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EVALUATION OF KRIGING WITH EXTERNAL DRIFT METHOD IN SPATIAL MODELLING OF PRECIPITATION: A CASE OF AEGEAN REGION, TURKEY

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Abstract

The structures and geographical formations observed in the Aegean region of Turkey differ from the other coastal regions of the country. Especially, elevation and aspect have different characteristics in this region. Thus, the precipitation conditions are influenced and the annual precipitation amounts observed in the plains are not consistent. In this study, Kriging with External Drift was applied to obtain a prediction map of precipitation in the Aegean region. Annual mean total precipitation data obtained from 36 stations (1976–2010) were used. Elevation was used as a secondary variable in Kriging with External Drift calculations. The R^2 of 0.35 shows that at least one quarter of the precipitation behaviour can be explained by the model. A distribution that complies with the orographic extension draws attention in the Kriging with External Drift precipitation estimation map. The results show that Kriging with External Drift and incorporation of elevation as a secondary variable could be used to supplement sparse observations in the mapping of precipitation.

Keywords: Precipitation, elevation, geostatistics, kriging with external drift

YAĞIŞIN MEKÂNSAL OLARAK MODELLENMESİNDE KRIGING WITH EXTERNAL DRIFT YÖNTEMİNİN DEĞERLENDİRİLMESİ: EGE BÖLGESİ

Öz

Ege Bölgesi’nde görülen coğrafi oluşumlar ve yapılar, Türkiye’nin diğer kıyı bölgerinden farklılık göstermektedir. Özellikle bu bölgedeki yükseklik ve bakı, farklı karekteristiklere sahiptir. Bu nedenle, yağış durumu etkilenmektedir ve düzlük alanlarda görülen yıllık yağış miktarlarında bir istikrar gözlenmemektedir. Bu çalışmada, Ege Bölgesi’nde yağış haritası tahmini için Kriging with External Drift yöntemi kullanılmıştır. Çalışmada 36 istasyonda 1976–2010 yıllarında ölçülmüş aylık ortalama yağış değerlerinden elde edilen yıllık toplam yağış verisi kullanılmıştır. Yağış tahmininde yardımcı değişken olarak yükseklik verisinden yararlanılmıştır. Kriging with External Drift yağış tahmin haritasında orografik uzanımlar ile uyumlu bir dağılım dikkat çekmektedir. Sonuçlar, yüksekliğin yardımcı değişken olarak kullanıldığı Kriging with External Drift analizinin seyrek gözlemlerin olduğu yerlerin yağış haritalarının oluşturulmasına yardımcı bir yöntem olduğunu göstermiştir.

Anahtar Kavramlar: Yağış, yükseklik, jeoistatistik, kriging with external drift

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Introduction

Evaluating the spatial distribution of precipitation is indispensable for water resource management, hydrologic analysis and designs, ecologic modelling and irrigation scheduling. However, spatial distribution of precipitation is more complicated in mountainous regions because patterns are influenced by large changes in topographical relief over relatively short distances. The ability to accurately characterize variable precipitation patterns requires a dense network of gauges. Indeed, inadequate and heterogeneous horizontal or vertical distribution of a meteorological observation network also makes it difficult to fully assess the precipitation distribution. Thus, these factors might hamper the ability to obtain accurate information about the precipitation distribution of the region.

A variety of spatial interpolation techniques ranging from simple to more complex were developed for the estimation of the precipitation values. Conventional interpolation approaches are methods like Thiessen Polygon, Spline and Inverse Distance Weight (IDW). Beside conventional approaches, more sophisticated methods such as geostatistical methods are used for precipitation estimation. Geostatistics is based on the theory of regionalized variables and provides a set of statistical tools for incorporating the spatial correlation of observations in data processing (Goovaerts 1997). It is increasingly preferred as it allows one to capitalize on the spatial correlation between neighbouring observations to predict values at unsampled locations (Goovaerts 2000). Various studies have shown that estimation of precipitation using geostatistical tools produces better results than conventional methods (Philips et al. 1992; Goovaerts 2000; Buytaert et al. 2006; Tobin et al. 2011; Aydın and Çiçek 2013; Silva and Simões 2014). Another advantage of geostatistics is that the inclusion of secondary attributes (e.g., weather radar data, elevation) with sampled measurements of the primary attribute (e.g., precipitation) can be used to improve precipitation estimation (Mair and Fares 2011). Some researchers used elevation alone as an auxiliary variable (Phillips et al. 1992; Wotling et al. 2000; Lloyd 2005; Lloyd 2010). Other researchers used some other auxiliary variables along with elevation that might affect precipitation, such as aspect, slope, land use, distance from the sea, solar radiation, temperature, wind and humidity (Hutchinson 1998; Kieffer Weisse and Bois 2002; Boer et al. 2001; Kyriakidis 2001; Hofierka et al. 2002; Diodato 2005; Yin et al. 2008; Apaydin et al. 2011; Hession and Moore 2011). In these studies, it was stated that models generated with the help of variables that affect rainfall gave more accurate results.

Hevesi et al. (1992) reported a significant 0.75 correlation between average annual precipitation and elevation recorded at 62 stations in Nevada and south-eastern California. They used Co-kriging (CK) to incorporate elevation into the mapping of precipitation. Goovaerts (2000) made a comparison between the use of only the dependent variable (rainfall data from 36 stations) and the combination of dependent variable with secondary data (elevation). It was observed that methods allowing the incorporation of secondary variable yielded more accurate predictions. In this study, Ordinary Kriging (OK) which considers only the dependent variable, however generated more accurate results as compared to Linear Regression, which makes the use of secondary data, in the case that the correlation between precipitation and elevation is less than 0.75. Similarly Lloyd (2005) compared five interpolation techniques, namely IDW, OK, Moving Window Regression (MWR), Simple Kriging with Varying Local Means (SKlm) and Kriging with External Drift (KED), to investigate monthly precipitation in England. The last three methods which allows the use of auxiliary information were able to map the local variations of the data since elevation and precipitation vary locally.

Moral (2010) has compared the different geostatistical techniques on modelling of precipitation using monthly and annual precipitation data obtained from 136 meteorological stations in Extremadura in the southwest of Spain. For this purpose; CK, SKlm and Regression Kriging

(RK) multivariate algorithm methods using variables such as elevation plus OK, Simple Kriging (SK) and Universal Kriging (UK) methods were used. According to the cross validation results the smallest forecast errors were obtained from multivariate algorithm techniques. It has been proved that taking elevation into account in the calculations helps to create more accurate monthly and annual precipitation maps. Kumari et al. (2016) compared several spatial interpolation methods for mapping precipitation in a region of the Indian Himalayas. IDW, OK, SKlm, RK and Ordinary Cokriging (OCK) were applied using elevation or slope as auxiliary variables. The inclusion of auxiliary information improves the prediction of precipitation in the mountainous region. SKlm perform better than OCK in all the cases. The prediction using OK and OCK yields similar result when the correlation between rainfall and elevation is moderate. Elevation is accepted as the most common topographic variable used to explain spatial variations in precipitation for precipitation enhancement through orographic uplift (Qing et al. 2011). Although precipitation increases as the elevation increases, its values have shown a plateau after a certain elevation. But the increase stops after a certain elevation. This mostly changes according to the precipitation level, climate type, characteristics and frequencies of the air masses, seasons and elevation. The genetic factors of the Aegean Region's climatic conditions are related to the circulation characteristics that depend on the wide field action centres developing in the Black Sea and Eastern Mediterranean basins. Therefore, they are under the effect of the air currents that come from different environments and weather conditions that continuously change during the year. Depending on the seasonal changes, air currents that manage the climatic circumstances in the study area are also exposed to thermic and dynamic modifications due to friction, and characteristics and directions of the relief shapes on earth (Koçman 1993). Significant differences exist in the amount of annual precipitation between the places, which have different locations in terms of the elevation conditions within the region. This is especially true in mountainous regions, where spatial distributions are complex and measurement conditions difficult. Thus, it is necessary to develop methods to estimate precipitation in areas where precipitation has not been measured, using data from surrounding weather stations together with other relevant information available.

The aim of this study was to evaluate precipitation estimation across the Aegean Region using, the spatial interpolation, KED. Elevation data was used as auxiliary variable.

1. Materials and Methods

1.1. Study Area

The Aegean Region, which is located in the west of Turkey, is bordered with the Marmara Region in the north, Central Anatolian Region in the east and Mediterranean Region in the south. It comprises 11% of the country's area with an area of 79.000 km^2. The region is divided into two parts as the Aegean Section and the Hinterland Section of the Western Anatolian (Figure 1). The region consists of eight cities: Izmir, Manisa, Denizli, Aydın, Muğla, Afyon, Uşak and Kütahya (Figure 1). Generally, the disintegration and separation of the high topography, which runs perpendicular to the coast, with east-west directional plains leading to a more diverse and very indented coast across the Aegean Region. Observed as per the characteristics of the structures and geographical formations, this situation caused this region to differ from the other coastal regions of the country and it is the region, which has the longest coastal line of Turkey. The average elevation in the region is 715 m. The elevation is in excess of 1000 m in the Hinterland Section of the Western Anatolian, but does not reach 400 m in the Aegean Section. Although the elevation variation is high in the Aegean Section, it is low compared to Turkey and the overall region. The Aegean Region is under the effect of the Mediterranean climate, which is identified with hot and arid summers, and mild and rainy winters. Great climatic contrasts, which are caused by the mountains parallel to the coast in places close to each other in the Black Sea and Mediterranean regions, are not observed here (Darkot and Tuncel 1988). Three sections can be selected for the Aegean Region, where the climate presents more or less differences compared to each other: 1) the Aegean coasts where the whole Mediterranean climate is dominant, 2) the plains of the Aegean Section, bases of which are not much higher than the sea surface, and the summer and winter temperature differences increase a bit more than the coast, 3) the Hinterland threshold of the Western Anatolia, which has a high base and more differences between the summer-winter temperatures (Darkot and Tuncel 1988). Moreover, the location of the plains and the elevation and aspect conditions surrounding them have different characteristics in the region. Due to these characteristics, the precipitation conditions and the annual precipitation amounts in the plains are different from each other (Koçman 1993).

1.2. The Data Set Used in Study

In the study, annual mean total precipitation data of 1975–2010, which were obtained from 36 meteorological stations that made long-term precipitation observations, were used to determine the annual mean total precipitation pattern of the Aegean Region. The data were received from the General Directorate of Meteorology. Although there were a lot of active meteorology stations, stations that made measurements for a period of 36 years were selected and annual mean precipitation values were calculated. The Lambert Conformal Conic projection system of the station locations were set as Datum European 1950 (ED50). The locations of the meteorological stations, which were used in this study, are shown in Figure 1. The Digital Elevation Model (DEM) is another significant variable used in the study. The Shuttle Radar Topography Mission (SRTM) was obtained from the satellite data. Each grid cell represents 1 km^2. Figure 2 shows the correlation between precipitation and elevation. It seems worth accounting for this exhaustive secondary information into the mapping of precipitation. When the whole region is reviewed, it is observed that precipitation is high in the low coastal section (Coastal Aegean) and precipitation is low in the high Hinterland of the Western Anatolia. In this study, the database was created and displayed using ArcGIS 10.1 (ESRI, Redlands, CA) software; further exploratory and geostatistical analyses were performed using an open source software, R 3.1.0 (Ihaka and Gentleman, Auckland, New Zealand) and gstat package (Pebesma and Wesseling 1998; Pebesma 2004; Bivand et al. 2008).

Figure 1: *Annual mean total precipitation of Aegean Region, Turkey measured at 36 meteorological stations from 1976 to 2010 displayed over the region elevation map*

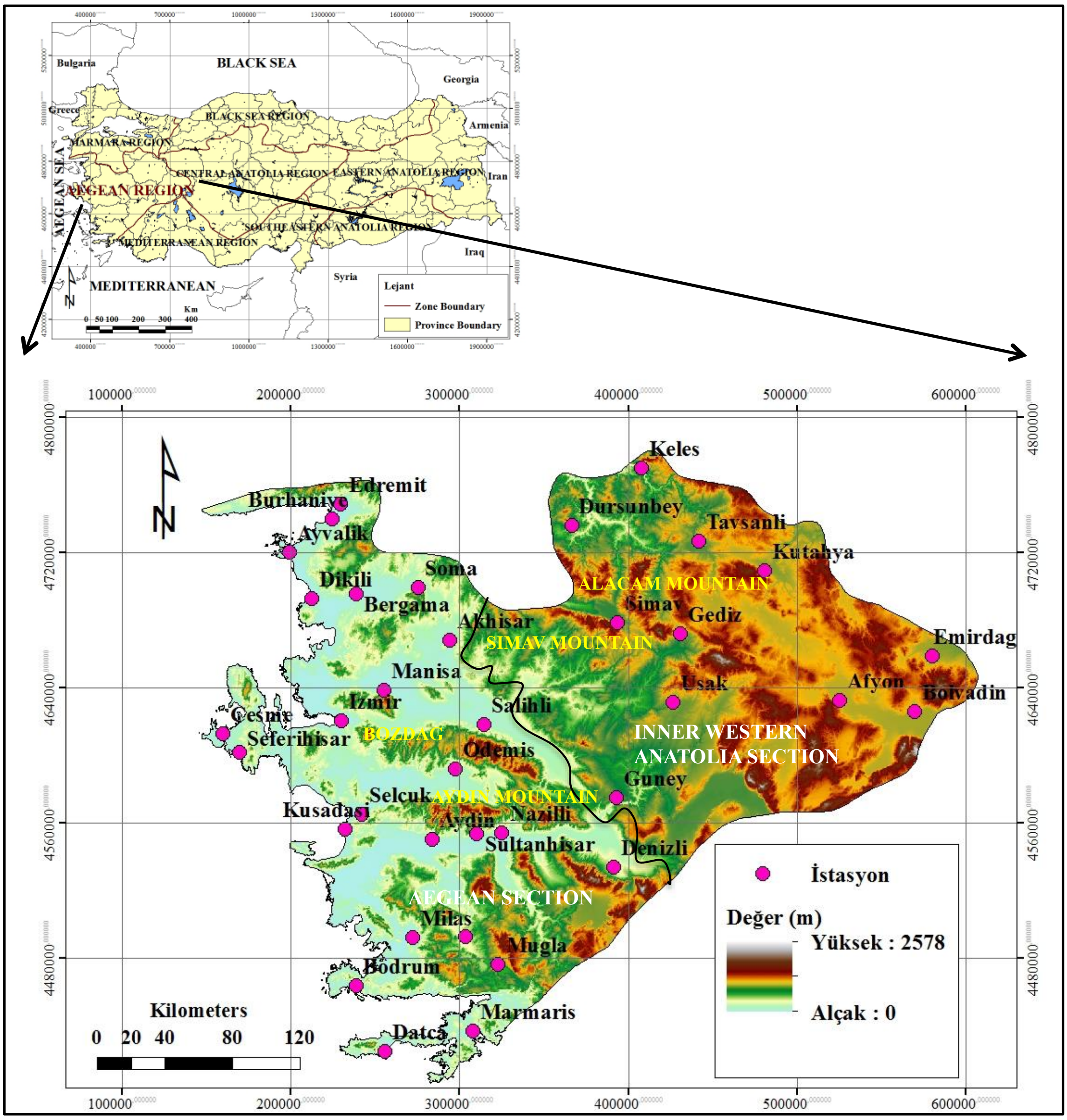
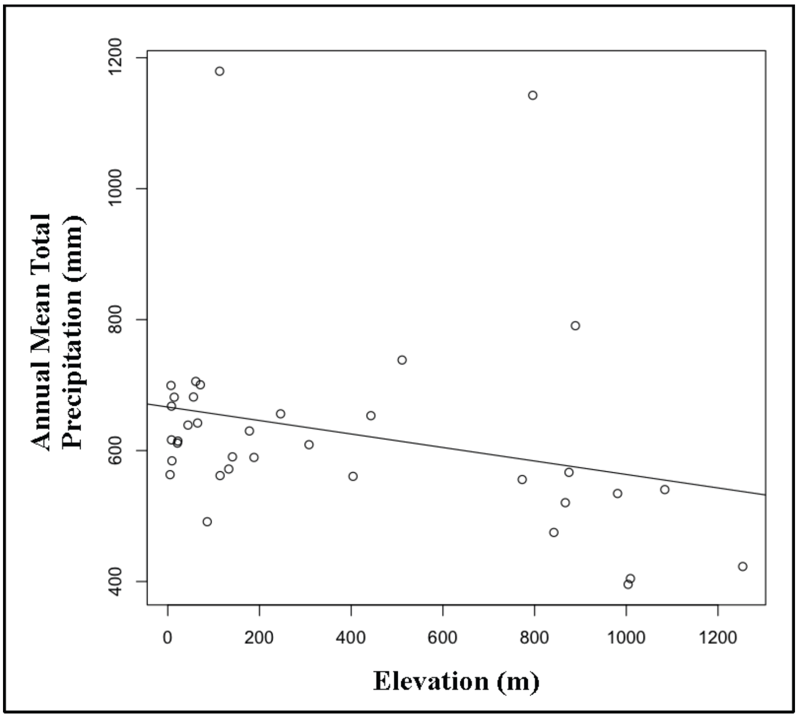


Figure 2: *Correlation of the annual mean total precipitation and elevation*



1.3. Geostatistics Technique

1.3.1. Semivariogram analysis

Geostatistical methods operate under the assumption that values at close locations tend to be more similar. Semivariogram is one of the most essential tools in geostatistical analysis to quantify this change in correlation with increasing distance. The semivariogram is defined as half the variance of the increment in the random function (Bivand et al. 2008).

$$\gamma(h) = \frac{1}{2}E\big(Z(X) - Z(X+h)\big)^2$$

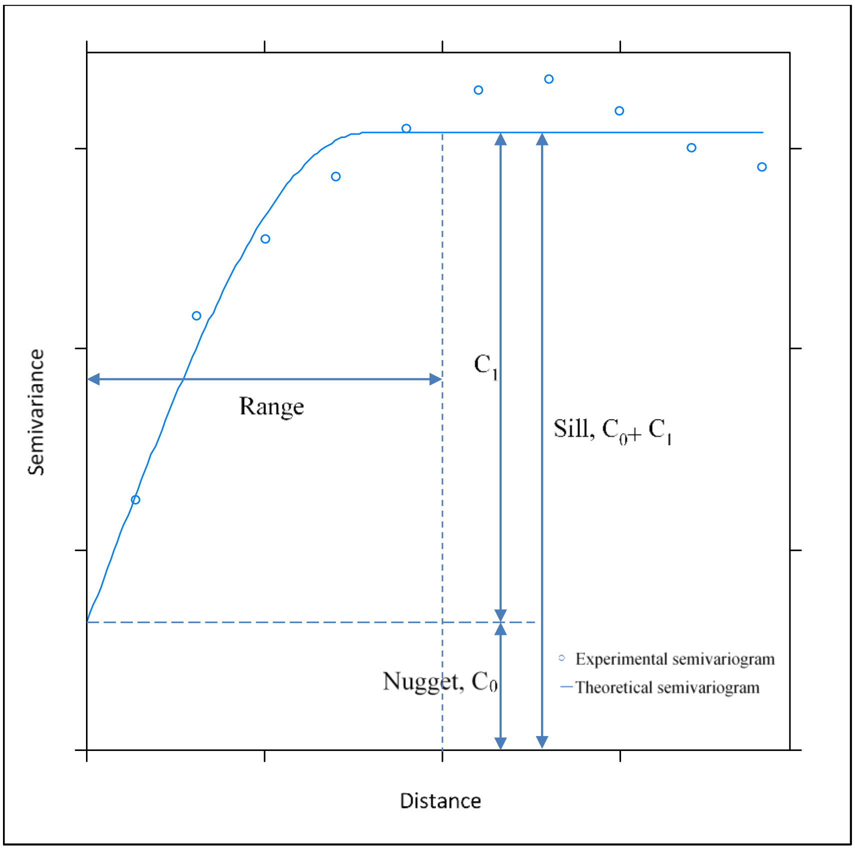
As more examples are given, graphical demonstration and interpretation of $X + h$ distance and $\gamma(h)$ value gets more difficult. Therefore, by determining the appropriate steps, it is attempted to create an experimental semivariogram. The estimation of the semivariogram obtained from the sample can be calculated from this equation below (Bivand et al. 2008).

$$\hat{\gamma}(\tilde{h}_j) = \frac{1}{2N_h}\sum_{i=1}^{N_h}\big(Z(X_i) - Z(X_i + h)\big)^2$$

In this equation $N(h)$ shows the number of sample pairs which have the distance h away from each other whilst $Z(X_i)$ and $Z(X_i + h)$ shows the value of variables at X_i and $X_i + h$ points (Isaaks and Srivastava 1989; Bailey and Gatrell 1995; Bivand et al. 2008; Hengl 2009). After obtaining the semivariogram value against each h distance, it is noted on the graphics. To determine the distance, half of the distance between the furthest two points in the data set is calculated, which is then considered to be equal to the class number and number of steps multiplied together.

Important information about the spatial variation of variables can be obtained with the experimental semivariogram. However, these cannot be used directly in the estimation analysis. Therefore, a second type of semivariogram is required for the estimation process. The modelling of the semivariogram, i.e. adaptation to a function at the *"theoretical semivariogram"* value is necessary for this situation (Isaaks and Srivastava 1989; Bailey and Gatrell 1995; Bivand et al. 2008; Hengl 2009). Determination of the theoretical semivariogram means finding out the dependency rule that exists at the location to form the spatial model. The theoretical semivariogram model is the most important part of any geostatistical study. This is based on mathematical models and obtained by fitting an experimental semivariogram. A semivariogram graph is defined by the parameters *"sill, range, nugget"* (Figure 3). As the lag distance between the samples in a semivariogram increases, the semivariogram values increase too.

Figure 3: *Experimental and theoretical semivariogram model*



The maximum value of the semivariogram is achieved giving the sill, "$c_0 + c_1$"; and observation points varies around this value. The distance at which the semivariogram reaches the sill value is known as, *"range, R"*. Variables are not related to each other at distances greater than range. Variables of the semivariogram remain constant beyond this distance. The nugget refers to the variance at a separation distance of zero. In theory, it should be zero. However, noise or uncertainty in the sample data map produce variability that is not spatially dependent. Theoretically, due to reasons mentioned, the positive value of the semivariogram when $h = 0$, is known as the *"nugget effects, c_0"* (Aydin and Çiçek 2015).

1.3.2. Kriging

Kriging refers to the generic name of the technique used to estimate the values of the variables in locations that have not been measured using the locations that have been measured. The overall estimation process is performed on the weighted average of the known values.

The basic equation is shown in the following formula;

$$\hat{Z}(X_0) = \sum_{i=1}^{N} W_i \, Z(X_i)$$

In this equation $\hat{Z}(X_0)$ represents the Kriging value of X_0 point; $Z(X_i)$ represents the observed values of variables in each X_i point; W_i represents the corresponding values of each $Z(X_i)$; N represents the number of points of $\hat{Z}(X_0)$ to be used in Kriging estimation. The Kriging method based on the smallest mean square error method is known as the best linear unbiased estimator. The weights determined by the Kriging method depends on the semivariogram and spatial position of the data. The Kriging error average is calculated as zero and variance is calculated as the smallest.

The point number used to achieve a predicted value in any X_0 point, affects the number of weights to be calculated. A weight is calculated for each point. This situation means there is repetitive weight account for each new point in the Kriging algorithm (Isaaks and Srivastava 1989). The error variance obtained by estimation is called the Kriging variance and the Kriging variance is;

$$\sigma_K^2 = 2\sum_{i=1}^{N} W_i \, \gamma(X_0 - X_i) - \sum_{i=1}^{N}\sum_{j=1}^{N} W_i W_j \, \gamma(X_i - X_j)$$

$$= \sum_{i=1}^{N} W_i \gamma(X_0 - X_i) + \lambda$$

The Kriging variance is not connected to the actual value of the data. It is a function of the distance between the positions of the data quantity and data. Therefore the Kriging variance can be used to test potential points before acquiring the actual value of data and to determine the optimum ones among these points. Kriging methods used in accordance with the work area and structure of the data are available in different types such as OK, SK, UK, Indicator Kriging (IK), CK, KED. In this study, the KED method was applied because it allows incorporation of many covariates. It also requires a less demanding semivariogram analysis compared to collocated Kriging which requires a semivariogram for each of the covariates.

KED allows the use of auxiliary information, available at all locations,which has an effect on the local spatial trend of the dependent variable (Deutsch and Journel 1998; Goovaerts 1997). The KED method generates the model under the assumption that a linear trend exists between the dependent variable and the auxiliary variable. One of the advantages of KED is that it utilizes non-stationary random function model, whereby stationarity is limited to a certain range. This in turn generates in model with more local details as compared to OK (Deutsch and Journal 1998). The KED estimator is;

$$Z_{KED}^{*}(u) = \sum_{\alpha=1}^{n(u)} \lambda_{\alpha}^{KED}(u) Z(u_{\alpha})$$

Where $Z_{KED}^{*}(u)$ is the KED estimator at location u, $\lambda_{\alpha}^{KED}(u)$ are the KED weights corresponding to the n samples at location u, and $Z(u_{\alpha})$ are the sample values within the search neighborhood.

1.3.3. Cross Validation

One of the commonly used methods for estimating semivariogram model parameters is the Cross Validation technique. The Cross Validation technique, using the information available in the sample data set, examines the relationship between the predicted and actual values (station measured values) (Isaaks and Srivastava 1989). In this technique, the value in one location is temporarily removed from the data set and estimates are made for this extracted location using the rest of the values (Leave One Out). This process is repeated for all remaining samples in the same way (Isaaks and Srivastava 1989). Thus, the observed values are estimated by the Kriging method and the difference noted as the error value (residual). A variety of error measurement methods are used in the evaluation of prediction maps. Coefficient of Determination (R^2), Root Mean Square Error (RMSE), Mean Error (ME), and Absolute Error (MAE) are some of these measurements. The R^2, RMSE, ME, and MAE values are calculated, respectively, by:

$$R^2 = 1 - \frac{\sum_i \left(\hat{Z}(X_i) - Z(X_i)\right)^2}{\sum_i \left(\hat{Z}(X_i) - \overline{Z(X_\iota)}\right)^2}$$

$$\text{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} \left(\hat{Z}(X_i) - Z(X_i)\right)^2}$$

$$ME = \frac{1}{N}\sum_{i=1}^{N} \left[\hat{Z}(X_i) - Z(X_i)\right]$$

$$MAE = \frac{1}{N}\sum_{i=1}^{N} \left|\hat{Z}(X_i) - Z(X_i)\right|$$

Where N is the number of sample stations used in the validation sets, $Z(X_i)$ are the observed values $\hat{Z}(X_i)$ are the estimated values, and $\overline{Z(X_\iota)}$ is the spatial average of the observed vaules.

2. Results and Discussion

The geographical distribution map of the annual mean total precipitation values, obtained for Aegean Region between 1975 and 2010, shows that highest rainfall areas of the region are located at the Muğla and Marmaris stations in the south. These stations respectively have 1142 mm and 1179 mm annual mean total precipitation values. However, low rainfall areas are obviously seen at the eastern section of the region with Bolvadin (395 mm annual mean total precipitation) Emirdağ (404 mm) and Afyon (422 mm) stations the most obvious. There are significant reasons for precipitation to be lower in the hinterland compared to the coastal areas. Firstly, the coastal zone of the humid air masses, which reach the coastal areas, rise from the slopes of the mountain ranges and cause precipitation. Thus, the air masses that reach the hinterland give off an important part of the humidity in the coastal areas and get warm adiabatically while they descend after overpassing the mountains. This results in the air masses with a relatively low humidity. Moreover, the frontal depressions that move from the western to the eastern part of the country cause more precipitation over the slopes that face the west and northwest (Koçman 1993). The Mediterranean air mass, which emerges as a result of the thermic change over the Mediterranean in winter months, and the relative frontal systems come to Turkey with the southwestern winds and cause orographic-frontal precipitation especially in Southwestern Anatolia. While the southwestern winds that result from the warm sector of the frontal system that descends to the Mediterranean cause frontal-orographic precipitation in the Southwestern Anatolia, the air masses penetrating in the west reach the inner sides without being forced for uplift so much, because the mountains are perpendicular to the coasts in the Aegean Region, and this situation limits the orographic-rooted precipitation. In Salihli, which falls into the rainfall zone of Bozdağlar, katabatic winds that are connected to the southwestern systems demonstrate the effect of these factors in the precipitation distribution.

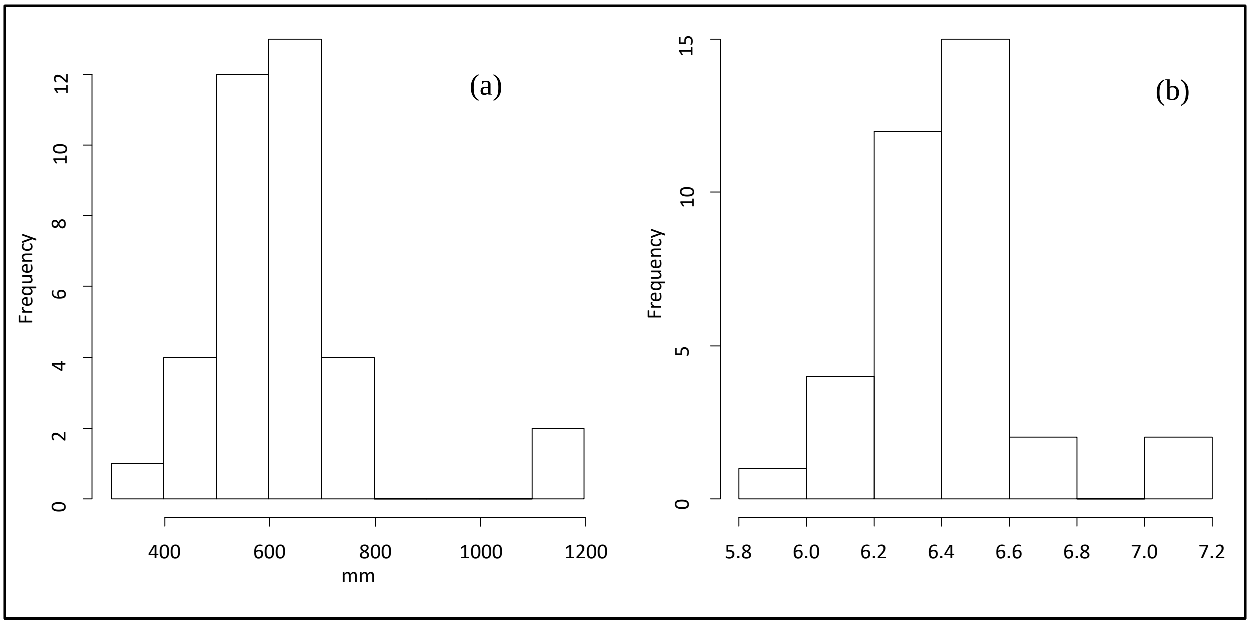
Descriptive statistical values of the annual mean total precipitation for the Aegean Region are shown in Table 1. The standard deviation is 158.57 mm for the region. The standard deviation is 1/4 of the annual mean total precipitation and this indicates high precipitation variability in the region (Table 1).

Table 1: *Descriptive statistics values for annual mean total precipitation in Aegean Region*

Mean (mm)	**Sdandart Deviation (mm)**	**Minimum (mm)**	**Median (mm)**	**Maximum (mm)**
627.43	158.57	395.60	610.20	1179.40

Figure 4 shows the histogram of annual mean total precipitation and its log-transform. Log transformation removed the skewness that is observed slightly and the transformed data are reasonably symmetrically distributed. It was therefore decided to apply the spatial interpolation methods to the log-transformed precipitation data.

Figure 4: *The annual mean total precipitation (mm) histogram,* **(a)** *the data skewed to the right;* **(b)** *logaritmic transformation of the allocations*

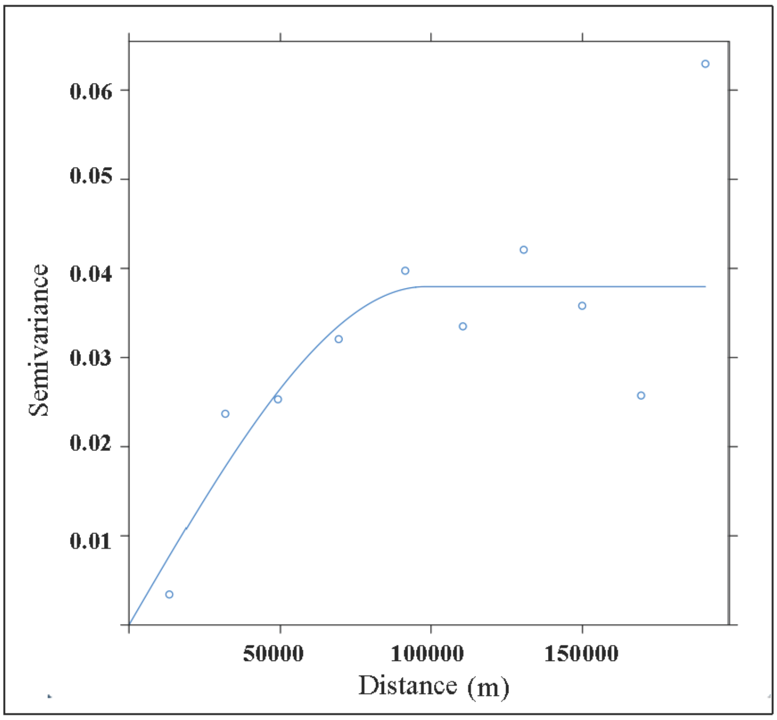


Class interval and class number between the stations were put into operation at various intervals and numbers until the most suitable model which could represent the examined annual mean total precipitation variable would be found. KED experimental semivariogram results that indicate the most suitable class interval and number that belong to the annual mean total precipitation values are shown in Table 2 and Figure 5. According to the result of the KED analysis, semivariance value increment continues until 91.4 km (5th lag distance) and reaches the 0.04 sill value. After these points, it did not change so much.

Table 2: *Experimental semivariogram results*

	Kriging with External Drift (KED)		
	Number of Pairs	**Distance (km)**	**Semivariance**
1	4	13.4	0.00
2	12	31.7	0.02
3	31	49.2	0.03
4	45	69.3	0.03
5	46	91.4	0.04
6	42	110.3	0.03
7	44	130.5	0.04
8	59	149.9	0.04
9	52	169.5	0.03
10	40	190.8	0.06

Figure 5: *For the annual mean total precipitation of the Aegean Region, KED theoretical semivariogram*



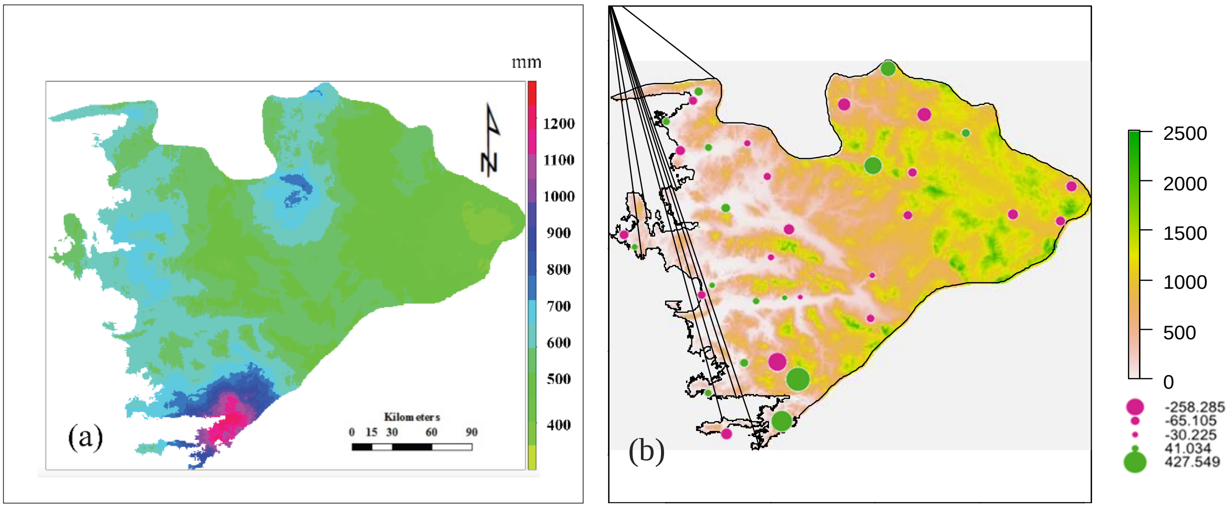
The interaction between the stations in the precipitation distribution ended after these sill value even some fluctuations had been seen (Figure 5). The semivariogram structures of the annual mean total precipitation variable were determined as the *"Spherical"* type theoretical semivariogram model (Figure 5). In the models of this type, the semivariogram increases regularly with the h distance and it becomes fixed at a certain sill value when the range is reached. Settled in the theoretical semivariogram, the sill value of the annual mean total precipitation variable was determined as 0.038 and range as 98.0 km for the KED analysis (Table 3). After the determination of the model parameters, point values of the places without observations were obtained using KED analysis method.

Table 3: *Theoretical semivariogram result*

	Model	Partial Sill	Range (km)
	Nug	0.00	0.0
KED	Sph	0.04	98.0

The estimation map is shown in Figure 6(a) for the KED. Figure 6(b) shows the error estimation map generated of Cross Validation results. High estimation errors were encountered in areas with high precipitation and low estimation errors in areas with low precipitation. Precipitation estimations are almost accurate in the stations facing south such as Aydın, Nazilli and Ödemiş, whilst the high estimation was observed in Salihli, which is beyond of the precipitation area.

Figure 6: (a) *Annual mean total precipitation estimation map of the Aegean Region as a result of the KED analysis;* **(b)** *Error map obtained by Cross Validation (Leave One Out) method*



KED method can be applied when the auxiliary information is available at all grid-nodes and correlated with the target variable. Whereas, in case of number of auxiliary information is low and they are not available at all grid-nodes, CK should be used to improve the prediction. Also with the KED method, the magnitude of the estimation error can be assessed through the Kriging variance. Although the Kriging interpolation method is generally not influenced by the data without a normal distribution (Hohn 1998), log transformation was applied to the data to obtain better results in this study.

When the descriptive results of the observed and estimated values are examined for the results of the KED analysis, the KED mean value has a difference around 3.5 mm. Negative differences occur between the observed value and the estimated value according to the precipitation increase. The precipitation value, which was 671.2 mm in the upper quartile, was estimated as 649.0 mm in the KED.

For the Cross Validation, statistical calculations that show the error between the estimated data and the real data as suggested by Wilmott (1982), were used. Because the relationship between the R^2 value and model performance could not be determined very well and the size of R^2 was not in a consistent connection with the accuracy of the estimation, other statistical methods such as ME, MAE and RMSE were also used in the study. The average difference of the observed and estimated values provides a better assessment of model performance with the RMSE and MAE compared to the other methods (Wilmott 1982). Therefore, RMSE and MAE values were also calculated besides R^2 and ME. Performance results of the KED are given in Table 4. The R^2 of 0.35 showed that more than one quarter of the precipitation behaviour can be explained by the model. For the precipitation, RMSE, ME and MAE values are low. As it is especially difficult to provide an accurate estimation for precipitation where spatial distribution has particularly high variability, the error metrics and thus the model are considered to be acceptable.

Table 4: *Performance result of Kriging with External Drift (KED) model*

	R^2	RMSE (mm)	ME	MAE
KED	0.35	126.28	3.51	88.05

Note: *In the table following abbreviations are used, Coefficient of Determination (R^2); Root Mean Square Error (RMSE); Mean Error (ME); Mean Absoluate Error (MAE)*

An important gain of geostatistic approaches is unbiased predictions with minimum variance and the spatial correlation between observations. As well as providing the prediction error, another advantage is the possibility of adding auxiliary variables. Multivariate geostatistics like KED and CK, which are applied using the auxiliary variables, were recommended in the literature (Goovaerts 2000; Llyod 2005). Both researchers concluded that multivariate techniques provide the most accurate estimates of precipitation. Pardo-Igúzquiza (1998) found the best results for the prediction of precipitation by means of KED. Aydın and Çiçek (2013) suggested that a secondary variable for obtaining a more accurate estimation map is essential in places where high mountainous areas are common. In the case that the correlation between the dependent variable and the secondary variable is low, the use of the later can still improve interpolation results (Carrera-Hernandez and Gaskin 2007).

In regions of high climatologic and geomorphologic complexities, as those observed in the study area, the KED approach proved to be a powerful tool that could allow a more detailed study of the spatial distribution of precipitation. Besides the statistical calculation tools used in the evaluation of the interpolation results, Daly et al. (2002) emphasize that the interpretation and assessment of the results must not be ignored. Therefore, interpretations were made on the basis of the information related to the spatial distribution of the precipitation.

The sections around Muğla and Bozburun peninsula are the rainiest areas in the KED precipitation estimation maps and precipitation is above 1000 mm in this district. The rainfall of the high sites where the Simav and Domaniç Mountains are located on the border of the Marmara Region is around 800-1000 mm. The “Main Aegean Section” of the region receives more rainfall than the hinterland. In the Hinterland of the Western Anatolia, Emirdağ and its vicinity constitute the district that receives the least rainfall. Height and extension of the relief reveals itself as an important factor in the areal distribution of the precipitation as a result of the KED analysis. Iso-precipitation curves are distributed in compliance with the topographic extensions in the results of the KED analysis. It is possible to see the best example of this in the separation of the “Coastal Aegean Section” and the “Hinterland Section of the Western Anatolia”. The 700 mm iso-precipitation curve is obvious enough to make this separation. High rainfall sections in the Menteşe district with the aspect and elevation factors and the sections with 600 mm low rainfall in the wind-sheltered part of Aydın Mountains reflect the topographic effect. Simav and Alaçam Mountains receive high rainfall with the effect of the topography in the Hinterland of the Western Anatolia. However, Simav Mountains and Alaçam Mountains are stated as two different areas receiving high rainfall in the KED precipitation estimation map. But, this district is observed as a single area, which receives high rainfall in the IDW precipitation estimation map (Aydin and Çiçek 2013). In principle, IDW cannot clearly give a description of climatic condition while elevation extrapolation is considered necessary (Tobin et al. 2011). Consequently, a distribution that complies with the orographic extension draws attention in the KED precipitation estimation map. When the results are evaluated, KED is a promising approach for predicting precipitation in this study.

3. Conclusions

Spatial distribution of precipitation presents high variability. Therefore, it is quite difficult to make accurate estimation. Obtaining high-quality precipitation maps is important in regions where water is the primary resource in terms of agriculture and hydrology. Precipitation data recorded from 1976 to 2010 from a network 36 gauges located across the Aegean Region were analyzed to investigate patterns of spatial variability. In this study, one method of interpolation has been used to provide the annual mean total precipitation spatial variability over the territory of the Aegean Region, Turkey. The accuracy of the spatial prediction estimated by interpolation methods was evaluated using Cross Validation. The Cross Validation results were assessed by RMSE, ME, MAE and R^2. The evaluation results show that use of elevation as a secondary variable improved the accuracy of spatial precipitation estimation. The KED method, which incorporates elevation produced an acceptable result in terms of R^2, RMSE, ME and MAE.

When the KED precipitation estimation map is examined, isolation increases depending on the extension and elevation presented by the topography. While areas with 600-700 mm precipitation are located as places of great areal expansion, they expand separating into many islands in the high sections of the mountains. This results from the good reflection of the elevation-dependent precipitation distribution.

The KED precipitation estimation map reveals that precipitation decreases from the coast towards the hinterland. The negative correlation between precipitation and elevation does not mean that elevation decreases the precipitation value. This is related to the continentality and maritime characteristic of the stations. Maritime value, which is high in the coastal section, and accordingly more absolute humidity in the air masses cause high values of precipitation in the Aegean Section. Decrease in the absolute humidity of the air masses depending on the continentality, which increases in the Hinterland of the Western Anatolia, leads to decrease in the annual precipitation amount. But this does not change the fact that precipitation increases depending on elevation. It only shows a change in the elevation-dependent precipitation increase rates in continental and marine districts. Therefore, it is also necessary to consider the maritime-continentality values of the stations to form a precipitation estimation map with higher estimation values for the study area. The results shown in this paper will help guide the selection of appropriate sites for placing rain gauges so that it can aid in reducing errors during precipitation estimation in complex terrain.

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