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Mapping of Precipitation, Temperature and Evaporation Distributions in the Porsuk Basin Using Distant Forecasting Methods

Recep Bakış[1], Yıldırım Bayazıt[2], Hakan Uyguçgil[1], Cengiz Koç[3*]

[1]Department of Civil Engineering, Anadolu University, Eskişehir, Turkey
[2]Department of Civil Engineering, Bilecik Şeyh Edebali University, Bilecik, Turkey
[3]Department of City and Regional Planning, Faculty of Architecture, Muğla Sıtkı Koçman University, Muğla, Turkey
Email: rbakis@anadolu.edu.tr, yildirim.beyazit@bilecik.edu.tr, huygucgil@anadolu.edu.tr, *cengizko9@gmail.com

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Abstract

Geographical data are of great importance in meteorology and climate science. These data can create the areal distribution models analyzed by spatial interpolation methods. The values of the areas without measurement data are estimated with these distribution models. In this study, distribution of meteorological parameters such as precipitation, temperature and evaporation in Porsuk basin, which is determined as research area, was investigated by Inverse Distance Weighting (IDW) and Ordinary Kriging methods. Actual meteorological data analyzed of the basin do not show a normal distribution statistically. Therefore, the data were firstly subjected to normalization and then analyzed according to the IDW and Ordinary Kriging methods to create distribution maps of precipitation, temperature and evaporation data. Quadratic mean error values were compared to investigate the reliability of analyzes. In this study, the analysis results of precipitation, temperature and evaporation data have been calculated by two different methods. Ordinary Kriging method has been determined as the method making the most accurate estimation.

Keywords

Geographical Information Systems, Inverse Distance Weighting, Ordinary Kriging, Meteorology, Porsuk Basin, Turkey

1. Introduction

Water resources need to be managed on a watershed basis and in harmony with other natural resources, while they also need to be consistent with the principle of sustainable development. The basic mean of achieving these conditions is a

*Corresponding author.

continuously updated and adaptable watershed information system. In our country, the concept and philosophy of "watershed information system" is not yet established. Therefore, even in the initial stage of watershed management, there is a significant shortage [1]. The main target in watershed management is; conservation of natural resources, bringing the environment into a state where it can renew itself, and sustainable management of resources. Geographical Information Systems (GIS) are seen as a technological and indispensable tool for the preparation of the environments necessary for the collection of the data for the basin and its storage in the digital environment [2].

In basin management planning, spatial distributions of climate data can be produced in different layers by using point observation values with the aid of GIS. This situation has made the use of GIS inevitable. If the spatial distribution of climate parameters is to be determined and the corresponding climate layers are produced, it is possible to encounter multiple methods. However, the method suitable for one region is not suitable for another region. For this reason, it is necessary to apply similar studies to each region with different methods depending on the characteristics of the region and the structure of the data [3]. That being the case, the determination of the method which is best suitable for each region or basin becomes a problem.

Evaporation, temperature, precipitation climate data are spotted at meteorological observation stations. Since the data are obtained in this way, they are point-shaped in the basin. Therefore, spatial distributions using point data and climate data need to be generated in different layers in the GIS environment. Thus, relationships between data layers can be investigated and interrogation possibilities can be achieved. In studies on the development of water resources, the average areal precipitation depth over a given area is used instead of point precipitation values [4].

2. Material and Methods

In the survey, 250 raster maps (scanned and positioned) and vector (digital map) maps, 106 geological digital maps (with European Datum 1950 (ED50)-UTM 35N - 36N, with 1/25,000 scale covering the Porsuk basin and neighboring basins around the basin Zone coordination system) have been obtained from the III. Regional Directorate of General Directorate of State Hydraulic Works (DSI). From these maps, Digital Elevation Model (DEM) was created. Digital Elevation Models (DEMs) are a type of raster GIS layer. Raster GIS represents the world as a regular arrangement of locations. In a DEM, each cell has a value corresponding to its elevation. The slope, elevation, elevation and relief maps of the basin are derived using the digital elevation model. With hydrological models, hydrological boundaries of the basin and synthetic drainage network have been obtained. The data required to determine the long-run magnitudes of the meteorological characteristics of the basin (evaporation, temperature, precipitation) were obtained from the General Directorate of State Meteorology Affairs (DMI).

The Meteorological Observation Station (MOS) data are taken as monthly averages covering the years 1991-2011. In the Microsoft Excel environment, the data were analyzed and arranged according to the MOS data of each province. Coordinates of each province are transferred to GIS environment. To be able to predict correctly with a dataset, the dataset must have a normal distribution. When the obtained meteorological data were examined, it was found that they did not show statistically normal distribution. For a normal distribution of a data set, it is necessary that the Skewness coefficient is zero (0) and the Kurtosis coefficient is close to (3). In addition, mean and median values should be close to each other. Some transformations such as log, ln, sin, cos, tan, and square root have been applied to normalize the data set to make predictions. These values are used in the estimation process based on the transformations that approximate the normal distribution. However, since the temperature distribution is close to the normal distribution in the original values, no transformation is needed. It is aimed to compare these methods using two distance-dependent methods (IDW, Ordinary Kriging).

3. Description of the Study Area

The research area is Porsuk Creek Basin. Porsuk Basin is a sub-basin of the Sakarya basin and has an area of 11,113.66 km^2 in northwest Anatolia. The basin lies between 29˚38' - 31˚59' East longitudes and 38˚44' - 39˚99' North latitudes. The basin is 202 km long in the east-west direction and 135 km long in the north-south direction (**Figure 1**). More than 60% of the basin is mountainous. The surface waters of the Porsuk Basin are collected by the Porsuk Stream and discharge into the Sakarya river at 660 m elevation, after having traveled 436 km in the basin.

4. Determination of Porsuk Hydrological Basin Boundaries by Geographical Information System

Basin-based meteorological data for Porsuk basin requires estimation of the hydrological boundaries of the basin and analysis of the basin surface for estimation and surface analysis. For this purpose, the characteristics of the basin have been determined with the help of digitized maps. Basin's Digital Elevation Model (DEM) was extracted using 1/25.000 scaled digitized vector maps. The digital elevation model was analyzed by cutting it according to the hydrological basin boundary. The digital elevation model of Porsuk basin and the lower basins are given in **Figure 2(a)** and **Figure 2(b)**.

4.1. Determination of the Lower Basins and the Drainage Areas in Porsuk Basin

The lower basins which make up the main basin have been created from the hydrological analysis based on the digital elevation model. Also by using the digital elevation models, the slope, height and the three dimensional maps have been

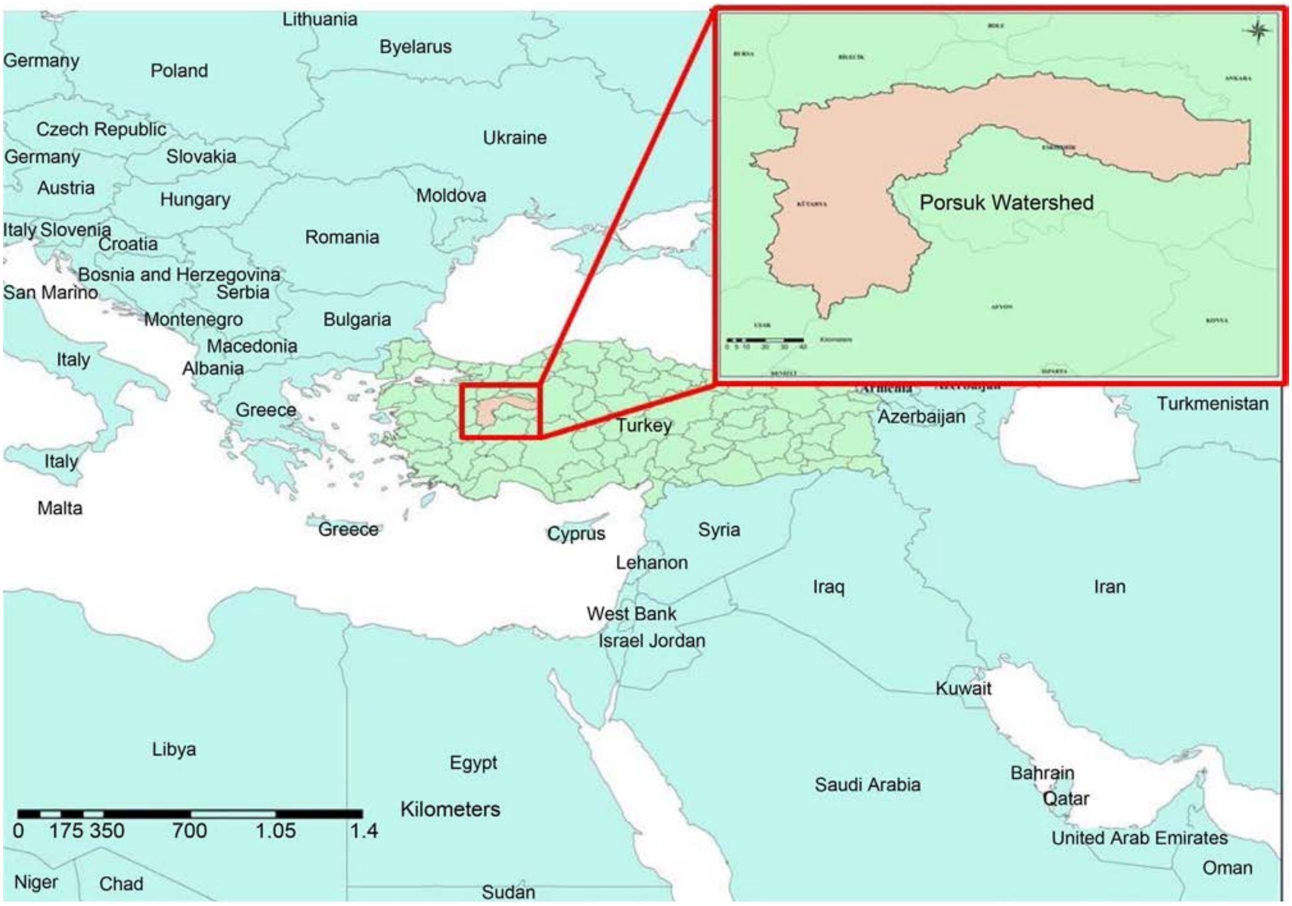


Figure 1. Location of Porsuk basin in Turkey.

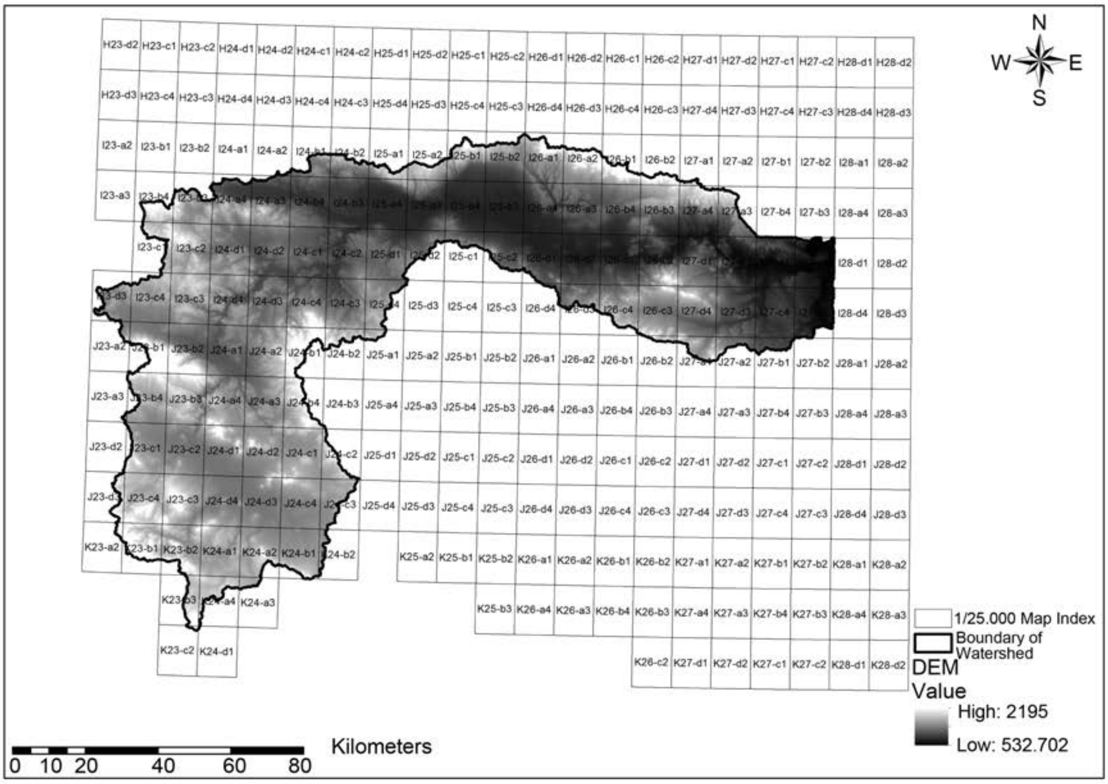
derived from CBS environment. Again by using the numerical height model, the drainage area and the boundaries of the lower basins and the flow direction have been determined. Thus, the drainage network and area caused by the precipitation on each sub-basin has been obtained and given in **Figure 2(b)**. Furthermore, main stream for each sub-basin have also been determined in the study.

In this study, important data such as the number of the main streams and secondary streams in each lower basin, total stream lengths, slope of each stream were obtained. The longitudinal sections of main streams have been removed. The total area of the Porsuk Basin is 11,113.66 km^2 from the hydrological point of view.

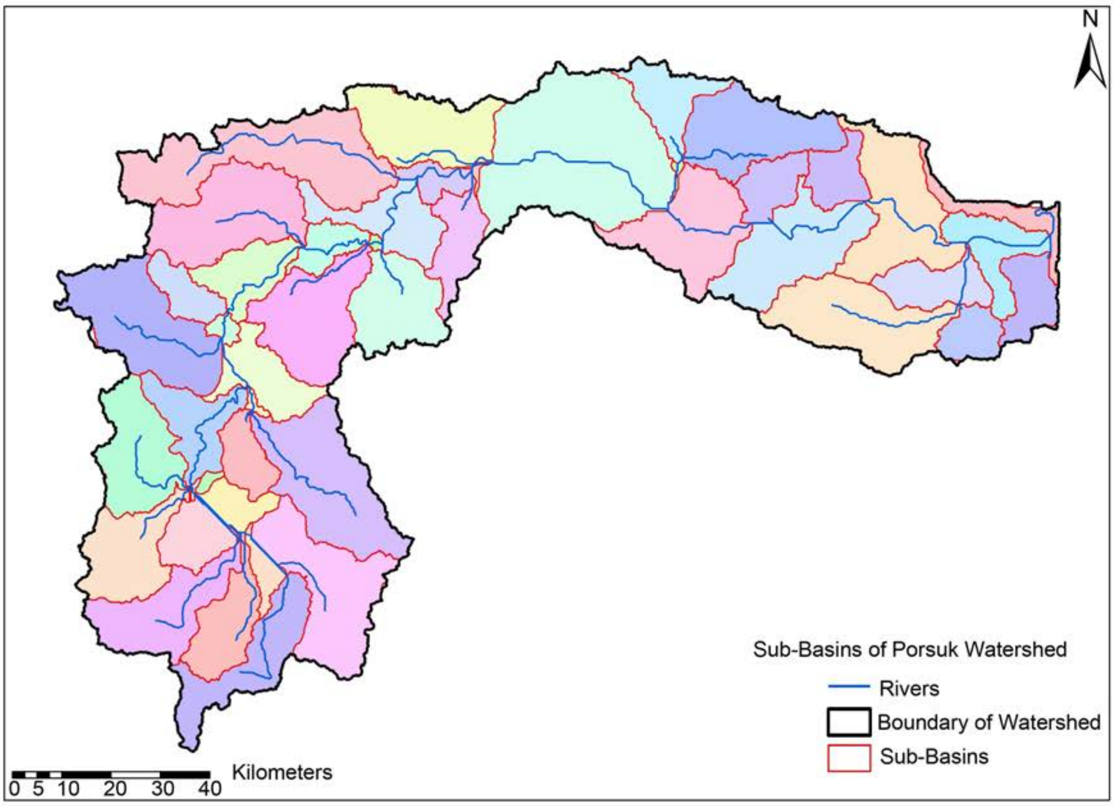
4.2. Spatial Features of the Porsuk Basin

Using the digital elevation model of the Porsuk basin, spatial features related to the basin have been derived by obtaining more data and maps of the basin height, slope, view, shaded relief map and so on. Each dataset is an important piece of information in basin planning. The spatial properties of the basin are classified and given in **Figures 3(a)-(d)**.

When the topographic maps of Porsuk basin are examined, it is observed that the basin has elevations ranging between 500 m and 2250 m elevations. 50% of

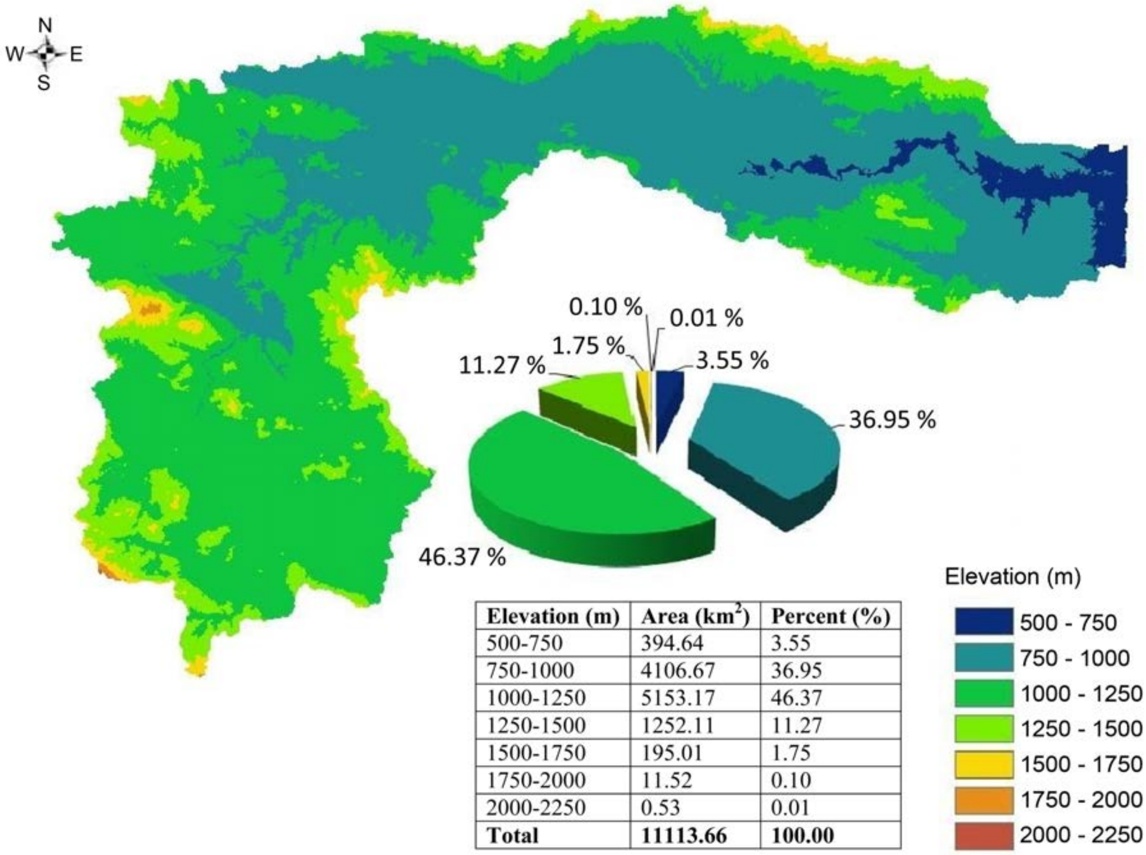


(a)



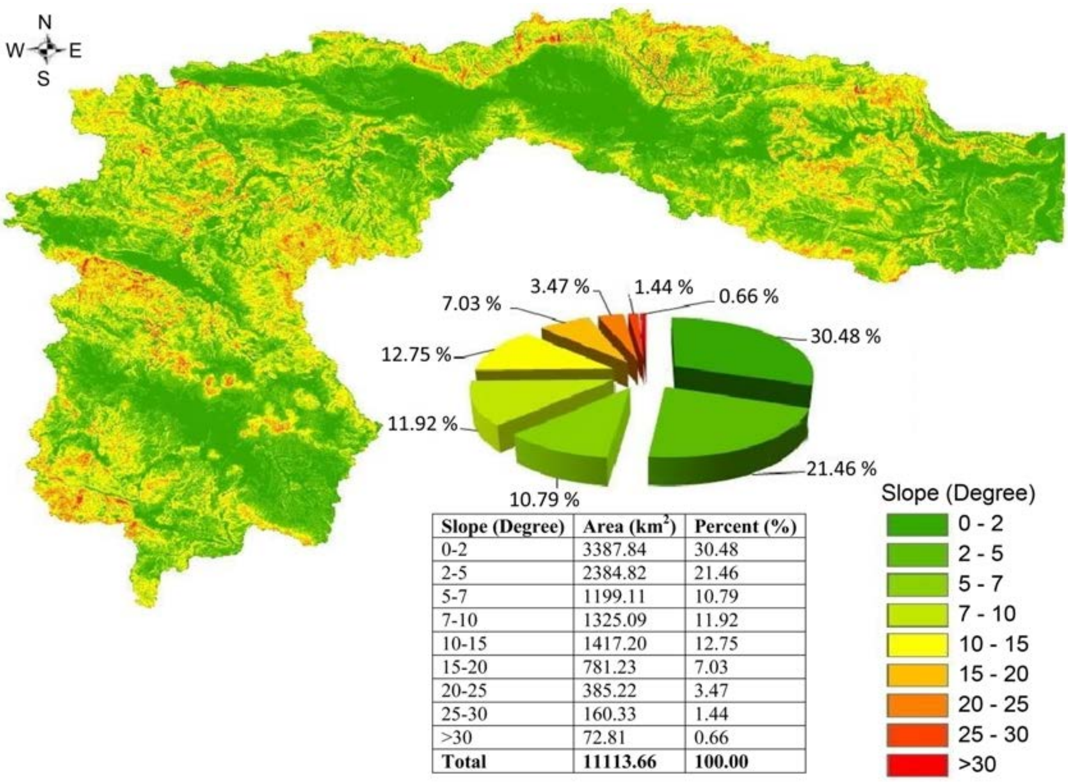
(b)

Figure 2. Drainage network of DEM and lower basins of Porsuk basin.



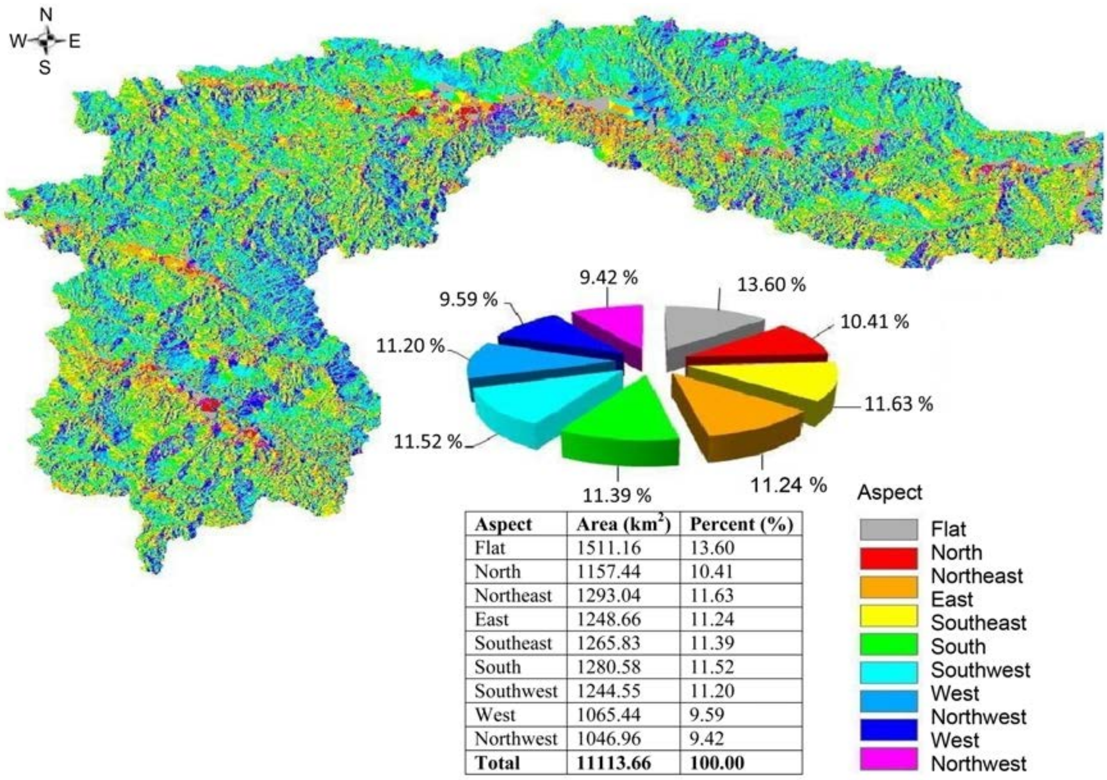
Elevation (m)	Area (km²)	Percent (%)
500-750	394.64	3.55
750-1000	4106.67	36.95
1000-1250	5153.17	46.37
1250-1500	1252.11	11.27
1500-1750	195.01	1.75
1750-2000	11.52	0.10
2000-2250	0.53	0.01
Total	**11113.66**	**100.00**

(a)



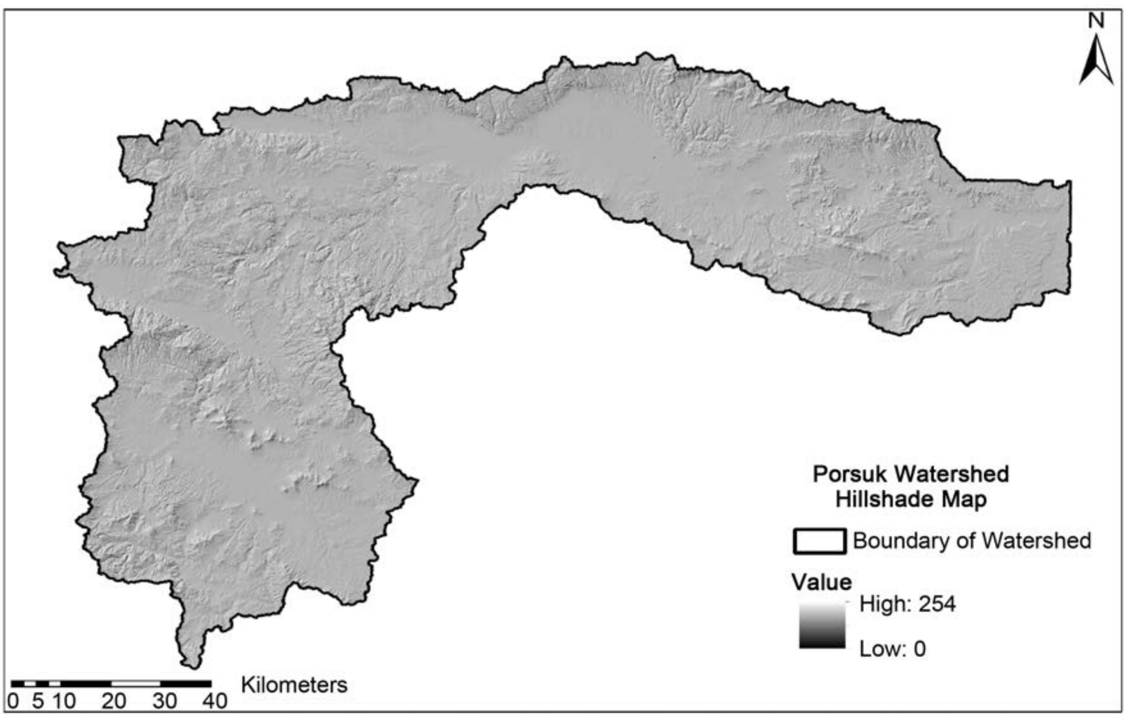
Slope (Degree)	Area (km²)	Percent (%)
0-2	3387.84	30.48
2-5	2384.82	21.46
5-7	1199.11	10.79
7-10	1325.09	11.92
10-15	1417.20	12.75
15-20	781.23	7.03
20-25	385.22	3.47
25-30	160.33	1.44
>30	72.81	0.66
Total	**11113.66**	**100.00**

(b)



Aspect	Area (km^2)	Percent (%)
Flat	1511.16	13.60
North	1157.44	10.41
Northeast	1293.04	11.63
East	1248.66	11.24
Southeast	1265.83	11.39
South	1280.58	11.52
Southwest	1244.55	11.20
West	1065.44	9.59
Northwest	1046.96	9.42
Total	**11113.66**	**100.00**

(c)



(d)

Figure 3. Spatial maps of Porsuk basin. (a) Elevation (topography) map. (b) Slope map. (c) Aspect map. (d) Shaded map.

the Porsuk basin is more than 1200 m in height (**Figure 3(a)**). The basin generally has a lower gradient than the 15 degree slope. The slope of the area of approximately 72.81 km^2, which is 0.66% of the Porsuk basin, and it has a topography above 30˚ (**Figure 3(b)**). Aspect analysis is the geographical angle of the surface to the north. Approximately 3790.96 km^2 of the survey area is the slopes facing south, southeast and southwest (**Figure 3(c)**). From the shaded relief map given in **Figure 3(d)**, it is generally possible to see clearly the structure and flat areas of the basin.

5. Determination of Meteorological Features of the Basin

The Porsuk basin reflects the regional climatic characteristics of the Central Anatolian Region. However, it is also under the minor influence of the Aegean region. There are climatic differences between the western and eastern parts of the basin. In general, the summers of the Porsuk basin are arid and hot, and the winters are cold and rainy. The meteorological data in the basin is measured by Meteorological Observation Stations (MOS) located in the provinces of Eskişehir, Kütahya, Afyon, Bilecik, Sakarya and Ankara. Data such as measured rainfall (mm), temperature (˚C) and evaporation (mm) of the basin are obtained from the DMI between 1930-2010 (70 years) [5]. These raw data were edited to obtain averages of the monthly average, minimum and maximum values.

Statistical Evaluation of Meteorological Data

The distribution parameters of the data sets were statistically examined before estimating the distance by using the data obtained from the DMI and DSI and by using the distance-based estimation methods. The data set should show normal distribution, so that a reliable estimation can be made. Estimates made with non-normal data sets will not yield reliable results. For this reason, the distribution parameters of precipitation, temperature and evaporation data sets are evaluated statistically. This assessment is shown in **Table 1**.

Table 1. Distribution parameters of meteorological data.

PARAMETERS	EVAPORATION (mm)	TEMPERATURE (˚C)	PRECIPITATION (mm)
Number of Stations	42	86	137
Standard Deviation	337.93	1.4475	164.09
Min	21.2	7.1889	284.72
Max	2298.4	14.225	1249.6
Mean	1166.7	11.223	486.19
Median	1165.5	11.179	440.05
Skewness Coefficient	0.0011155	−0.068171	2.1913
Kurtosis Coefficient	6.9031	2.9384	8.4775

When the distribution parameters shown in **Table 1** are examined, it is seen that the data are not statistically normal distributions. For a normal distribution of a data set, the Skewness coefficients should be close to zero (0), and the Kurtosis coefficients should be close to three (3). In addition, the mean and median values should be close to each other. Some transformations such as log, ln, sin, cos, tan, and square root were applied to normalize the precipitation, temperature, and evaporation data sets which didn't have normal distribution (**Figure 4**). These values are used in the estimation process based on the transformations that approximate the normal distribution. Ln for evaporation, log for precipitation transformations have been observed to approach normal distributions. However, since the temperature data show normal distribution without the necessity of these conversions, the distribution is made using the original data. This assessment is shown in **Table 2**.

When **Table 1** and **Table 2** are examined, it is observed that the Skewness coefficient approaches zero (0) and the Kurtosis coefficient approximates (3) times of its original value. It is not possible to obtain a perfectly normal distribution, because the data do not have a uniformly distribution and because there are

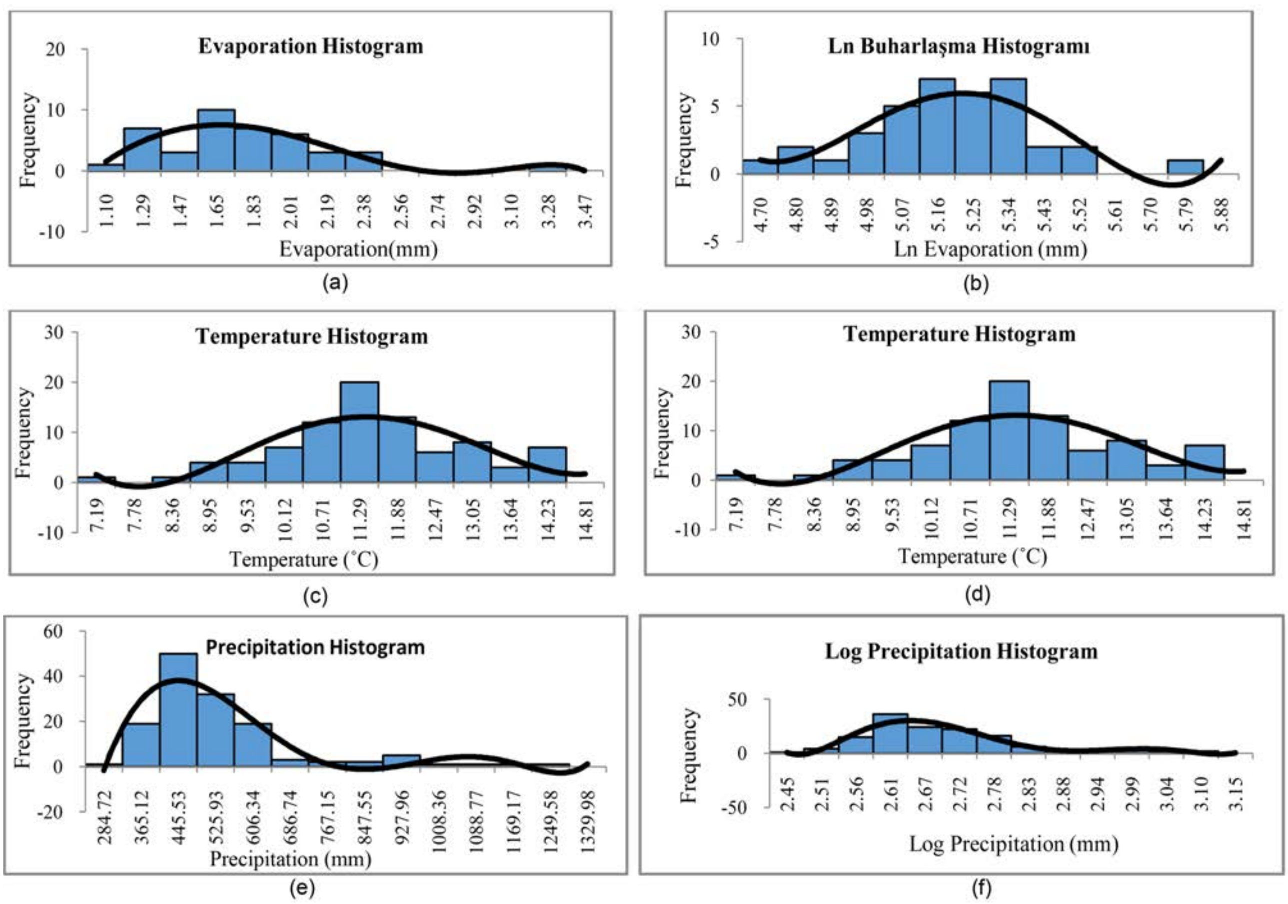


Figure 4. Crude and regulated histograms of meteorological data of Porsuk basin. (a) Annual evaporation histogram. (b) Annual evaporation histogram converted to ln. (c) Annual temperature histogram. (d) Unconverted annual temperature histogram. (e) Annual precipitation histogram. (f) Log-transformed annual precipitation histogram.

Table 2. Distribution parameters approaching the normal distribution after statistical analysis of data.

PARAMETERS	LN EVAPORATION (mm)	TEMPERATURE (˚C)	LOG PRECIPITATION (mm)
Number of Stations	41	86	137
Standard Deviation	0.23604	1.4475	0.12037
Min	4.7046	7.1889	2.4544
Max	5.7941	14.225	3.0968
Mean	5.1021	11.223	2.6682
Median	5.0896	11.179	2.6435
Skewness Coefficient	0.27394	−0.068171	1.2504
Kurtosis Coefficient	3.3119	2.9384	4.6878

only a few point measurement stations. The closest distribution parameters to normal distributions are obtained by the appropriate transformations.

6. Positional Prediction Methods

Estimation is defined as a mathematical method developed to calculate missing data on a series [6]. Estimation, which allows the derivation of new data by means of calculations based on the data at specific points, is actually the computation period of the function necessary for this calculation [7] [8]. Today, in GIS applications, spatial coordinates are calculated from known points, that is to say point-referenced, and distance-dependent spatial estimation methods are used to represent the field in terms of space. As a result of estimation, raster surfaces are calculated from vector data defined on point geometries. Spanning and distance-dependent estimation methods (IDW, Natural Neighbors, Spline, Kriging, etc.) try to estimate the value at unknown points. Based on the modeled data model, selected estimation methods reveal more accurate models. In this study, the applicability of the IDW and Ordinary Kriging methods to the data is investigated and the raster surfaces are cut to the basin boundary (clip) to model rainfall, temperature and evaporation distribution maps for the basin.

6.1. Inverse Distance Weighted Method-IDW

Inverse distance weighted method is a method of estimation that takes a higher weight value than nearby points and considers all possible sample points. Each sample point has a weight value in the opposite direction according to its distance to the point to be estimated. x_0 predicted value is calculated as shown in Equation (3)

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

$$Z^*(x_0) = \sum W_i \cdot Z(x_i) \tag{2}$$

where:

$Z^*(x_0)$: Value of the estimate at point x_0,

$Z(x_i)$: sample point value at x_i,

W_i: The inverse distance weight according to the point x_0 at the point x_i,

d: the distance between the sample point and the point to be estimated,

p: exponential value,

n: number of sample points.

6.2. Ordinary Kriging Method

The Kriging interpolation method is an interpolation method that estimates optimal values of the data at other points by using known values at near locations [9]. Kriging interpolation is a technique in which the unbiased estimation of the positional changes at the sampled points using semi-parametric structural features is performed optimally [10] [11]. The most important feature that distinguishes the Kriging method from other methods is that a variance value can be calculated for each estimated point or area, which is a measure of the confidence level of the value [11]. Ordinary Kriging is the simplest form of kriging. It uses dimensionless points to estimate other dimensionless points, e.g. elevation contour plots. In Ordinary kriging, the regionalized variable is assumed to be stationary.

In our case Z, at point p, $Z_e(p)$ to be calculated using a weighted average of the known values or control points (Equation (3)):

$$z_e(p) = \sum w_i \cdot z(p_i) \tag{3}$$

This estimated value will most likely differ from the actual value at point p, $Z_a(p)$, and this difference is called the estimation error (Equation (4))

$$\varepsilon_p = z_e(p) - z_a(p) \tag{4}$$

If no drift exists and the weights used in the estimation sum to one, then the estimated value is said to be unbiased. The scatter of the estimates about the true value is termed the error or estimation variance (Equation (5)),

$$\sigma_z^2 = \frac{\sum_{i=1}^{n} \left[z_e(p_i) - z_a(p_i) \right]_i^2}{n} \tag{5}$$

Kriging tries to choose the optimal weights that produce the minimum estimation error. Optimal weights, those that produce unbiased estimate sand have a minimum estimation variance, are obtained by solving a set of simultaneous equations (Equations (6) and (7)).

$$\begin{aligned} w_1\gamma(h_{11})+w_2\gamma(h_{12})+w_3\gamma(h_{13})&=\gamma(h_{1p}) \\ w_1\gamma(h_{21})+w_2\gamma(h_{22})+w_3\gamma(h_{23})&=\gamma(h_{2p}) \\ w_1\gamma(h_{31})+w_2\gamma(h_{32})+w_3\gamma(h_{33})&=\gamma(h_{3p}) \end{aligned} \tag{6}$$

$$w_1+w_2+w_3=1 \tag{7}$$

A fourth variable is introduced called the Lagrange multiplier (Equation (8)),

$$\begin{bmatrix} \gamma(h_{11}) & \gamma(h_{12}) & \gamma(h_{13}) & 1 \\ \gamma(h_{21}) & \gamma(h_{21}) & \gamma(h_{23}) & 1 \\ \gamma(h_{31}) & \gamma(h_{32}) & \gamma(h_{33}) & 1 \\ 1 & 1 & 1 & 0 \end{bmatrix} \cdot \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ \lambda \end{bmatrix} = \begin{bmatrix} \gamma(h_{1p}) \\ \gamma(h_{2p}) \\ \gamma(h_{3p}) \\ 1 \end{bmatrix} \tag{8}$$

Once the individual weights are known, an estimation can be made by Equation (9),

$$z_e(p)=w_1z_1+w_2z_2+w_3z_3 \tag{9}$$

And an estimation variance can be calculated by Equation (10),

$$\sigma_z^2=w_1\gamma(h_{1p})+w_2\gamma(h_{21p})+w_{13}\gamma(h_{3p})+\lambda \tag{10}$$

7. Modeling of Meteorological Data Based on Seydisuyu Basin Distribution Maps

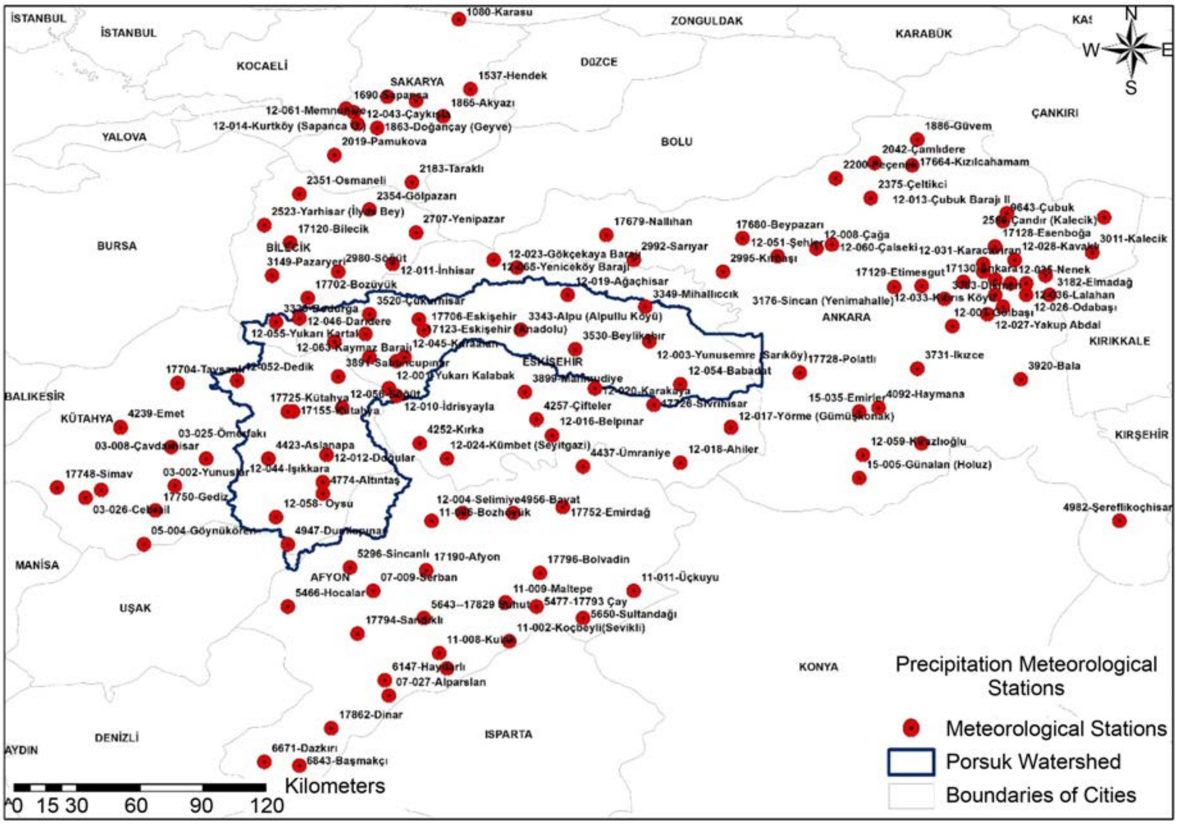
7.1. Modeling of Meteorological Data on the Basin Using Inverse Distance Weighted Method

The geographical locations of meteorological data (precipitation, temperature, evaporation) are shown in **Figures 5(a)-(c)**. The raw data given in **Figure 4** were transformed into normal distribution values in order to normalize the data, since it was not statistically normal. The histograms of the transformed data were generated and statistically re-evaluated. The distribution maps on the basin are then modeled using the distance tiller weighting method. The modeling results are given in **Figures 6(a)-(c)**.

The maps obtained as a result of the estimation should be converted to their actual values since the converted applied result is obtained. For this reason, values are converted to real meteorological values using the raster calculator in precipitation and evaporation data. The data for the temperature distribution are not recycled, because they are modeled with their original values (**Figures 7(a)-(c)**).

Accuracy Analysis of IDW Method

Randomly selected meteorological observation stations with appropriate spatial distribution were selected as control points and rainfall, temperature, evaporation distributions were applied by IDW interpolation method (without these data to determine the correctness of the predictions). These control stations are selected up to 20% of the number of stations available. This number is ideal for estimating the accuracy of the distribution. Then, we compare the calculated values


Precipitation Meteorological Stations
Meteorological Stations
Porsuk Watershed
Boundaries of Cities
0 15 30 60 90 120
Kilometers
İSTANBUL
ZONGULDAK
KARABÜK
KOCAELİ
DÜZCE
SAKARYA
YALOVA
BOLU
ÇANKIRI
BURSA
BİLECİK
ANKARA
ESKİŞEHİR
KIRIKKALE
BALIKESİR
KÜTAHYA
KIRŞEHİR
MANİSA
AFYON
UŞAK
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ISPARTA
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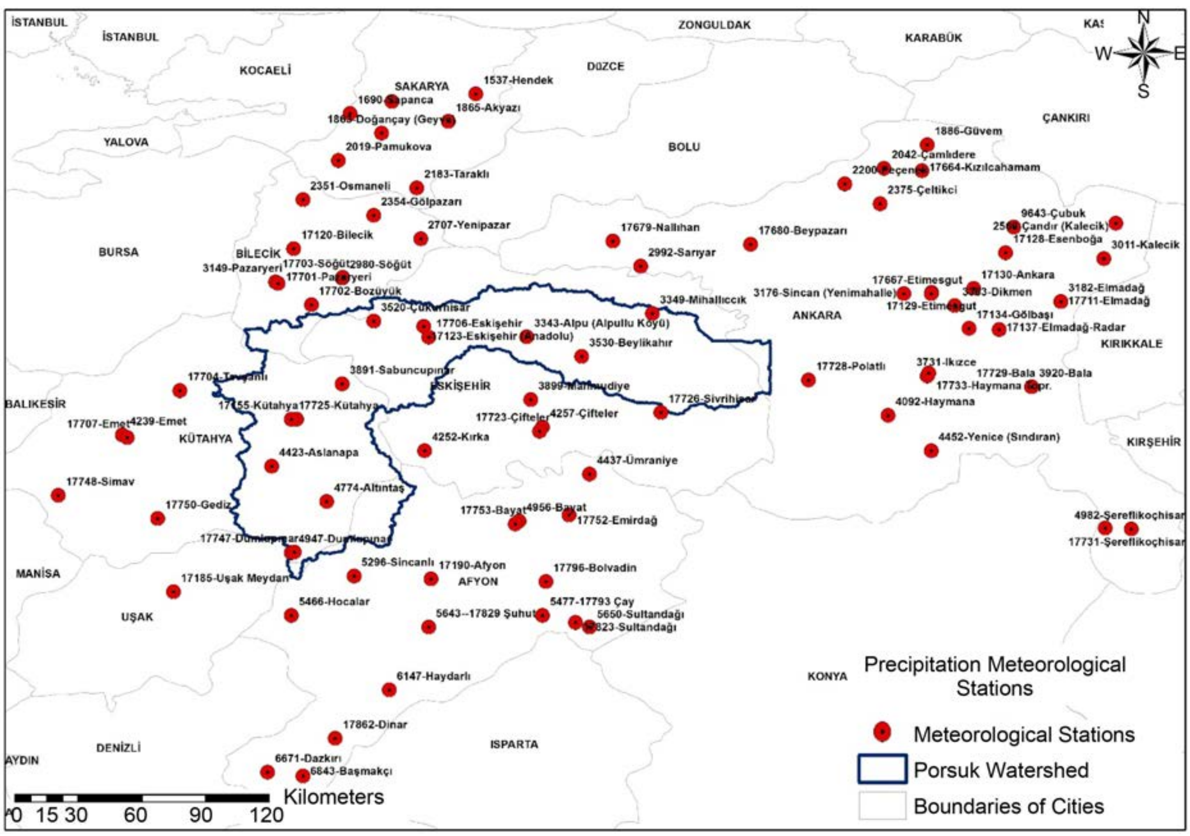
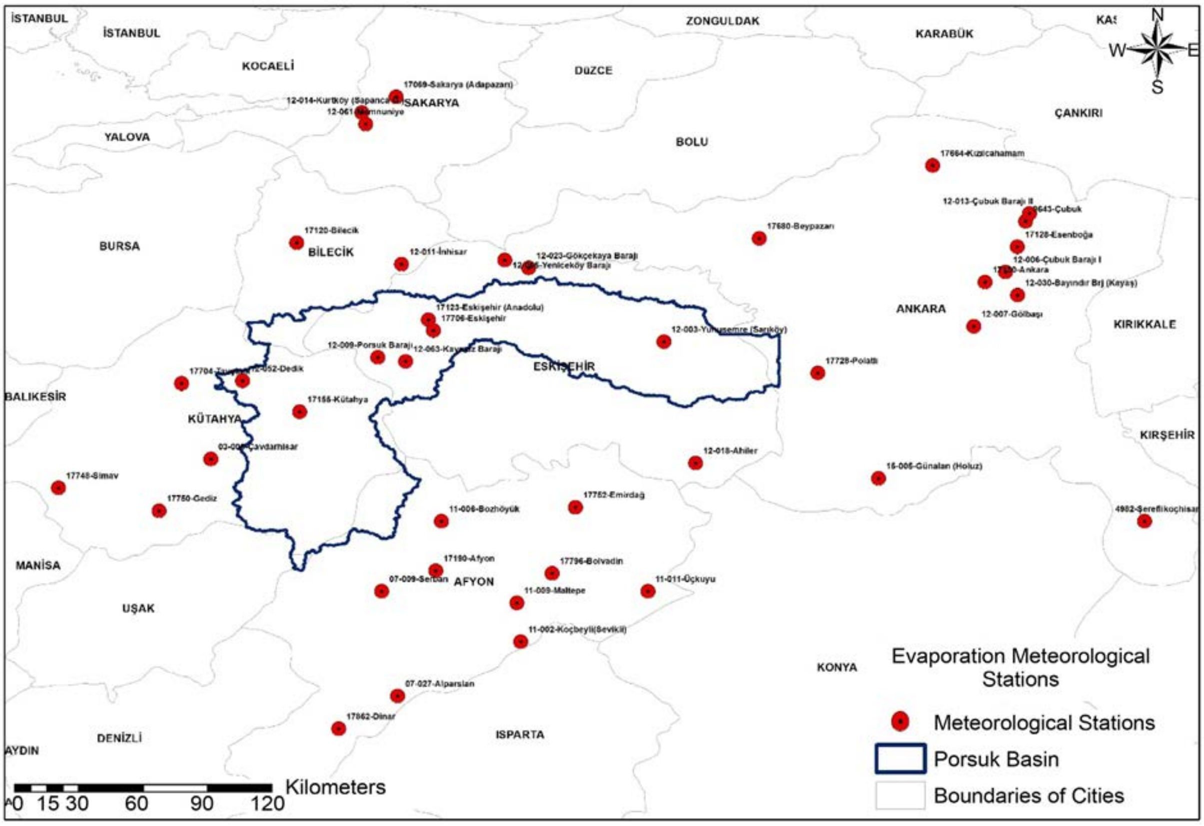
(a)


Precipitation Meteorological Stations
Meteorological Stations
Porsuk Watershed
Boundaries of Cities
0 15 30 60 90 120
Kilometers
İSTANBUL
ZONGULDAK
KARABÜK
KOCAELİ
DÜZCE
SAKARYA
YALOVA
BOLU
ÇANKIRI
BURSA
BİLECİK
ANKARA
ESKİŞEHİR
KIRIKKALE
BALIKESİR
KÜTAHYA
KIRŞEHİR
MANİSA
AFYON
UŞAK
KONYA
DENİZLİ
ISPARTA
AYDIN

(b)



(c)

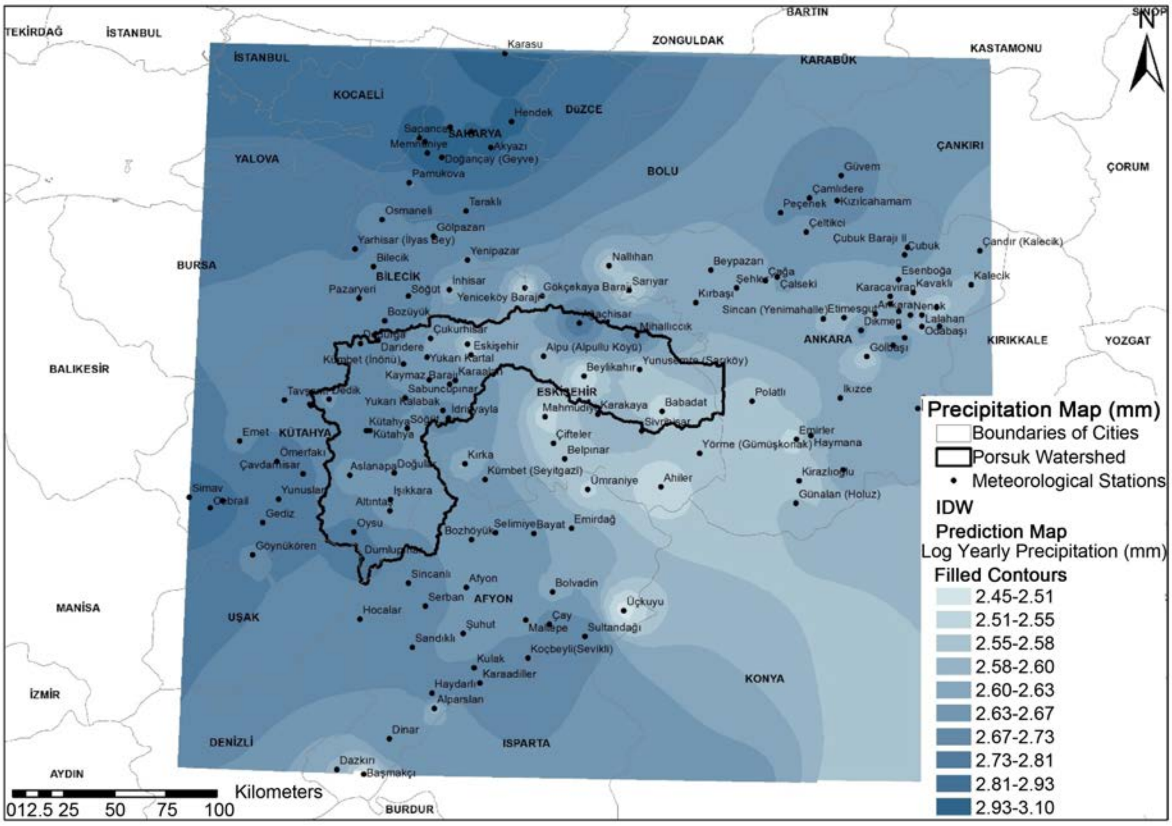
Figure 5. Spatial maps of meteorological stations. (a) Precipitation Measurement Stations. (b) Temperature Measurement Stations. (c) Evaporation measurement stations.

with the surface values calculated by using the data that were transformed for the normal distribution before the actual values of the control stations, and the accuracy of the estimations made by calculating the squared mean errors (SME) were analyzed (Tables 3-5).

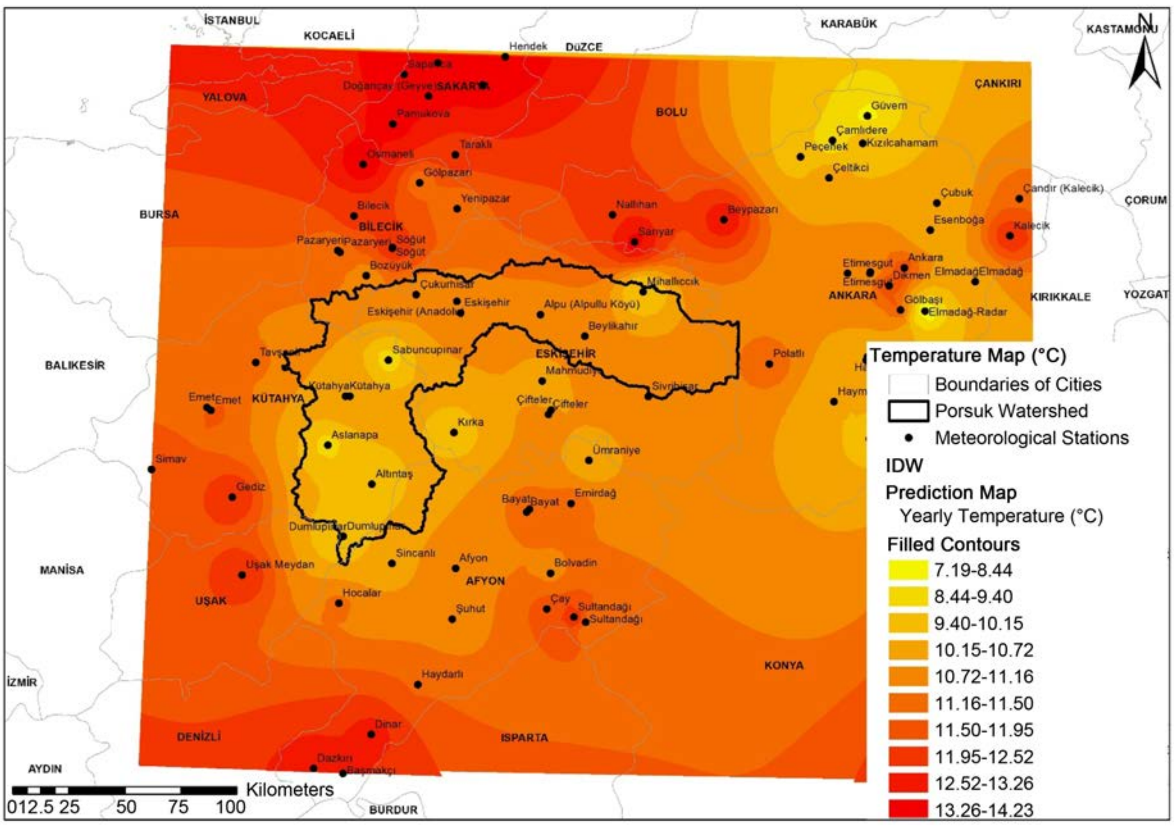
7.2. Modeling of Meteorological Data on Basin Using Ordinary Kriging Method

Ordinary Kriging method was chosen as the second method for distribution of spot meteorological data in the area of the Porsuk basin. Kriging methods require a more comprehensive statistical evaluation as compared to the IDW method. In order to create the Kriging model, first the variogram models of the data must be created. The variance of the difference between the values of the spatial variables in geo-statistics is expressed by the variogram function (Figure 8). The variogram function is expressed as the variance of the difference between two positional variables at distance s and is denoted by $2\gamma(s)$. The semi-variogram function is calculated as in the Equation (12), which is expressed as half of the variogram function [12] [13] [14] [15].

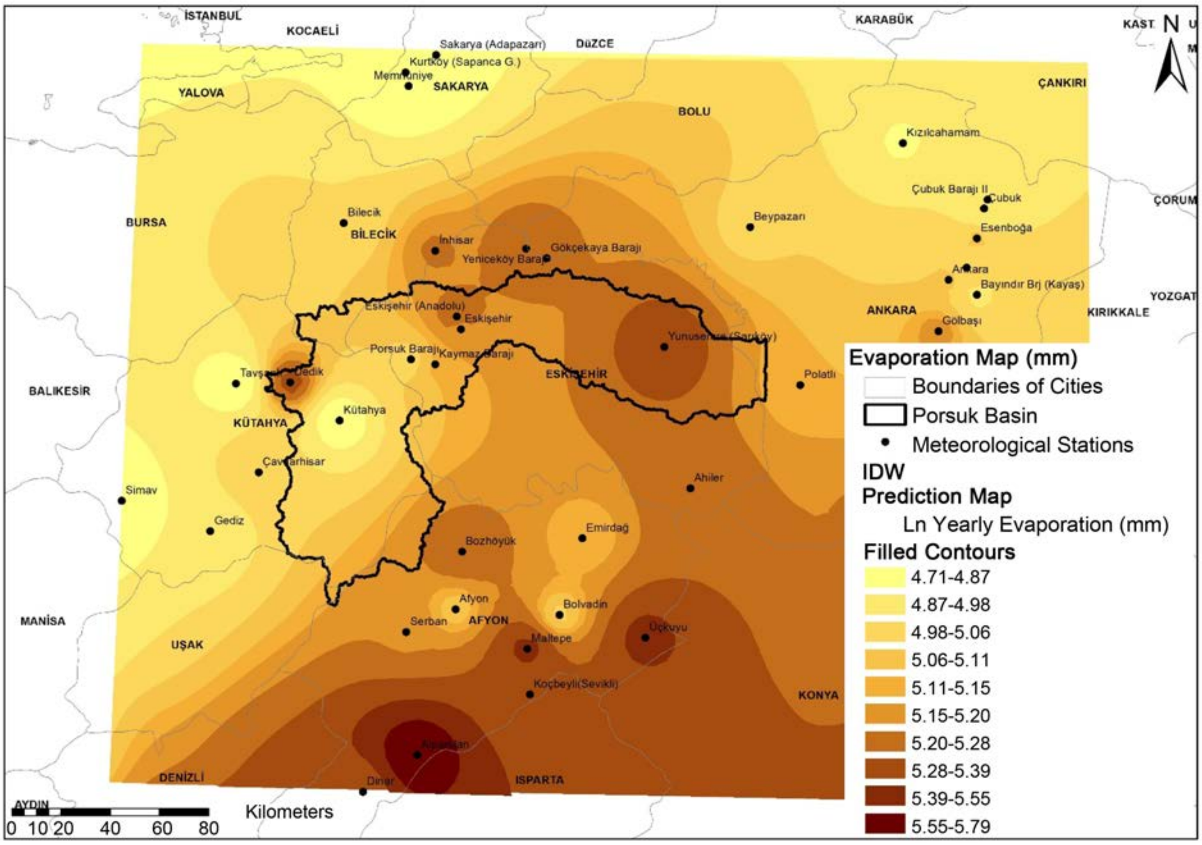
$$\gamma(s) = \frac{1}{2n(s)} \sum_{S_{ij}}^{n(s)} N(x_i y_i) - N(x_j, y_j)^2 \quad (11)$$


Precipitation Map (mm)
Boundaries of Cities
Porsuk Watershed
Meteorological Stations
IDW
Prediction Map
Log Yearly Precipitation (mm)
Filled Contours
2.45-2.51
2.51-2.55
2.55-2.58
2.58-2.60
2.60-2.63
2.63-2.67
2.67-2.73
2.73-2.81
2.81-2.93
2.93-3.10
Kilometers
0 12.5 25 50 75 100
TEKİRDAĞ
İSTANBUL
BARTIN
ZONGULDAK
KARABÜK
KASTAMONU
KOCAELİ
DÜZCE
SAKARYA
YALOVA
BOLU
ÇANKIRI
ÇORUM
BURSA
BİLECİK
ANKARA
KIRIKKALE
YOZGAT
BALIKESİR
ESKİŞEHİR
KÜTAHYA
MANİSA
UŞAK
AFYON
İZMİR
KONYA
DENİZLİ
ISPARTA
AYDIN
BURDUR

(a)


Temperature Map (°C)
Boundaries of Cities
Porsuk Watershed
Meteorological Stations
IDW
Prediction Map
Yearly Temperature (°C)
Filled Contours
7.19-8.44
8.44-9.40
9.40-10.15
10.15-10.72
10.72-11.16
11.16-11.50
11.50-11.95
11.95-12.52
12.52-13.26
13.26-14.23
Kilometers
0 12.5 25 50 75 100
İSTANBUL
KOCAELİ
DÜZCE
KARABÜK
KASTAMONU
YALOVA
SAKARYA
BOLU
ÇANKIRI
ÇORUM
BURSA
BİLECİK
ANKARA
KIRIKKALE
YOZGAT
BALIKESİR
ESKİŞEHİR
KÜTAHYA
MANİSA
UŞAK
AFYON
İZMİR
KONYA
DENİZLİ
ISPARTA
AYDIN
BURDUR

(b)



(c)

Figure 6. (a)-(c) Distribution model of data by IDW method. (a) Log precipitation distribution by IDW method. (b) Temperature distribution with IDW Method. (c) ln evaporation distribution with IDW method.

$$S_{ij} = \sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2} \tag{12}$$

S_{ij} = Horizontal distance between *i* and *j* points.

$n(s)$ = Number of point pairs at distance *s*;

N_i = Geodesic undulation in point I;

N_j = Geodesic undulation in point I;

$\gamma(s)$ = S semiparametric value;

The necessary rules to be taken into account when calculating the semi-variogram are [16] [17]:

1) There must be enough sample pairs for the distance between the samples to be used in the calculations.

2) Since there cannot be enough sample pairs in the hand, it is necessary to calculate the variance diagram for the half of the longest edge of the land.

3) In cases where irregular sampling is performed, it is necessary to take the smallest sample interval as an initial value when calculating.

Theoretically, when $s = 0$, the value of the variogram is equal to zero [$\gamma_{(0)} = 0$]. There is a limit value that can be determined from the distance dependent change, which is the distance between the two closest samples. In practice, the

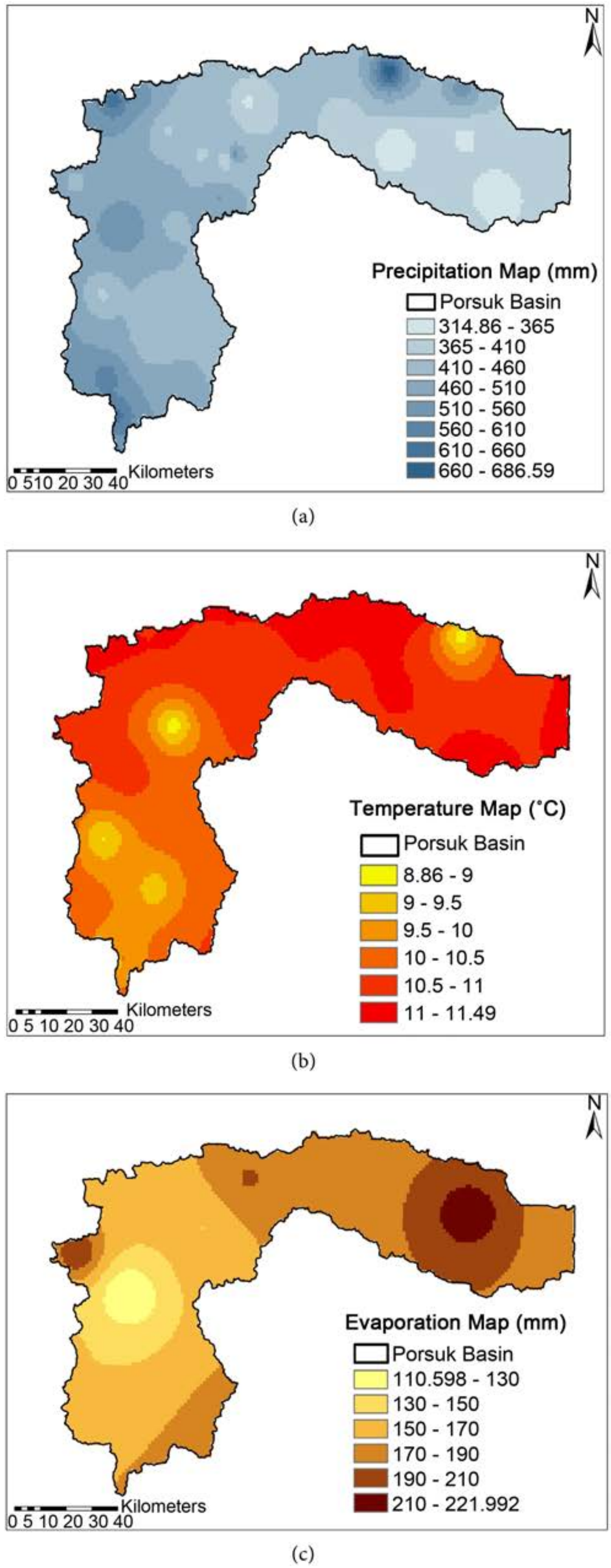


Figure 7. (a)-(c) Rainfall, temperature and evaporation distribution maps prepared by applying IDW method of Porsuk Basin. (a) Precipitation map. (b) Temperature map. (c) Evaporation map.

Table 3. Real and calculated values of rainfall control stations.

STATION NAME	MEASURED LOG PRECIPITATION VALUE (mm)	CALCULATED VALUE	ERROR
		IDW	
4437-Ümraniye	2.533454	2.608392	0.074938045
5466-Hocalar	2.661311	2.703292	0.041980734
6671-Dazkırı	2.598275	2.677013	0.078738536
6843-Başmakçı	2.521119	2.673091	0.151971227
11-011-Üçkuyu	2.482522	2.661763	0.179241043
2992-Sarıyar	2.532435	2.638344	0.105908302
3920-Bala	2.627451	2.606468	−0.020983356
12-008-Çağa	2.585554	2.612541	0.026987383
12-034-Karapürçekli	2.645376	2.61098	−0.034396082
12-060-Çalseki	2.676402	2.618173	−0.058229379
2354-Gölpazarı	2.686786	2.741485	0.054698918
2707-Yenipazar	2.659831	2.691772	0.031940775
3530-Beylikahır	2.49799	2.636779	0.138789285
3899-Mahmudiye	2.515543	2.629744	0.11420091
4257-Çifteler	2.543572	2.595262	0.051690002
17706-Eskişehir	2.570368	2.601006	0.030638474
17726-Sivrihisar	2.607603	2.561625	−0.045977767
12-017-Yörme (Gümüşkonak)	2.584371	2.563882	−0.020488916
12-020-Karakaya	2.592123	2.608154	0.016031167
12-055-Yukarı Kartal	2.622784	2.647065	0.024281706
12-063-Kaymaz Barajı	2.559511	2.704239	0.144728439
4423-Aslanapa	2.602326	2.704016	0.101689901
03-026-Cebrail	2.93984	2.825682	−0.114158209
05-004-Göynükören	2.69653	2.7665	0.069970305
12-012-Doğular	2.649215	2.671991	0.022776043
12-058-Oysu	2.767052	2.717811	−0.049241686
17069-Sakarya (Adapazarı)	2.916222	2.951641	0.035419255
	Mean Square Error (MSE)		0.08221

change of the difference between the values cannot be determined at a smaller distance than this distance, which leads to a discontinuity in the origin of the variogram. One reason for discontinuity is sampling and analysis mistakes. In the variogram, this is indicated as "nugget effect" C_0. This value is also called the uncontrolled variance of effects [15] [18]. It does not affect the estimate value.

Table 4. Actual and calculated values of temperature measuring control stations.

STATION NAME	MEASURED TEMPERATURE (˚C)	CALCULATED VALUE	ERROR
		IDW	
4437-Ümraniye	10.14226	10.99191	0.849644078
17185-Uşak Meydan	12.53458	11.02207	−1.512515026
1886-Güvem	8.033796	10.24181	2.208015733
2042-Çamlıdere	8.709537	10.29777	1.588237307
3182-Elmadağ	10.11424	10.73265	0.618415242
3731-Ikızce	10.01083	10.73928	0.728442802
3920-Bala	8.958552	10.96431	2.005753968
4982-Şereflikoçhisar	12.4041	12.99925	0.59514217
17711-Elmadağ	10.91806	10.73265	−0.185404203
2351-Osmaneli	14.18643	12.24579	−1.940636351
17701-Pazaryeri	12.14319	10.29287	−1.850323459
17702-Bozüyük	10.64808	11.40021	0.752125903
3530-Beylikahır	11.09236	10.86663	−0.225731364
17123-Eskişehir (Anadolu)	10.75778	10.96861	0.210831497
17723-Çifteler	11.28875	10.29495	−0.993801389
17155-Kütahya	10.67912	10.57766	−0.101466833
1863-Doğançay (Geyve)	13.6713	13.38929	−0.282005481
Mean Square Error (MSE)			1.204414

Table 5. Actual and calculated values of evaporation control stations.

STATION NAME	MEASURED LN EVAPORATION AMOUNT (mm)	CALCULATED VALUE	ERROR
		IDW	
17752-Emirdağ	5.078269	5.22072	0.142455099
17862-Dinar	5.274596	5.21786	−0.056731492
07-027-Alparslan	5.794077	5.2377	−0.556376588
17680-Beypazarı	5.021803	5.12606	0.10425682
12-030-Bayındır Brj (Kayaş)	4.947599	5.05591	0.108313341
17123-Eskişehir (Anadolu)	5.281088	5.15623	−0.124860661
17155-Kütahya	4.704643	5.12474	0.420093136
12-061-Memnuniye	4.73533	4.76994	0.034609451
Mean Square Error (MSE)			0.261948

Only change in the Kriging variance is caused [14] [19].

The spatial variable variogram stops incrementing after a certain distance, and the peak variance (sill, sill) begins to take values around the value "$C_0 + C$". The distance domain (structural distance, range) where it reaches the threshold value of the variogram is called "a". For larger distances than this particular distance, the positional dependence comes to an end [11] [14]. The determination of the experimental variogram structure of observational data and the fitting of a theoretical model to this variogram form the basis of geostatistical studies [11] [20] [21] [22]. The most common variogram models used in geostatistics are shown in **Table 6**. The parameters forming the variogram models are shown in **Table 7**.

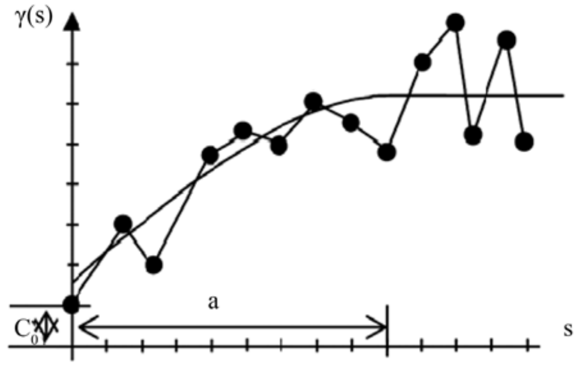


Figure 8. Variogram plot and parameters.

Table 6. Various variogram models [23].

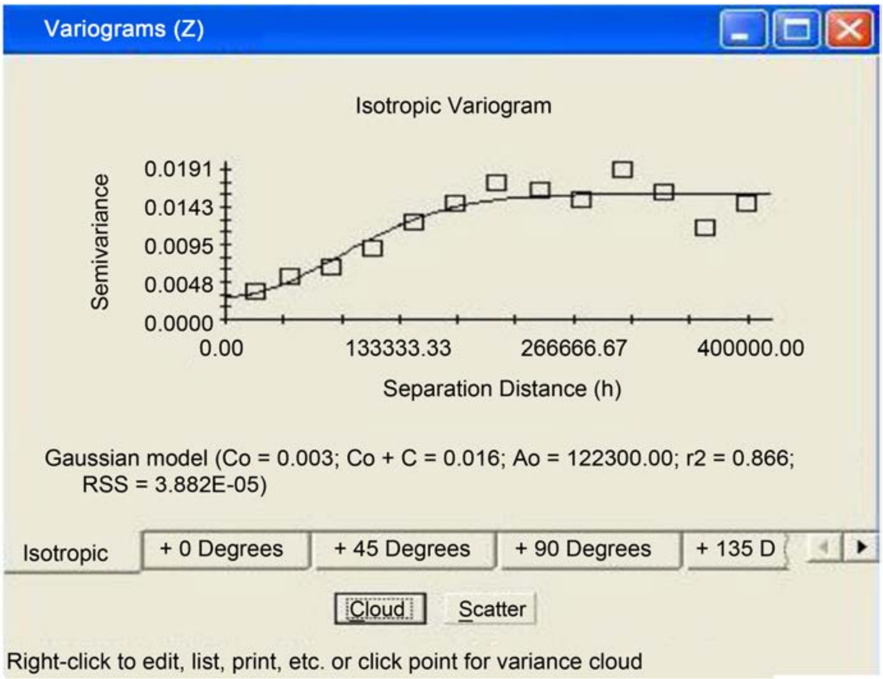
Variogram model	Function	State
Gauss	$\gamma(s) = C_0 + C\left(1 - \exp\left(\frac{-S^2}{a^2}\right)\right)$	
Exponential	$\gamma(s) = C_0 + C\left(1 - \exp\left(\frac{-S}{a}\right)\right)$	
Global	$\gamma(s) = C_0 + C\left(\left(\frac{3S}{2a}\right) - \left(\frac{S^3}{2a^3}\right)\right)$	$(0 \le s \le a)$
	$\gamma(s) = C_0 + C$	$s > a$
Linear	$\gamma(s) = C_0 + C \cdot S$	
Logarithmic	$\gamma(s) = C_0 + C \cdot \log(s)$	$(s > 0)$

Table 7. Variogram parameters.

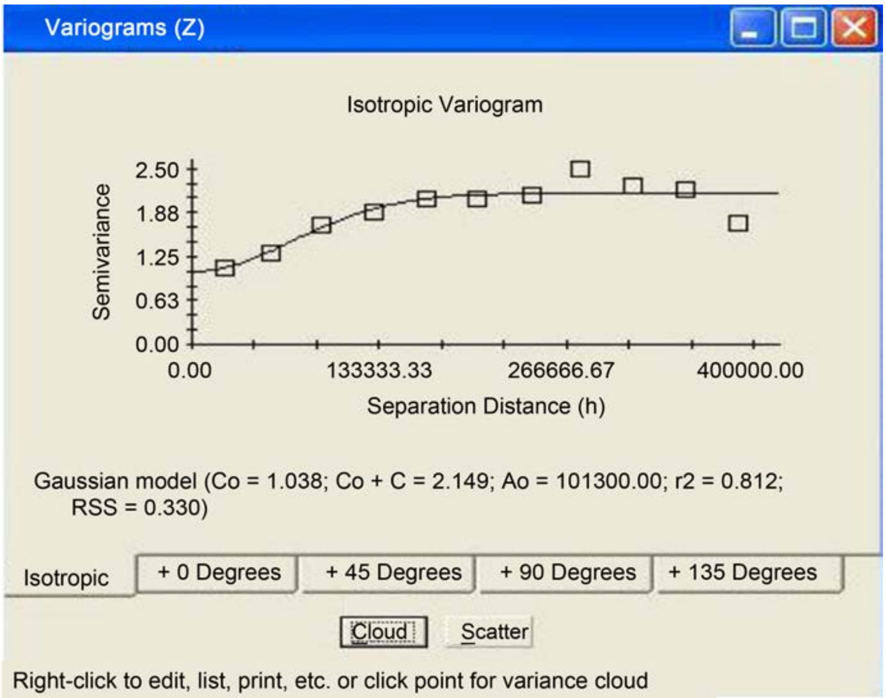
	Active Lag Distance	Lag Class Distance (Uniform Interval)	Isotropy	Model Type	Nugget Variance (C_0)	Sill ($C_0 + C$)	Range (A)
ln evaporation	300,000.00	15,000.00	Isotropic	Spherical	0.0037	0.0415	49,010.290
temperature	400,000.00	37,000.00	Isotropic	Gaussian	1.0380	2.1490	101,300.432
log precipitation	400,000.00	32,000.00	Isotropic	Gaussian	0.002850	0.01590	122,300.013

Semi-variogram model was created with GS + (Gamma Software) software. The variograms for precipitation, temperature and evaporation are shown in Figures 9(a)-(c).

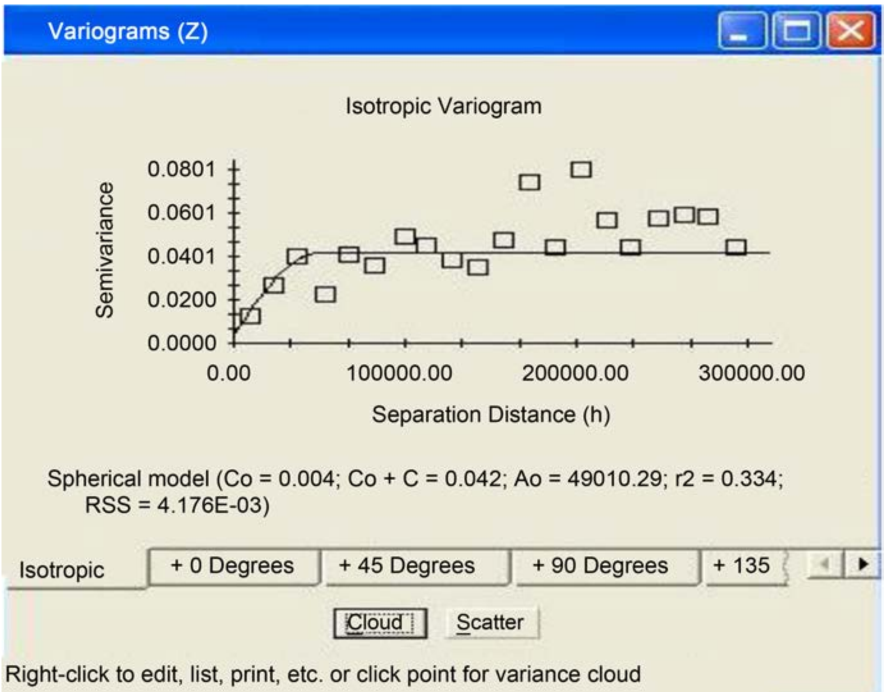
The variogram parameters were transferred to the GSI environment and the Ordinary Kriging method was used to interpolate the variogram parameters. As a result of this method, distribution maps are shown in Figure 10.



(a)

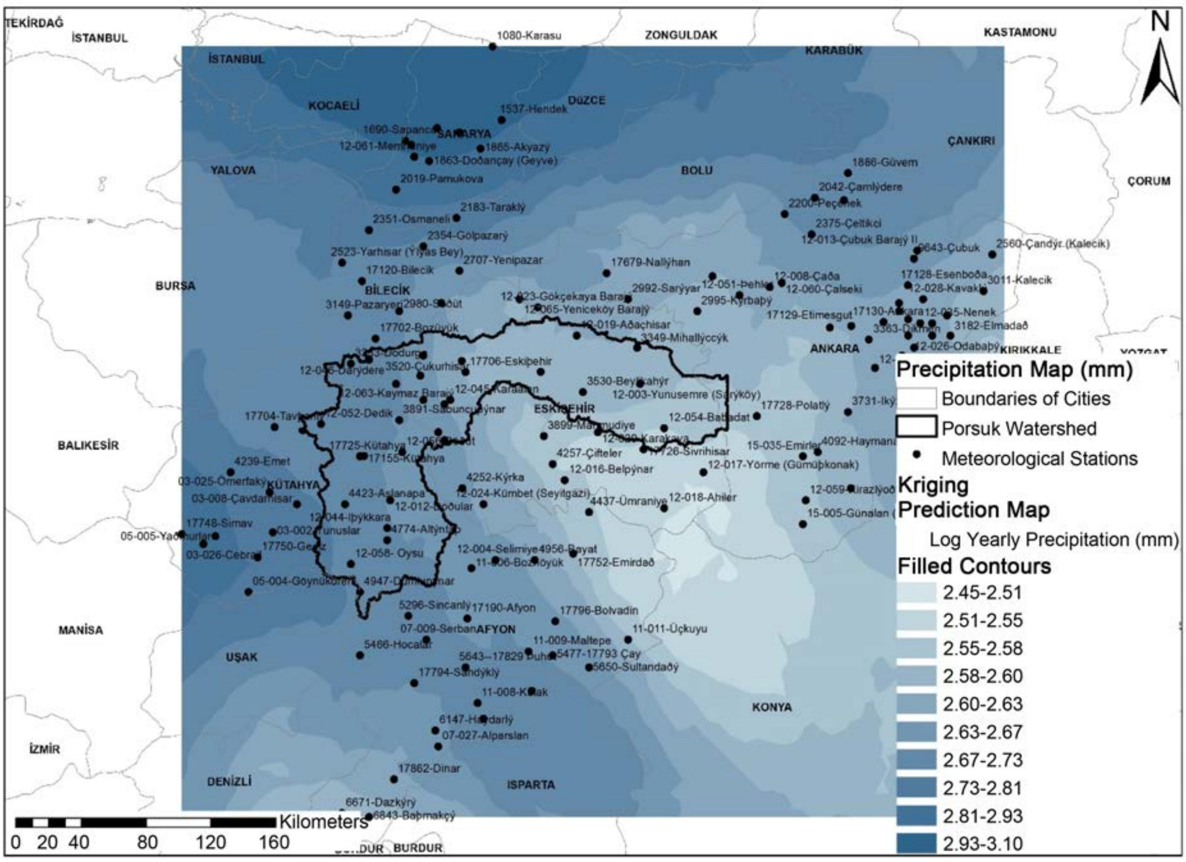


(b)

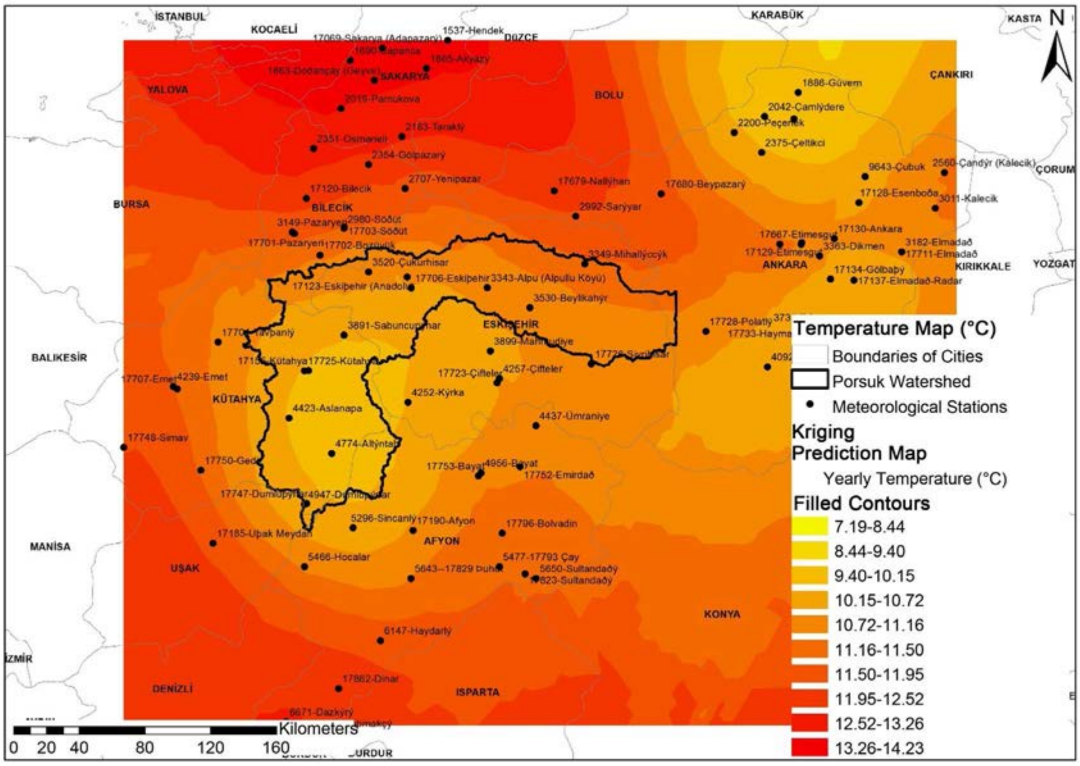


(c)

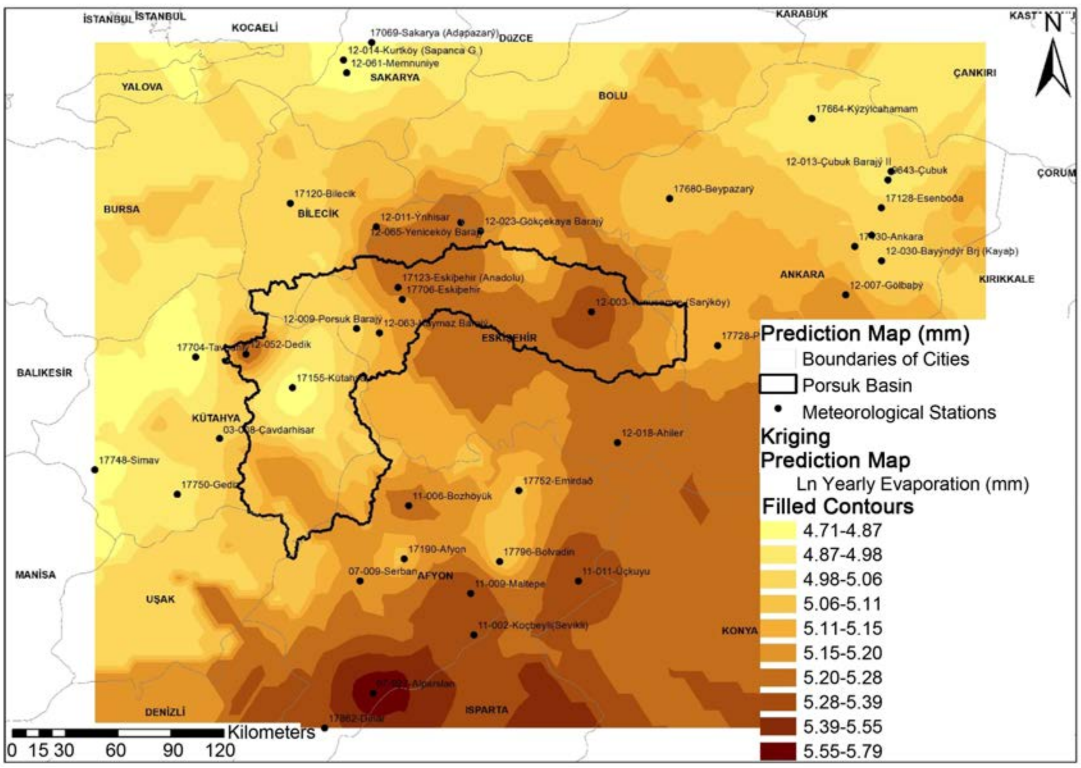
Figure 9. Variogram models for precipitation, temperature and evaporation distribution models.



(a)



(b)



(c)

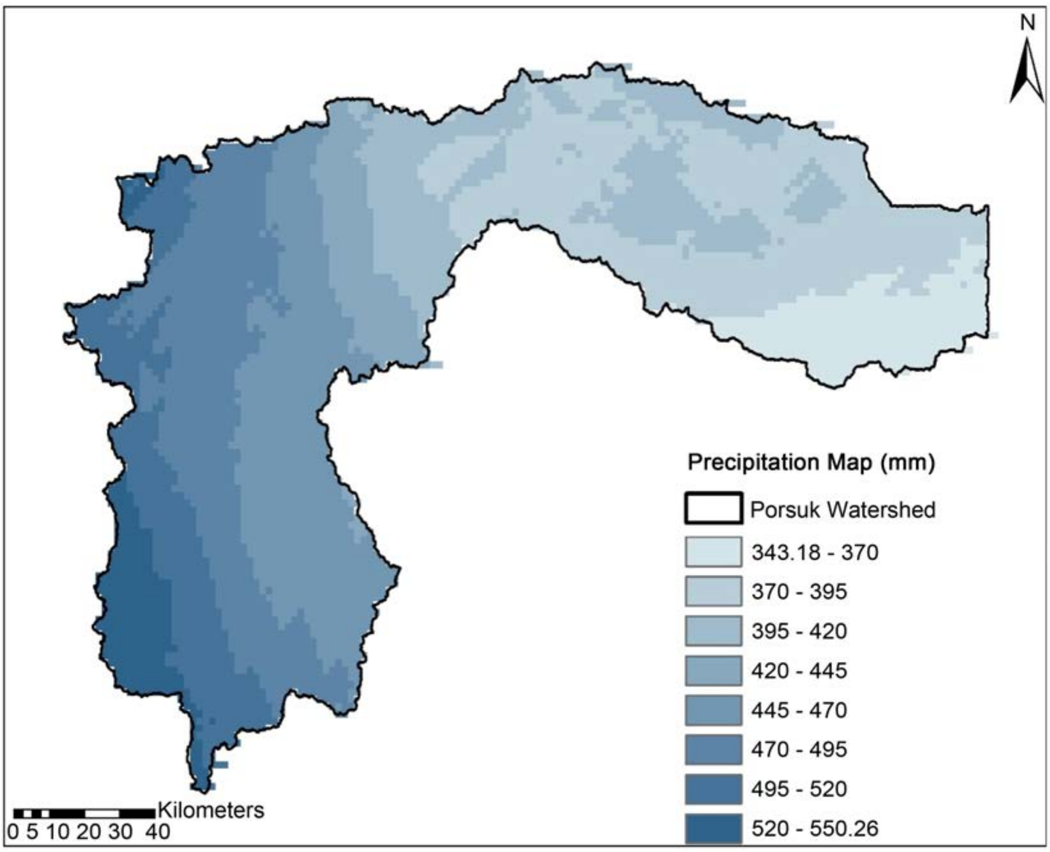
Figure 10. (a)-(c) Ordinary Kriging model of data distribution. (a) Log precipitation distribution by Ordinary Kriging method. (b) Temperature distribution by Ordinary Kriging method. (c) Ln evaporation distribution by Ordinary Kriging method.

As we have already done in the IDW method, maps obtained after the estimation are converted into real meteorological values by the raster calculator command (Figures 11(a)-(c)).

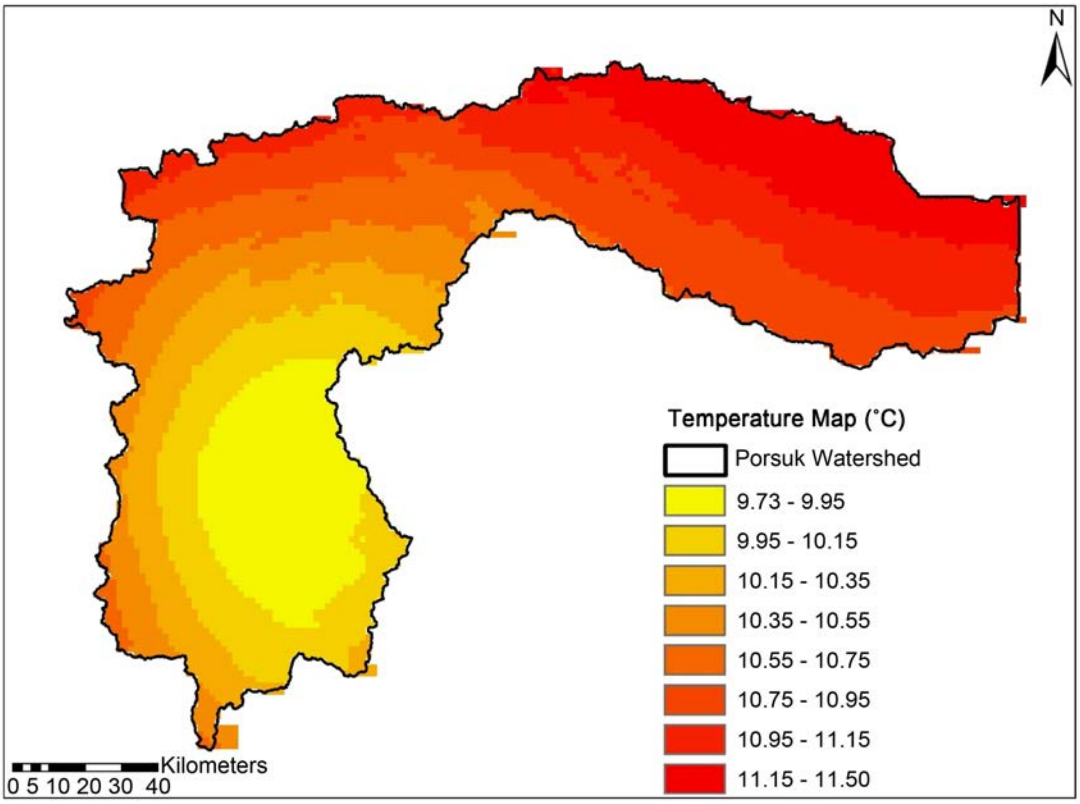
Accuracy Analysis of Ordinary Kriging Method

Randomly selected meteorological observation stations with appropriate spatial distribution to determine the accuracy of the predictions, such as accuracy analysis after IDW interpolation, were selected as control points and precipitation, temperature, evaporation distributions were applied by Ordinary Kriging interpolation method without this data. The actual and estimated results of the selected control stations are compared with 20% of the number of existing stations and the mean square error (MSE) is determined (Tables 8-10).

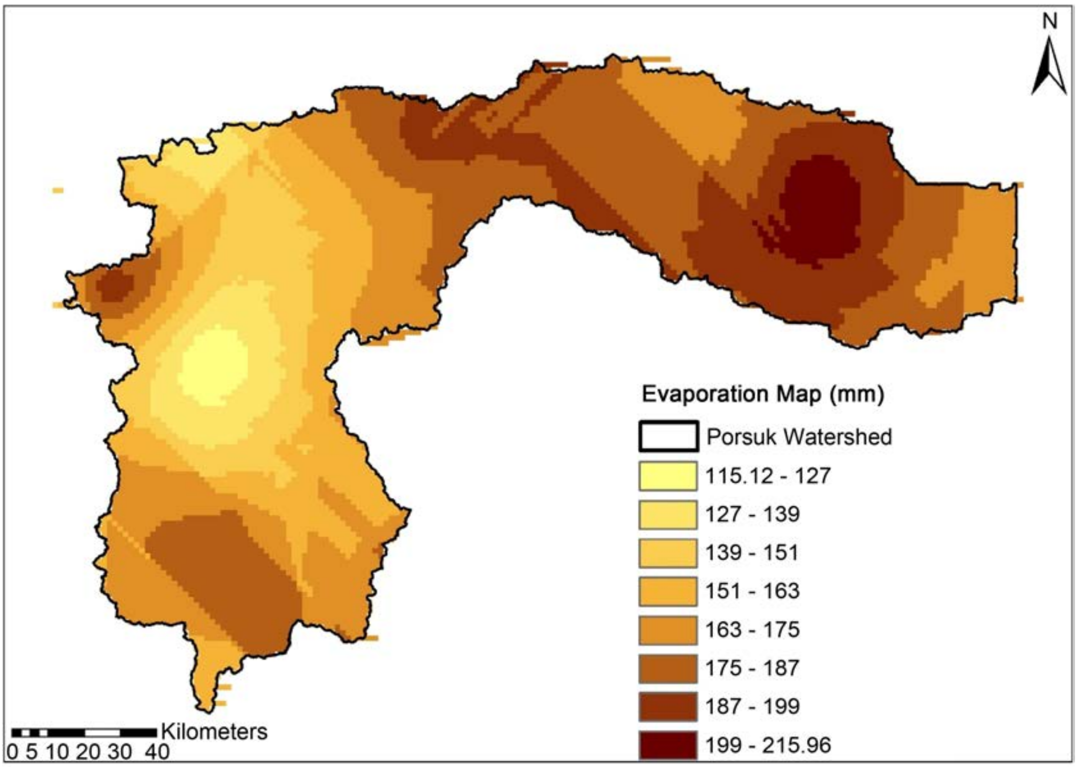
The accuracy of the estimates is also dependent on the location of the selected control stations during the accuracy analysis as well as the location in the general data group of the measured value made at that station, and also the distribution of the data source points to the distribution in the working area. If the control station data contains the largest or smallest value of the data set, or if the position of this station is close to the working area, it will not be possible to calculate this station value with high accuracy using other station data. For this reason, determining the control stations during the accuracy analysis is an important component for the correct evaluation of the results of the study.



(a)



(b)



(c)

Figure 11. (a)-(c) Precipitation, temperature and evaporation distribution maps generated by applying Ordinary Kriging method of Porsuk Basin. (a) Precipitation map. (b) Temperature map. (c) Evaporation map.

Table 8. Real and calculated values of rainfall control stations.

STATION NAME	MEASURED LOG PRECIPITATIONAMOUNT (mm)	CALCULATED VALUE ORDINARY KRIGING	ERROR
4437-Ümraniye	2.533454	2.533454	2.55478
5466-Hocalar	2.661311	2.661311	2.75047
6671-Dazkırı	2.598275	2.598275	2.68116
6843-Başmakçı	2.521119	2.521119	2.66462
11-011-Üçkuyu	2.482522	2.482522	2.64775
2992-Sarıyar	2.532435	2.532435	2.64219
3920-Bala	2.627451	2.627451	2.61563
12-008-Çağa	2.585554	2.585554	2.60771
12-034-Karapürçekli	2.645376	2.645376	2.60971
12-060-Çalseki	2.676402	2.676402	2.61244
2354-Gölpazarı	2.686786	2.686786	2.7145
2707-Yenipazar	2.659831	2.659831	2.65552
3530-Beylikahır	2.49799	2.49799	2.61173
3899-Mahmudiye	2.515543	2.515543	2.6172
4257-Çifteler	2.543572	2.543572	2.59441
17706-Eskişehir	2.570368	2.570368	2.6314
17726-Sivrihisar	2.607603	2.607603	2.52519
12-017-Yörme (Gümüşkonak)	2.584371	2.584371	2.50169
12-020-Karakaya	2.592123	2.592123	2.57604
12-055-Yukarı Kartal	2.622784	2.622784	2.65723
12-063-Kaymaz Barajı	2.559511	2.559511	2.64336
4423-Aslanapa	2.602326	2.602326	2.72733
03-026-Cebrail	2.93984	2.93984	2.83435
05-004-Göynükören	2.69653	2.69653	2.82895
12-012-Doğular	2.649215	2.649215	2.68244
12-058-Oysu	2.767052	2.767052	2.74893
17069-Sakarya (Adapazarı)	2.916222	2.916222	2.99317
MEAN SQUARE ERROR (MSE)			0.082847

8. Conclusion

As a result of the accuracy analyses, the squared mean error values of the estimation

Table 9. Actual and calculated values of temperature measuring control stations.

STATION NAME	MEASURED TEMPERATURE (˚C)	CALCULATED VALUE	ERROR
		IDW	
4437-Ümraniye	10.14226	11.0492	0.906925868
17185-Uşak Meydan	12.53458	11.4643	−1.070295047
1886-Güvem	8.033796	10.296	2.262191485
2042-Çamlıdere	8.709537	10.4733	1.763781159
3182-Elmadağ	10.11424	10.9706	0.856336969
3731-Ikızce	10.01083	10.5108	0.499976773
3920-Bala	8.958552	10.6035	1.644971284
4982-Şereflikoçhisar	12.4041	12.1076	−0.29650336
17711-Elmadağ	10.91806	10.9706	0.052517524
2351-Osmaneli	14.18643	12.4111	−1.77529364
17701-Pazaryeri	12.14319	11.3976	−0.745558325
17702-Bozüyük	10.64808	11.1254	0.477338821
3530-Beylikahır	11.09236	10.8009	−0.291496565
17123-Eskişehir (Anadolu)	10.75778	10.7332	−0.024605504
17723-Çifteler	11.28875	10.6448	−0.643942705
17155-Kütahya	10.67912	9.94927	−0.729856473
1863-Doğançay (Geyve)	13.6713	13.2538	−0.417508072
Mean Square Error (MSE)			1.060494

results obtained according to the IDW and Ordinary Kriging method are closest to zero (0) as compared to other methods, as seen in **Table 11**. In order for the estimation method to be able to produce a reliable result, the data to be used in estimation must first be statistically evaluated. In the study, the meteorological data were analyzed statistically and the values which did not show normal distribution were normalized. Then the normalized data sets are modeled by weighting with the inverse of distance. Estimation results obtained according to normalized values need to be converted to their real values, since they do not have real values. For this purpose, pixel based recycling process has been applied in order to return the data to real values using raster calculator. The accuracy of the obtained models is an important parameter in terms of the reliability of this study. For this reason, accuracy analysis is performed on the models and it is observed that the quadratic mean error values are close to zero. The fact

Table 10. Actual and calculated values of evaporation control stations.

STATION NAME	MEASURED LN EVAPORATION AMOUNT (mm)	CALCULATED VALUE	ERROR
		ORDINARY KRIGING	
17752-Emirdağ	5.078269	5.2129	0.134670127
17862-Dinar	5.274596	5.2469	−0.02773521
07-027-Alparslan	5.794077	5.1585	−0.635568535
17680-Beypazarı	5.021803	5.1468	0.124990475
12-030-Bayındır Brj (Kayaş)	4.947599	5.0925	0.144879268
17123-Eskişehir (Anadolu)	5.281088	5.1671	−0.113942937
17155-Kütahya	4.704643	5.1692	0.464591479
12-061-Memnuniye	4.73533	4.8429	0.107615363
Mean Square Error (MSE)			0.295777

Table 11. MSM values according to IDW and Ordinary Kriging method.

	IDW	OK (Ordinary Kriging)
log precipitation	0.08221	0.082847
Temperature	1.204414	1.066494
ln evaporation	0.261948	0.295777
Arithmetic Mean of Quadratic Mean Errors	0.51619	0.48706

that the square mean error values are close to zero is an indication that the accuracy of the obtained models is high and reliable.

Acknowledgements

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