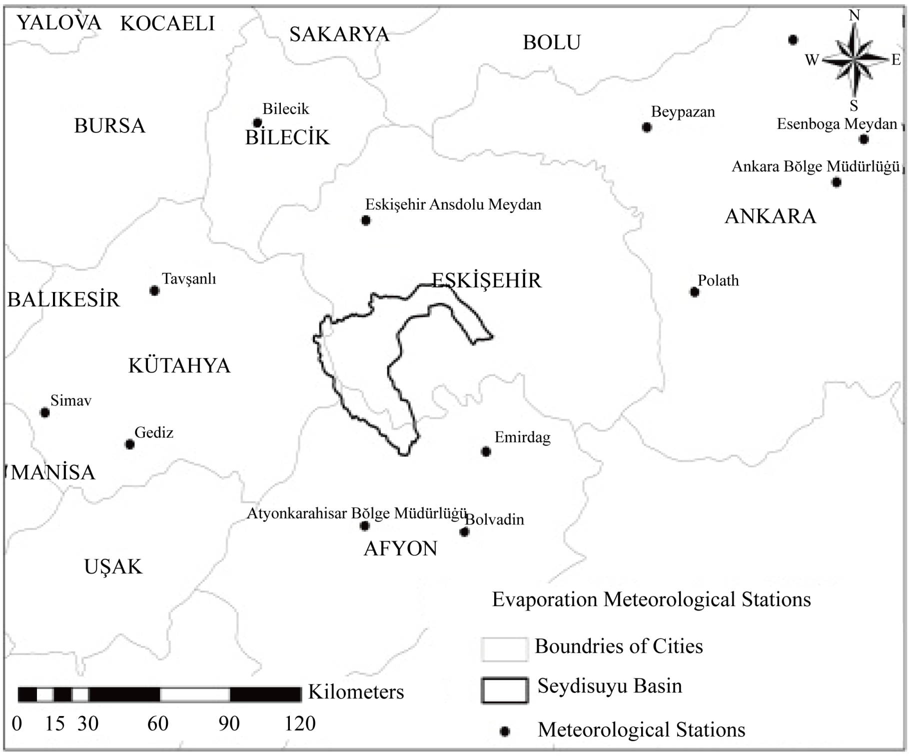
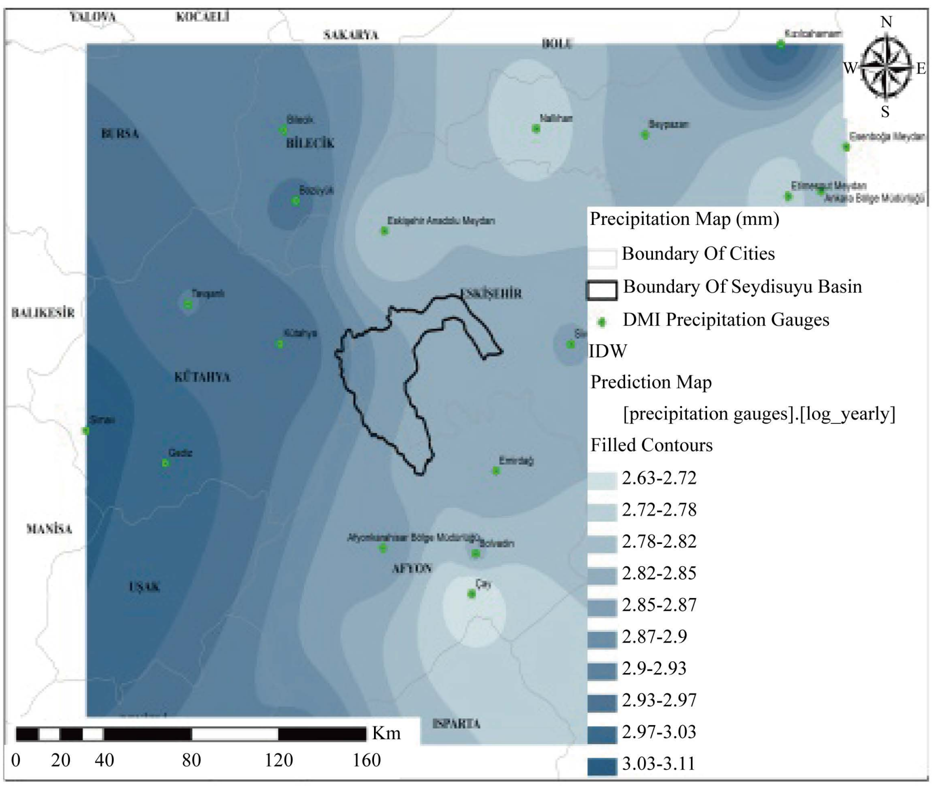
Nallean
Beypazarı
Esenboga Meydan
Bozüyük
Etimesout Meydan
Ankara Bölge Müdürlüğü
ANKARA
Elmadag Radar
Ufuk Danişment (Goltap)
Eskişehir Ansdolu Meydan
Eskişehir Bölge Müdürlüğü
Tavşanlı
BALIKESİR
ESKİŞEHİR
Polath
Haymana Tanm
Bala
Kütahya
Sivrihisar
Emet
KÜTAHYA
Simav
Gediz
Bayat
Emirdag
MANİSA
Dumlupirar
Atyonkarahisar Bölge Müdürlüğü
Bolvadin
AFYON
UŞAK
Şuhut
Çay
Yakasenek
Temperature Meteorological Stations
Boundries of Cities
Seydisuyu Basin
Meteorological Stations
Kilometers
0 15 30 60 90 120

(b)

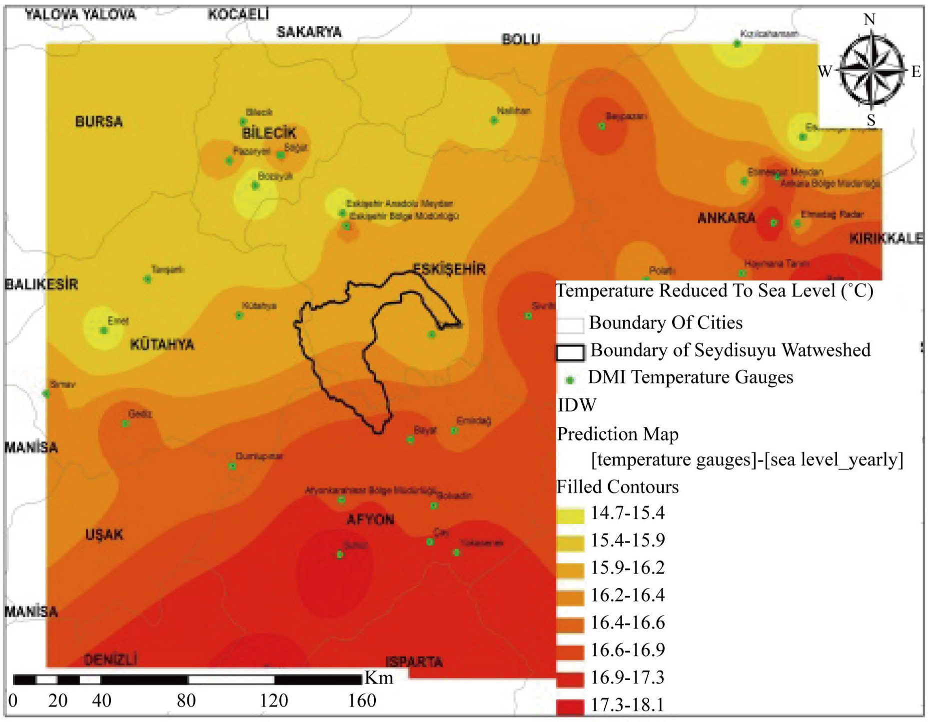


(c)

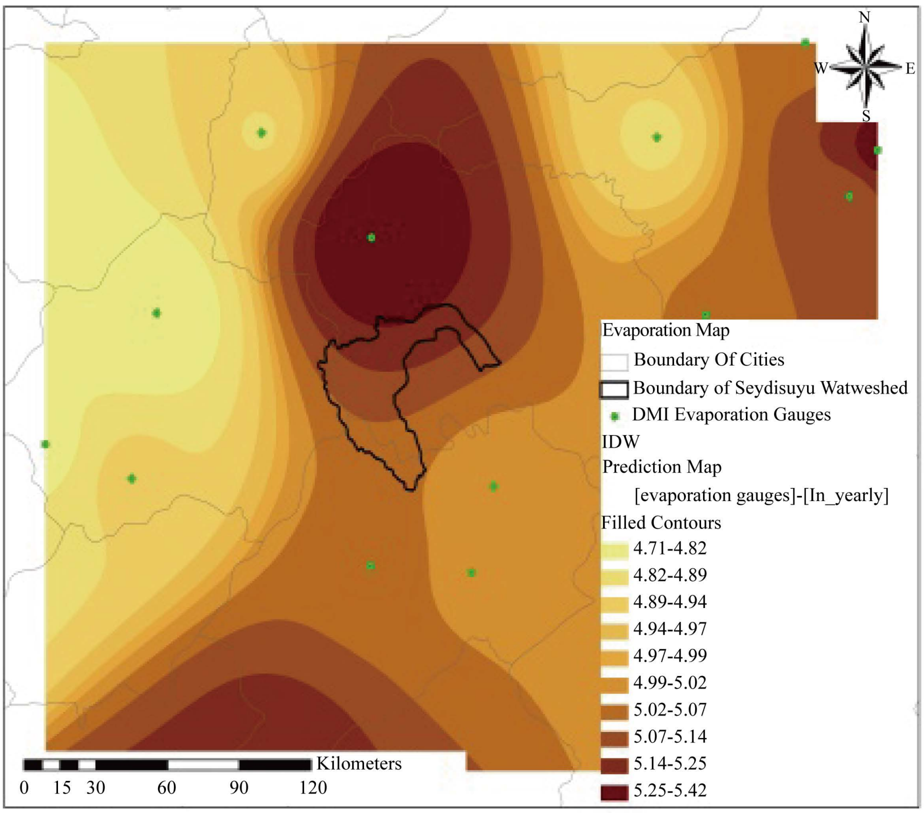
Figure 5. Spatial maps of meteorology stations.



(a)

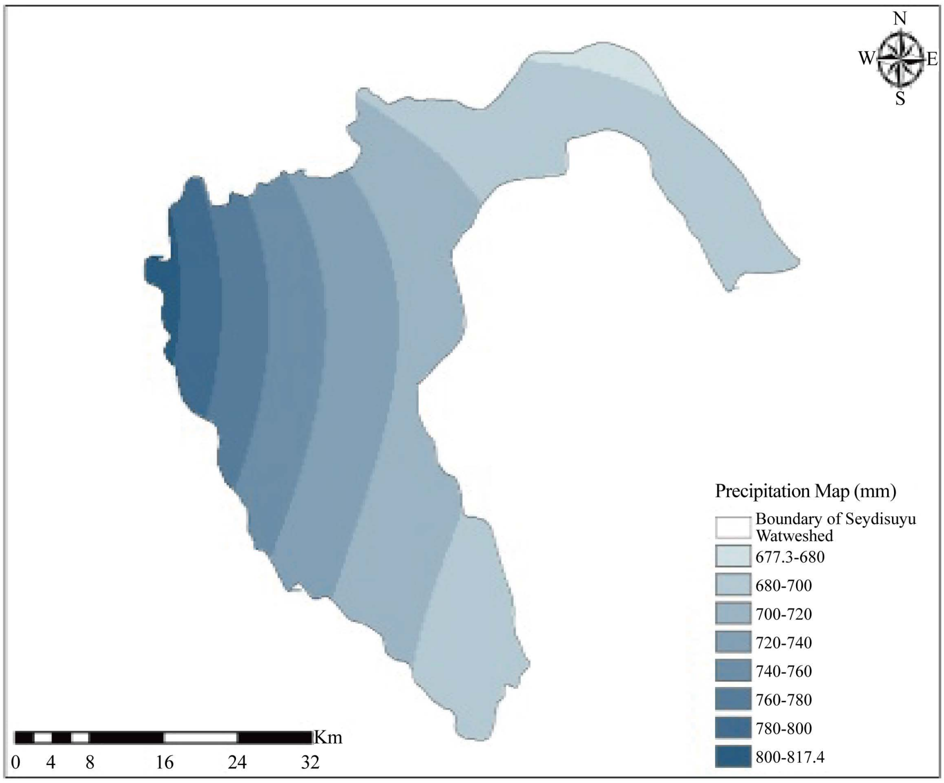


(b)

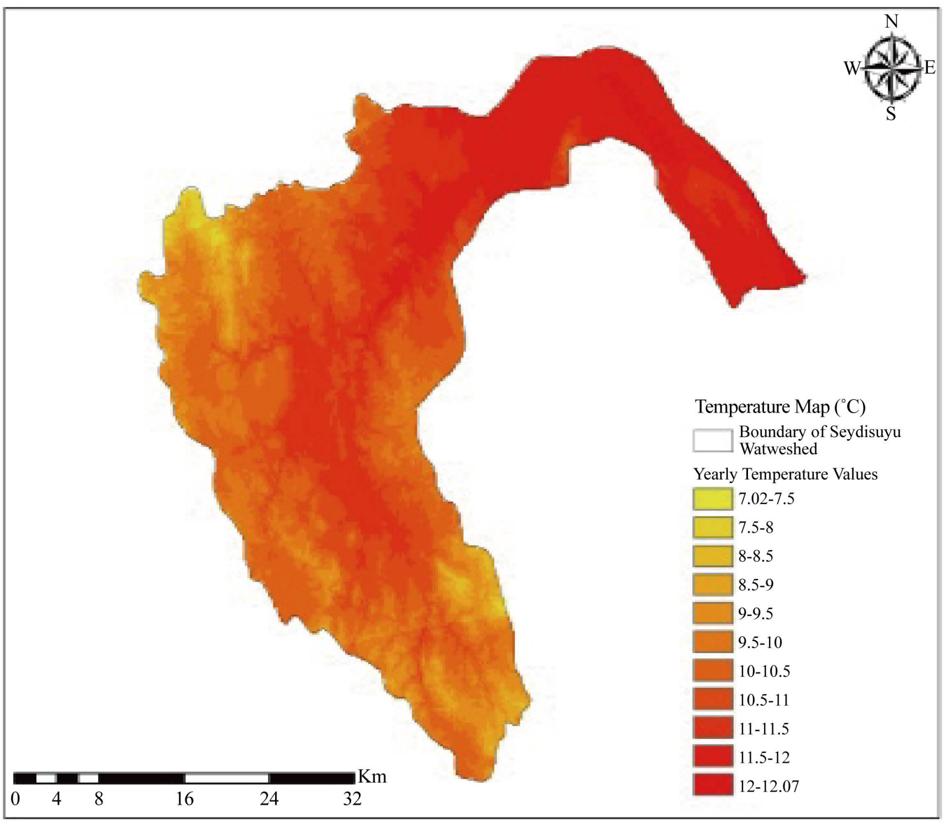


(c)

Figure 6. (a), (b), (c) Distribution modeling of inverse distance weighting method.


N
W
E
S
Precipitation Map (mm)
Boundary of Seydisuyu Watweshed
677.3-680
680-700
700-720
720-740
740-760
760-780
780-800
800-817.4
Km
0 4 8 16 24 32

(a)


N
W
E
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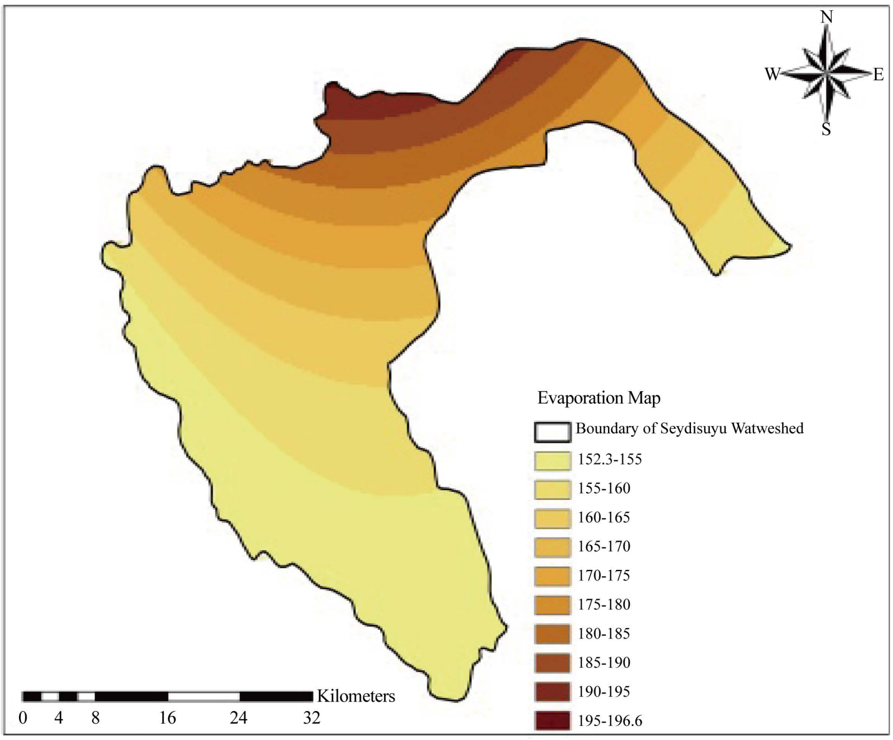
Temperature Map (˚C)
Boundary of Seydisuyu Watweshed
Yearly Temperature Values
7.02-7.5
7.5-8
8-8.5
8.5-9
9-9.5
9.5-10
10-10.5
10.5-11
11-11.5
11.5-12
12-12.07
Km
0 4 8 16 24 32

(b)



(c)

Figure 7. (a), (b), (c) Precipitation, temperature and evaporation distribution maps of Seydisuyu basin.

Table 4. Real and estimated values of control stations which measure precipitation.

Name of the Station	Measured Logarithm Amount of Precipitation (mm)	Estimated Value IDW	Error
17702-Bozuyuk	2.94	2.89	−0.05
17796-Bolvadin	2.84	2.70	−0.14
17680-Beypazari	2.85	2.81	−0.04
Root Mean Square Error (RMSE)			0.0392

Table 5. Real and estimated values of control stations which measure temperature.

Name of the Station	Measured Sea Level Temperature (˚C)	Estimated Value IDW	Error
17707-Emet	15.23	16.05	0.82
17190-Afyonkarahisar Regional Directorate	16.79	17.14	0.35
17728-Polatli	16.32	16.54	0.22
Root Mean Square Error (RMSE)			0.5338

stations will not be possible. Therefore, defining control stations is a significant component to evaluate the results of the research correctly during accuracy analysis.

Table 6. Real and estimated values of control stations which measure evaporation.

Name of the Station	Measured Natural Logarithm (Ln) Amount of Evaporation (mm)	Estimated Value	Error
		IDW	
17680-Beypazari	4.88	5.04	0.16
17796-Bolvadin	5.01	5.01	−0.000105
17750-Gediz	4.93	4.73	−0.20
Root Mean Square Error (RMSE)			0.1514

8. Results and Conclusion

According to the results of accuracy analysis, root mean square error values of estimation results, which were calculated with inverse distance weighting method, were close to zero (0), as it could be seen in **Tables 4-6**. First, it is necessary to evaluate the data, which will be used for estimation, statistically in order for the estimation method to give reliable results. In conclusion, distribution parameters of meteorological data were studied statistically, and values, which did not have a normal distribution, were normalized. After that, normalized data sets were modeled with inverse distance weighting method. Estimation results, which were obtained from normalized values, did not have real values, so it was necessary to convert them into their real values. With this aim, data were reconverted on the basis of pixel by using raster calculator to convert data into their real values. Accuracy rate of the models, which were obtained, was a significant parameter for the reliability of the research. Therefore, accuracy analysis was conducted on the models, and it was observed that the root mean square error values were close to zero. The fact that the root mean square error values are close to zero shows that the accuracy rate of the models, which are obtained, is high and reliable.

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