MODELLING OF SPATIALLY VARIED PRECIPITATION RECORDS OVER KARASU BASIN

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ABSTRACT

MODELLING OF SPATIALLY VARIED PRECIPITATION RECORDS OVER KARASU BASIN

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A study is carried out to present and apply recent approaches for spatial distribution of annual and seasonal precipitation. The methods which are considered for spatial distribution of precipitation are ordinary kriging, detrended kriging, arithmetical mean method and Thiessen polygon methods. A brief review of the methodology concerning spatial distribution of precipitation, all necessary computations and assessment of performance of methods are included within the scope of the study.

Precipitation records of meteorological stations in Karasu Basin on Eastern Turkey are analyzed. As a result, elevation is found to be an important parameter in estimating the mean areal precipitation in mountainous region. The number and the location of the meteorologic stations are noticed to be important factors to get accurate mean precipitation distribution. The grid cell size within the range of 3~10 kilometers has no effect on the precipitation-elevation relationships but affects the determination of mean areal precipitation.

Keywords: Precipitation Model, Spatial Distribution, Kriging, Detrended Kriging, Karasu Basin.

ÖZ

KARASU HAVZASINDA ALANSAL YAĞIŞIN MODELLENMESİ

BAŞBUĞ, Zerrin
Yüksek Lisans, İnşaat Mühendisliği Bölümü
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Alansal yıllık ve aylık yağış dağılımının uygulanması için bu çalışma yapılmıştır. Kriging, detrended kriging, aritmetik dağılım, Thiessen poligon yöntemi, alansal yağış dağılımını belirlemek için kullanılan metotlardır. Alansal yağış dağılımı ile ilgili metodolojisi, tüm gerekli hesaplamalar ve yöntem uygunluğunun değerlendirmesi bu çalışmanın kapsamında yer almaktadır.

Türkiyenin doğusunda Karasu Havzasındaki meteorolojik istasyonların yağış verileri analiz edilmiştir. Sonuç olarak, yüksekliğin, dağlık bölgelerdeki ortalama alansal yağış tahmininde önemli bir parametre olduğu bulunmuştur. Yağış istasyonlarının sayısı ve yerleşimi, alansal yağış dağılımı doğru tahmin edebilmek için önemli faktorlerdir. 3~10 km arası değşien gridlerin büyüklüğünün, yağış-yükseklik ilişkisinde etkisi yoktur, ama ortalama alansal yağışı etkilemektedir.

Anahtar Kelimeler: Yağış modeli, Alansal Dağılım, Kriging, Detrended Kriging, Karasu Havzası.

To my parents and my husband

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INTRODUCTION

1.1 IMPORTANCE OF THE PROBLEM

Quantitative evaluation of the amount and spatial distribution of precipitation is required for a number of applications in agricultural and natural resources management. These include water resources management, hydrologic modelling, forest modelling, soil moisture modelling for crop production and irrigation scheduling.

For many hydrologic analysis, precipitation data are important. Values of average annual precipitation are required for water-balance calculations, estimating recharge boundary conditions for groundwaterflow models, and defining current climatic conditions. One of the fundemantal problems of hydrology is to estimate precipitation at an unmonitored site using data from surrounding precipitation stations. Obtaining reliable estimates is particularly difficult when the areal coverage provided by surrounding stations is sparse or when precipitation characteristics vary greatly with location and altitude. This situation frequently occurs in mountainous terrain when few stations are available and orographic effects can play sufficient role.

Attemps to evaluate and compare the different methods are followed by various researchers but they are very rare. This is understandable for techniques that estimate spatial averages because of the lack of experimentally measured values. However, most techniques, may also be used for point values, where ground verification is possible. Point values are also of interest for contouring and for filling in gaps in records of existing stations.

In hydrology, techniques have been proposed for mapping rainfall patterns and for evaluating the mean areal rainfall over a watershed by making proper use of existing data points. Methods for precipitation interpolation from ground-based point data have ranged from techniques based on Thiessen polygons (Thiessen,1911) and simple trend surface analysis (Edwards, 1973; Hughes, 1982), inverse distance weighting (Shepard, 1968), multiquadratic surface fitting (Hardy, 1971; Shaw 1994), and Daulaney triangulations (Akima, 1978) through to more sophisticated statistical methods. When statistical techniques are used, the field is considered as a two-dimensional random process and the optimality of the method is conceived in terms of minimizing the estimation variance. In deterministic methods, the surface type and the optimality criterion are arbitrarily chosen. Among statistictical methods, the geostatistical interpolation techniques, such as kriging (Matheron, 1965), have been often applied to spatial analysis of precipitation.

Geostatistical interpolation methods, such as kriging, were originally developed for spatial analysis of ore reserves in mining (Matheron, 1971), but have been applied to a number of other problems, including spatial interpolation of precipitation. Tabios and Salas (1985) found kriging to be superior to the other commonly used interpolation techniques such as Thiessen polygons, polynomial trend surfaces, inverse distance, and inverse square distance methods for precipitation in 52 000 km^2 region in Nebraska and Kansas.

Kriging is defined as the process of estimating the value of a spatially distributed variable from adjacent values while considering the interdependence expressed in the variogram. The kriging process involves the construction of a weighted moving average equation that is used to estimate the true value of a regionalised variable at specific locations. This equation is designed to minimise the effect of the relatively high variance of the sample values by including knowledge of the covariance between the estimated point and other sample points within the range. The main aspects to consider in understanding the theory of kriging are the estimation error and the calculation of the weighting coefficients.

However, kriging does not explicitly account for influence of elevation on precipitation in mountainous areas except as reflected in the precipitation of surrounding precipitation stations. If, however, the neighboring stations are at different elevations than the point being estimated, the estimate is likely to be the error.

There is a fact that precipitation generally increases with elevation, and mountain ranges also create rain shadows on the leeward side. Meteorological stations tend to be sited at low elevations and may thus underestimate the regional precipitation (Phillips, Dolph and Marks,1992). Precipitation at higher or lower elevations near a meteorological station may not be accurately reflected by the meteorological station measurements.

For these reasons, especially in areas of high topographic relief, it will often be insufficient to use data from the nearest meteorological station to characterize the amount and spatial distribution of precipitation. This is especially true if the data are being used in models applied to a spatial distribution of points to represent different facets of the landscape. (Phillips, Dolph and Marks,1992). Spatially distributed precipitation estimates, which take into account the spatial arrangement of meteorological station data, precipitation-elevation relationships, and topographic relief are needed.

As a result, detrending is required to account for nonstationarity of the field due to orography. This is accomplished by calculating linear precipitation-elevation relationships from the measured data and performing spatial interpolation on the residuals. The spatial correlation structure of regression residuals is described by a linear semivariogram. Precipitation is estimated for each grid cell within a watershed, and these can either be used in spatially distributed form or arithmetically averaged to give the mean precipitation over the watershed or subareas thereof.

1.2 REVIEW OF LITERATURE FOR SPATIAL DISTRIBUTION

This part reviews the literature on the subject of spatial distribution including ordinary and detrended kriging.

In the following chapters, the recent techniques mainly developed by Chua and Bras (1982) and Matheron (1971) relating to the Spatial Distribution Analysis have been explained in detail and a spatial distribution analysis based on the mentioned theories has been illustrated by using annual and seasonal precipitation records measured at 11 precipitation stations in Karasu Basin located in the Eastern Anatolia Region in Turkey.

Chua and Bras (1982) studied that kriging can be used to estimate precipitation for cells on a rectangular grid throughout a watershed, these values can be arithmetically averaged to obtain mean areal precipitation (MAP). The grid is most conveniently established using a geographic information system, although it can also be done manually using maps. Each grid is characterised by its location (latitude and longitude or rectangular coordinates) and elevation. The number and size of grid cells should give an adequate representation of watershed's topography and should closely approximate the area elevation relationship derived from complete topographic data. The results of the study showed that the kriging estimation error is dependent on the structural model adopted for the drift and the variogram.

Dingman et. al (1988) evaluated the type of errors in the estimates of mean areal precipitation by applying kriging in two different approaches to estimate the mean annual precipitation in New Hampshire and Vermont, USA. In the first approach, kriging is applied directly to MAP values, in the second approach, kriging is applied to a precipitation delivery factor that represents the MAP without the orographic effect. Their first approach gave better kriged estimates of MAP, but results larger maximum errors over the region. Second approach had smoother error surface and was preferable as a basis for point and areal estimates of MAP.

Phillips, Dolph and Marks (1992) compared the three methods: kriging, detrended kriging and cokriging. The methods are applied to Willamette River Basin in Western Oregon. They lead to the conclusion that detrended and cokriging had precipitation estimates of improved accuracy and precipitation compared with ordinary kriging in mountainous terrain on the scale of a few million hectares.

Daly et.al. (1992) compared two methods; kriging and detrended kriging, the latter takes into account the orographic effects. The aim is to find out the effect of the mountainous areas while computing the spatial distribution of the precipitation.

Garen et. al (1994) used detrended kriging using the program SPAM to calculate daily values of mean areal precipitation for input to hydrological models. A detailed cross-validation procedure is done for Reynolds Creek research watershed in Southwestern Idoha. It is considered that the procedure can be used in routine operations of stream flow forecasting.

Garen (1995) shows that grid cell precipitation are obtained from a weighted sum of measurements at a number of stations in or near the watershed, where the sum of the weights is unity. The weights to be used on each measurement to estimate the precipitation at a grid cell are determined by solving a system of linear equations, the coefficients of which are a function of the distances among the locations of the gages and the location of the grid cell. Each grid cell, then, has its own unique set of weights to be applied to the precipitation measurements. These estimates are optimal in that the spatial correlation structure is explicitly modelled, and the weights on the measurements are derived so as to give minimum error variance in the estimate.

1.3 PURPOSE AND SCOPE OF THE STUDY

In this study, Spatially Distributed Precipitation Analysis using two estimation methods, ordinary and detrended kriging is carried out for the 11 precipitation stations in Eastern Anatolia in Turkey. The annual and seasonal precipitation records of 26 years are used for the spatial distribution analysis with various conditions.

First of all, the theory behind the analysis is provided. The theory is applied with various conditions. The subject is considered from the practical point of view and every detail is tried to be included that will help in understanding the application, that will be useful to practicing engineers to perform the Spatial

Distribution Analysis and that will be a guideline for the future studies on the same subject.

The theory is considered in four parts. In the first part, Ordinary Kriging is explained: Definition, theoretical background is provided. Ordinary Kriging is followed by Detrended Kriging. Detrended Kriging is defined and the important features of Detrended Kriging and orograhic effect are explained. After the description of the theory, the formulation of the kriging and advantages of the method are given. The computations required by the methods described in Chapter 2 have been made by the programs, namely SPAM (SPAtially distributed hydro-Meteorological program) and GEO-EAS (Geostatistical Enviromental Assessment Software).

Then comes the application part. This part is the application of the two methods with various conditions. The effect of number of stations and grid cell size are considered and the validation procedure to compare the methods is given.

The discussion of the results is given after the application part. The discussions are most commonly on the comparison of two methods and characteristics of precipitation records. The last chapter includes the conclusion and recommendations, which are thought to be useful for the investigators working on the same subject.

The aims of this research are to give the necessary background and information about the computer programs, to provide sample applications using various methods, suggest ways to overcome the faced problems, to comment on especially the methods used analysing the precipitation data and also to make recommendations for the further studies. It is in summary to understand the subject both theoretically and practically, for anybody who has no idea about, for the users of the models in the future and for the researchers who want to study in this subject. It is important that all the techniques used in this study are newly illustrated in Turkey by applying to the real world hydrologic data. So, the application of the spatial distribution must be analyzed carefully.

The subjects described in the following sections are given below:

In Chapter 2 the theory behind the spatial distribution is considered, where Section 2.1 makes a general introduction to the subject. Section 2.2 gives the methods used in the analysis of the precipitation data to find the areal precipitation.

Section 2.3 is the description of kriging theory. The design and techniques developed for kriging is explained. The following subsection 2.3.1 gives the explanation of the semivariogram which is used for the pre-analysis of the precipitation records. The semivariogram models are given with related formulas and figures. Finally, this section is ended by the theoretical explanation of the Ordinary Kriging.

The theory of Detrended Kriging is described in Section 2.4, the most important features, advantages of the method, and the effect of orography is followed by the calculation procedure of Detrended Kriging.

The explanation of the computer programs is the scope of Section 2.5. Application steps of SPAM, for the analysis of Detrended Kriging, GEO-EAS, for the analysis of Ordinary Kriging are given. The procedures followed by the computer programs are explained.

The last section, Section 2.6 is the validation procedure used to compare the given methods. The steps used for validation are given by the related formulas.

Chapter 3 is the main part of the study. Precipitation records are analyzed due to the characteristics of precipitation data and comparison of two methods. Time series analysis of the precipitation data of 11 stations is provided by the related figures and application of ordinary and detrended kriging is given.

The first section of chapter 3, section 3.1, gives information about the basin, precipitation values and its characteristics. Section 3.2 is the time series analysis of precipitation data for the years that the precipitation data is analyzed. Section 3.3 includes the application of the analyses of the mean annual precipitation with various topographic grid sizes. Section 3.4 is the analysis of the precipitation for various numbers of stations with the one of the computer programs. Section 3.5 is the results of the annual and seasonal precipitation data applying the spatial distribution methods. Finally, Section 3.6 is the validation procedure of the methods explained in Chapter 2.

Chapter 4 is the discussion of results and conclusions. In section 4.1, the annual variation of mean absolute error for dry and wet years with various number of precipitation stations is considered. The elevation effect and seasonal variations are given. The results of the semivariogram analysis are supplied in section 4.2. Section 4.3 is the comparison of the methods using the validation procedure explained in Section 2.6.

The last chapter, namely chapter 5, is the conclusion and recommendations part. All the recommendations that are thought to be guidelines for the next studies on the same subject are provided in this chapter.

The annual and seasonal analysis is performed for the study. The daily precipitation records can also be analyzed for the future studies. SPAM can also be helpful for the distribution of the temperature records.

One of the purposes of this study is to provide an efficient tool to the users, such as private and governmental organizations that are in need of preparing spatially distributed precipitation for the model studies. This tool including remote sensing and GIS techniques provides all the necessary information considered from practical point of view, sample applications, a brief discussion on the results from the applications, some problems faced during the applications and possible solutions. A Master of Science student (Kaya, 1999) in Middle East Technical University applies the detrended kriging to daily temperatures and precipitation as input to the snow melt runoff model using remote sensing and GIS techniques. It is for sure that further studies made on the same topic with the inclusion of hydrometeorogic data will contribute a lot to the subject and will be very useful to the users and scientific researchers.

CHAPTER 2

THEORY OF SPATIAL DISTRIBUTION

2.1 GENERAL

Estimates of the amount and spatial distribution of temporarily varied (montly and annual) precitation are critical inputs to a variety of ecological and hydrological models. These include rainfall-runoffs, vegetation models, water balance models, water quality models, and crop production models. In mountainous regions, estimating precipitation and temperature is very challenging due to effects of elevation (orography and temperature lapse rates) and high spatial variability.

Various techniques have been developed and applied so far that use ground truth observations from surface hydrometeorogical stations, together with digital terrain analysis by digitilazing the elevation contour maps, to model precipitation- and temperature-elevation relationships and to interpolate between measurements to obtain complete gridded raster fields of estimated precipitation and temperature in micro scale. The grid is established by the geographic information system in digital form called as digital elevation model. Grid cell based precipitation estimates can be done from a weighted sum of measurements at a number of measuring stations in or near the basin, where the sum of the weights is unity.

2.2 METHODS FOR ESTIMATING AREAL PRECIPITATION

Most methods for estimating areal and gridded precipitation from point data have fallen into three major groups: graphical, topographical, and numerical.

Graphical methods involve mapping of precipitation data, sometimes in combination with precipitation-elevation analyses and include isohyet mapping, and Thiessen polygon estimation which is primarily based on proximal mapping, i.e. nearest distance neighbor. The estimate of the process precipitation at any point of interest is equal to the observed value of the nearest sampling point in the area.

Topographic methods involve the correlation of point precipitation data with an array of topographic and synoptic parameters such as slope, exposure, elevation, location of barriers, wind speed and direction. While these techniques are relatively simple and straightforward, they have simplistic assumptions about the spatial correlation and variability of precipitation, do not handle orographic effects well, can be subjective, and are not necessarily optimal. A procedure using isohyetal maps of mean annual or seasonal precipitation to evaluate the climatological average orographic effect has limitations in that it requires subjective selection of relative station weights, and it assumes that the orographic effect is the same as the climatological average for all storms.

The most commonly used precipitation distribution methods have been numerical. These are interpolation procedures in which a numerical function, developed or prescribed, is used to weight irregularly spaced point data to estimate a regularly spaced prediction grid. Inverse-distance weighting is an example of a simple numerical interpolation method. In this case, the weighting of the data points is prescribed to decrease as the distance between the measurement points increases.

A recent technique for estimating mean areal precipitation is the use of kriging interpolation (Sec 2.3 and Sec 2.4), an optimal spatial interpolation procedure for estimating the values of a random variable at unmeasured points from nearby measurements. It was first developed for use in mining industry and has subsequently found widespread use in geology and hydrology. Kriging is an objective, statistically rigorous, and performs as well as or better than other estimation techniques for precipitation or other ones used a similar technique to calculate mean areal snow water equivalent.

Recently, detrended kriging (Sec 2.5) and cokriging with elevation with covariate have been used to bring topographic influences into calculations. The resulting precipitation often show more topographically related spatial patterns in complex terrain than those from ordinary kriging. However, application is limited to areas characterised by a strong, precipitation elevation relationship.

Computer programs such as SPAM (SPAtially distributed hydroMeteorological variables program), Geo-EAS(Geostatistical Environmental Assessment Software) and PRISM (Precipitation-elevation Regressions on Independent Slopes Model) (Sec 2.5) is used to calculate gridded fields climatological average monthly and annual precipitation for ecosystem modelling and climate change studies.

Kriging and detrended kriging are two selected methods that are discussed in detail for estimation of spatial distribution of precipitation in this research.

2.3 KRIGING INTERPOLATION

There are three commonly used geostatistical methods for mapping climatological data over an area, ordinary kriging, elevationally detrended kriging and elevational cokriging.

Kriging is an estimation method for univariate data which vary in areal domain. But it assumes that the sampling domain has a local structure called variogram and that the knowledge of local structure can improve the accuracy of the estimated value. The estimation method assumes that the best estimate is a weighted average of one or more sample points. Kriging is one of the methods of analysis by which the optimal weights are determined.

The Kriging Process

Any kriging process must have a number of parameters. These include:

- Block and area description.
- Variogram model and parameters.
- Anisotropy parameters.
- Variable description with default values if appropriate.

Kriging, for various estimation purposes, must be able to supply an estimated grade plus a tonnage figure for a given block. The estimated grade may be a kriged estimate of point grades or a relative content kriged estimate divided by a thickness kriged estimate. To estimate the tonnage, the block area (length * width), thickness and density must be known. The block area is known from the area description. If the thickness is not constant then a kriged estimate must be used. Densities are usually or nearly constants and need not be kriged.

Kriging may be based on X- (line), X-Y- (plane) or X-Y-Z- (3D) coordinates. Both the line and plane, or 2D, kriging require the horizontal anisotropy factor (if any). Kriging in 3D requires both horizontal and vertical anisotropy factors.

The kriging process must also know the variogram model/s being used, along with the respective variogram parameters. For the models with a sill these parameters include the practical range and the nugget and sill values which will be defined in Section 2.3.1. For the models without a sill, the deposit variance needs to be known (this is obtained from the variogram) in addition to the parameters. These include the A and B values for de Wij's model and the n value for the power models. Nested models need the model type and parameters for each of the component models.

The actual kriging process involves firstly the calculation of the block variance for the specified block size. The kriging of each block then commences. The first step is to find all the data points to be included in the kriging calculations for the current block. This is usually done by searching for user specified number of data points (or less) located nearest to the current block by searching within some user specified search radius. The actual kriging uses these data points to calculate the covariance between each data point. Next the set of simultaneous equations are solved for the kriging weights used for the current block. These are then used to calculate the kriged estimate.

If incorporating a thickness variable in the kriging process, both the grade (or relative content) and thickness need to be kriged for each block.

Kriging Design and Techniques

Although the actual process of kriging is simple, its implementation can be quite time consuming. There exists techniques which will assist in the speeding up of the kriging process. Most of these involve reducing the number of simultaneous equations which need to be solved as the cost of solving a linear system of N equations is about N^3.

The most obvious solution is to reduce or limit the number of data points to be incorporated in the kriging process. This can be done by arbitrarily limiting the number of points to be included and also placing a limit on the search distance. These methods are based on the belief that more distant samples are of little interest as their weighting coefficients are negligible.

Although the influence of more distant data points may be negligible, their combined influence may not be negligible and may in fact have a significant influence in the grade estimation. An alternative is to use a different estimator for distant samples which averages their influence.

The block size is also critical in computation time. Having the dimensions of a block will increase the number of blocks to be estimated, and the number of systems of equations to be solved, by 8 times. Attempting to gain as much information as possible from a deposit by having a detailed estimation on the basis of the smallest possible block size is counter productive as small neighbouring blocks will be given very similar grades. Also, as the block size decreases the error of estimation will increase.

If the data points are regularly spaced on a grid, then for all similar geometric situations the same set of weights applies. It need only be computed once for all of the simultaneous equations. The block estimation is then reduced to a simple weighted average.

Tabios and Salas (1985) have a technique called random kriging that can be used in reducing the number of systems of equations to be solved. This method is applicable for irregularly spaced data which have a fairly regular sample density. Instead of calculating the covariances between two data points Xi and Xj, the method will either calculate the covariance between two random points which are respectively located in blocks i and j (the definition of the covariance of blocks), or the covariance between the block to be estimated and a random point in a neighbouring block (again, the covariance between the two blocks).

Additional Kriging Properties

Kriging has 5 additional properties . These are:

•Conditional Unbiasedness: This term means that, on average, the grade of all blocks will equal the estimated grade. Put in another way, if a deposit is mined according to the predicted grade then the final grade will equal the predicted grade. This is only true for values with a normal distribution.

If the values are non-normally distributed then kriging is the best approximation to the conditional expectation.

•The Smoothing Effect: Kriging results in a marked smoothing effect with high original values tending to be underestimated and low values being overestimated. The kriged values will be less variable than the original values.

This property can be used in assessing the quality of a kriging. A smoothing factor can be defined and used to show how much kriging reproduces reality in terms of block variability. This is important in grade-tonnage curves.

•Additivity Kriging is the only estimator in which the summation of the estimates of smaller blocks equals the estimate of one single larger unit. This allows for the recombining of smaller blocks into larger units. This is only true if the same data points are used for both calculations. It also only applies to the estimated values, not to precisions or variances.

•Exact Interpolation: Kriging is an exact interpolation method, ie the interpolation passes through the data points rather than near them. If point kriging is used to estimate a known data point, the weights will be 1.0 for the known data point and 0.0 for the rest. This will give an estimate equal to the actual value.

•Screen Effect: If the data is random, ie independent of each other, then the best estimator for any point is the arithmetic average of all the data points. This is the pure nugget effect. The weight for each data point is equal to 1/n as all of the covariances will equal zero. When there is no nugget effect, then the weights associated with more distant data points is markedly less than those of closer data points. With increasing nugget effect, each of the weights will move towards 1/n. This is the screen effect.

Various forms of Kriging techniques have been proposed and applied for hydrological studies. Kriging is similar to optimal interpolation except that the spatial correlation function is replaced by the so-called variogram.

2.3.1 SEMIVARIOGRAM ANALYSIS

Kriging is the process of estimating the value of a spatially distributed variable from adjacent values while considering the interdependence expressed in the variogram. The kriging process involves the construction of a weighted moving average equation which is used to estimate the true value of a regionalised variable at specific locations. This equation is designed to minimise the effect of the relatively high variance of the sample values by including knowledge of the covariance between the estimated point and other sample points within the range.

The main aspects to consider in understanding the theory of kriging are the estimation error and the calculation of the weighting coefficients.

The variogram is used to describe the spatial correlation between grades (or any other characteristic) in an ore deposit. A measure of the similarity between grades (the co-variance between the two grades) for distance h apart is obtained. This is repeated for all samples that are h distance apart and the average squared difference obtained. This similarity measure is called γ(h). These are plotted on an x-y plot with the x- axis being the distance h, and γ(h) on the y- axis. Shortly, the variogram is the variance of the differences between data values separated by a distance h and calculated as follows:

$$2\hat{\gamma}(h) = \frac{1}{n} \sum_{i=1}^{n} [Y_i(x) - Y_i(x+h)]^2 \qquad (2\text{-}1)$$

where $2\hat{\gamma}(h)$ is the sample estimate of the variogram,

h is the distance between data sites,

x is a vector in a 2-D coordinate system describing the spatial location of a data site,

$Y_i(x)$ is the data value at point x,

n is the number of site pairs separated by distance h.

The quantity 2γ(h) is the sample variance of the differences; it is the sample estimate of the population value 2γ(h). the quantity 2γ(h) is the variogram value for seperation distance h, and γ(h) is the semivariogram value.

When dealing with precipitation measurements, n is usually one; n is greater than one only if measurements are available on a regular grid. Data pairs can be grouped into distance categories to help smooth the variogram; n would be the number of pairs in each distance category.

A semivariogram is most often ploted as $\gamma(h)$ versus h at a separation point of zero, $Y(x) = Y(x+h)$, so $\gamma(h) = 0$. Thus the semivariogram passes through the origin of the $\gamma(h)$ versus h graph. As h increases from zero, the values of $Y(x)$ and $Y(x+h)$ will begin to differ some small amount, so the variable $\gamma(h)$ must be nonzero. Since each distance in Equation (2-1) is squared , thus $\gamma(h)$ must be positive. The variance will tend to increase with increased separation distance until some point where further increases in separation distance are not accompanied by increased variance. Thus the semivariogram has the shape in Fig 2.1.

For general shape of the semivariogram, there are two characteristics of special importance. At separation distance, r, the semivariogram approaches a constant value γ_r ; this separation distance is called *the radius of influence* (sill) and occurs when the semivariogram approaches the sample variance. The part of the semivariogram where $\gamma(\hat{h})$ approximates the sample variance is called the sill and is denoted as γ_r. This are indicated in Figure 2-1 (Garen, 1994).

Two other measures are obtainable. The first is the average distance of all the pairs of data points whose distance fell within a given class interval. This is calculated from the cumulative distance divided by the number of samples. The second is a measure of drift, or the general increase or decrease in grade with distance. This is calculated from the cumulative assay difference divided by the number of samples.

If the variogram rises, and then levels off or stabilises around some value, it is said to have reached a sill. This is theoretically the sample variance.

The distance at which the rising variogram reaches the sill is called the range, and is symbolised by a. The range is the distance at which the covariance becomes zero, so it marks the limit of the zone of influence of a single sample. Beyond the range samples are no longer correlated and are independent.

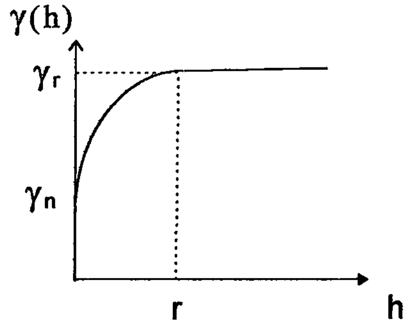


Figure 2.1 Characteristic shape of a semivariogram.

2.3.1.1 SEMIVARIOGRAM MODELS

In variogram analysis, the sample data are used to derive a model to represent the population. The semivariogram is usually modelled by one of the following functions.

Linear model

A linear model is the simplest form and easiest to calibrate. The model for a semivariogram has the form (Tabios and Salas, 1985):

$$\gamma(h) = bh \qquad (2\text{-}2)$$

in which b is the slope of the line and h is the separation distance. In this case, both sill and the radius of influence have no meaning.

The nonlinear power model is used quite frequently in hydrologic analysis and it could be used in a semivariogram analysis, (Tabios and Salas, 1985):

$$\gamma(h) = bh^{c} \qquad (2\text{-}3)$$

in which c is the power coefficient. Only c is less than 1 will be the power model have a form in which a radius of influence and sill could be inferred.

The exponential model is also linear at the origin, but reaches the sill asymptotically, well beyond the value of the true range, ie it approaches the sill gradually without ever reaching it and follows the general type of a semivariogram and provides coefficients that can be used as measures of the sill, γ_r, and the radius of influence, r, (Tabios and Salas, 1985):

$$\gamma(h) = \gamma_r \left[1 - e^{-\frac{h}{r}}\right] \qquad (2\text{-}4)$$

the coefficient r controls the rate at which $\gamma(h)$ approacvhes to sill. Thus it does not have a flexible shape.

Spherical model

The spherical model is linear at the origin indicating good continuity. The equation is, (Tabios and Salas, 1985):

$$\gamma(h) = \begin{cases} \gamma_r & \text{when } h > r \\ \gamma_r \left(\frac{3h}{2r} - \frac{h^3}{2r^3}\right) & \text{when } h \leq r \end{cases} \qquad (2\text{-}5)$$

In general, the spherical model will approach the sill at a smaller separation distance when compared with the exponential model for the same sill.

Figure 2.2 (Tabios and Salas, 1985), shows a comparison of the exponential (dashed line) and spherical (solid line) semivariograms for a sill of 1.0 and a radius of influence of 1.0; it is evident that the exponential model approaches to the sill much more slowly, with a value of 0.632 at the radius of influence. An exponential semivariogram (3) with a radius of influence of 4 also shown in Figure 2.2 illustrates that each model has a distinct shape and that the selection of a model to represent the population must consider the ability of the model to fit the sample values of the semivariogram.

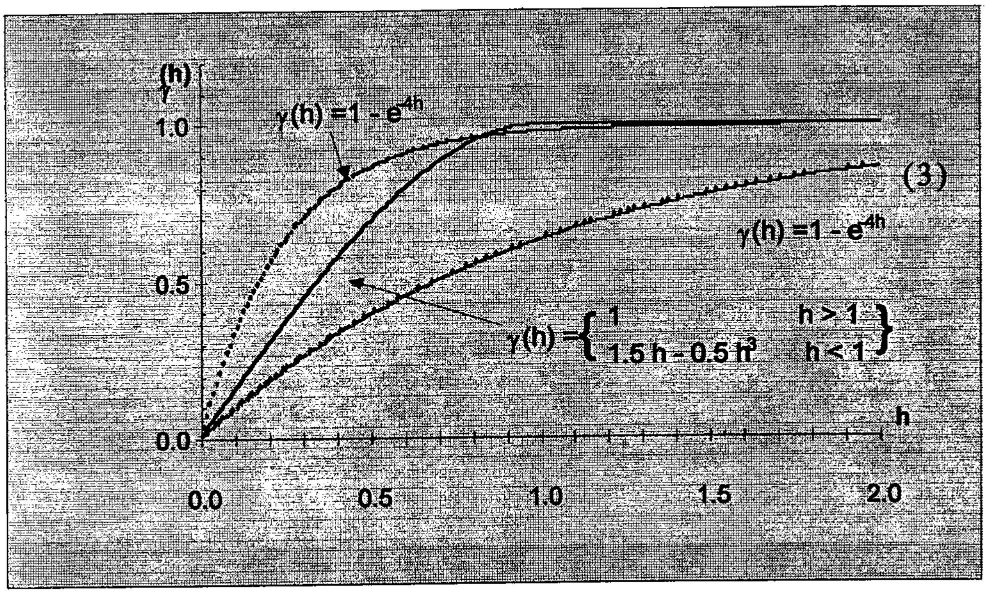


Figure 2.2 Comparison of Spherical and Exponential semivariograms for γ_r = 1.0

In addition to models above, other functional forms exist. For some physical processes, the variance of the differences increases very rapidly at separation distances near zero. In fact, for some data, the semivariogram value for the smallest separation distance is significantly different from zero and may actually be closer to the sill than zero. To overcome the fitting problem, combination model are sometimes used, with the combination model consisting of the sum of a constant, γ_n, one of the model structures is given above. Because of the origin of many of the concepts in semivariogram analysis, the constant is sometimes termed the nugget effect. The following are five combination models using the forms above as the non constant component:

$$\gamma(h) = \gamma_n + bh \qquad (2\text{-}6)$$

$$\gamma(h) = \gamma_n + bh^c \qquad (2\text{-}7)$$

$$\gamma(h) = \gamma_n + (\gamma_r - \gamma_n) \qquad (2\text{-}8)$$

$$\gamma(h) = \gamma_n + (\gamma_r - \gamma_n)\left[1 - e^{-\frac{h}{r}}\right] \qquad (2\text{-}9)$$

$$\gamma(h) = \begin{cases} \gamma_r & \text{when } h > r \\ \gamma_n + (\gamma_r - \gamma_n)\left(\frac{3h}{2r} - \frac{h^3}{2r^3}\right) & \text{when } h \le r \end{cases} \qquad (2\text{-}10)$$

It should be apperent that the structures of Equation 2-6 to Equation 2-10 are more flexible than the corresponding structures of Equation 2-2 to Equation 2-5 because there is an additional parameter that can be used to fit the data.

2.3.1.2 ESTIMATING SEMIVARIOGRAM PARAMETERS

The coefficients of Equations 2-2, 2-3, 2-4, and 2-6 can be obtained using bivariate regression analysis. The remaining models are best fit using a numerical method. When a model with a nugget effect included is being fit, it may be necessary to include constraints on the value of γ_n; otherwise an irrational value of γ_n may result. The selection of a final model will depend on the values of some goodness-of-fit criterion such as the standart error of estimate.

When the sample size is sufficiently small that the sample yields only a few points on the estimated semivariogram. This makes it difficult to estimate the value of the sill. It is important in the procedure of setting the value of the sill based on the variance of the differences and then optimizing the remaining coefficients to set the range of influence and nugget effect.

2.3.2 KRIGING ESTIMATION THEORY

As in optimal interpolation, Kriging interpolation requires that the observed process is second-order stationary. Essentially, this assumes homogenity in the means, variance and covariances. In addition, an isotropic spatial covariance structure is assumed. Then, the point variance is represented by $\mathrm{var}(h_i) = \sigma^2$ $i = 1,\dots,n$ stations and the covariance between stations i and j is represented by $\mathrm{cov}\,(h_i h_j) = \mathrm{cov}\,(d_{ij})$. Now, the homogeneous and isotropic semivariogram is defined as (Tabios and Salas, 1985):

$$\gamma\,(d_{ij}) = \frac{1}{2}\ \mathrm{var}\,(h_i h_j)$$

or

$$\gamma\,(d_{ij}) = \sigma^2 - \mathrm{cov}\,(d_{ij}) \qquad i\,,j = 1,\dots\dots,n \qquad (2.11)$$

in which $\gamma\,(d_{ij})$ is the semivariogram as a function of the distance d_{ij} between points i and j.

Consider that h_o is the process to be determined and Equation 2.1 is used to estimate h_o. Let $\hat{h}_o$ to be the estimate of h_o, as given by Equation 2.1. The weights are determined by minimizing the variance of the error of interpolation σ_e^2 which is given by:

$$\sigma_e^2 = \mathrm{var}\,[h_o - \hat{h}_o\,] = \mathrm{var}\,[h_o - \sum_{j=1}^{n} w_j h_j\,] \qquad (2.12)$$

Expanding Equation 2.12 gives

$$\sigma_e^2 = \sigma^2 - \sum_{j=1}^{n} w_j\ \mathrm{cov}\,(h_o h_j) + \sum_{j=1}^{n} \sum_{i=1}^{n}\ w_i\, w_j\, \mathrm{cov}\,(h_i h_j) \qquad (2.13)$$

where σ^2 is the variance of the process h_o and cov $(h_i h_j)$ represents the covariance between h_i and h_j.

Rewriting Equation 2.13 by substituting Equation 2.11 for $\text{cov}(h_i h_j) = \text{cov}(d_{ij})$ gives

$$\sigma_e^2 = \sigma^2 - 2\sum_{j=1}^{n} w_j \left[\sigma^2 - \gamma(d_{oj})\right] + \sum_{j=1}^{n}\sum_{j=1}^{n} w_i w_j \left[\sigma^2 - \gamma(d_{ij})\right] \qquad (2.14)$$

minimizing Equation 2.14

$$w_j \left[\gamma(d_{ij}) - \sigma^2\right] = \gamma(d_{oj}) - \sigma^2 \qquad j = 1,\ldots\ldots,n \qquad (2.15)$$

which must be solved simultanously to estimate the weights w_i.

The variance of the error of interpolation σ_e^2 may be obtained by combining Equations 2.14 and 2.15, so that

$$\sigma_e^2 = \sigma^2 \left[1 - \sum_{j=1}^{n} w_j\right] + \sum_{j=1}^{n} w_j \gamma(d_{oj}) \qquad (2.16)$$

Furthermore, h_o will be unbaised and the equations to be solved become

$$\sum_{j=1}^{n} w_i \gamma(d_{ij}) + \lambda = \gamma(d_{oj}) \qquad j = 1,\ldots\ldots,n \qquad (2.17)$$

and

$$\sum_{j=1}^{n} w_i = 1 \qquad (2.18)$$

where λ is a Lagrange multiplier and which must be solved simultaneously to obtain the weights. The variance of the error of interpolation becomes

$$\sigma_e^2 = \sum_{j=1}^{n} w_j \gamma(d_{oj}) + \lambda \qquad (2.19)$$

Other schemes of Kriging interpolation have been proposed in the literature. In an attempt to incorporate nonhomogeneity in the mean of the process, Delfiner and Delhomme (1975) proposed the so-called universal Kriging technique. In this technique, the mean m_0 at a given point (x_0,y_0) is represented as a linear combination of the observed station means m_j, as in Equation (2.1), such that

$$m_0 = \sum_{j=1}^{n} w_j m_j \qquad (2.20)$$

where w_j is the weight of station j for j = 1 , ... , n stations.

The corresponding variance of the error of interpolation is given by

$$\sigma_e^2 = \sum_{i=1}^{n} w_j \left(\gamma(d_{0j}) + \lambda_1, m_j \right) + \lambda_0$$

In fitting the foregoing variogram models, the sample variogram $\gamma(\hat{d}_{ij})$ is estimated between stations i and j as:

$$\hat{\gamma}(d_{ij}) = \frac{1}{2N} \sum_{t=1}^{N} \{ (h_i(t) - \hat{m}_i) - (h_i(t) - \hat{m}_j) \}^2$$

where $h_i(t)$ represents the time series of observations at station k, m_i is the estimated mean, and N is the total number of observations. The distance d_{ij} between two points is computed as in Equation 2-12. Thus, for a total of n stations, there are n(n-1)/2 pairs of points to use in fitting the model variograms.

2.4 DETRENDING

The Detrending Kriging method assumes a linear relationship between the drift and spatial dependency of precipitation influenced by orographic effects. The detrending method assumes a linear relationship between the drift and the ground elevation.

The important features of this procedure are:

1) Specific precipitation-elevation relationships are determined for each time period as opposed to using relationships based on climatological averages,
2) Spatial variability is incorporated by estimating precipitation for each grid cell over a watershed,
3) The spatial correlation structure of precipitation is modelled,
4) Station weights for precipitation estimates are determined objectively and optimally.

Orographic effects

In mountainaous areas, orographic effects complicate the estimation of MAP, since precipitation increases with elevation and is influenced by storm direction and topographic aspect. Chua and Bras (1982) used two methods for dealing with nonstationarity, one involving generalized covariances called cokriging, and the other subtracting a precipitation-elevation trend from the data before performing the kriging. Detrended kriging was used in the procedure reported herein because it gave better results for Chua and Bras (1982). Chua and

Bras (1982), Dingman et al. (1994) used linear precipitation-elevation relationships for the detrending.

Besides elevation, however, other factors, such as topographic aspect, can be important in affecting precipitation. For example, Hanson (1982) found that separate linear relationships were required for sites on the winward and leeward sides of topographic barriers in the Reynolds Creek watershed in southwest Idaho. Daly et al.(1994) used spatially smoothed elevations instead of actual point elevations, and they grouped stations according to similarity in aspect.

Garen (1994) explained that the property of a linear semivariogram is that the kriging weights are independent of the slope and intercept of the line. Since the semivariogram is a function of distances between stations, the kriging weights can be obtained by using these distances themshelves as the coefficients in the kriging system of equations.

2.4.1 CALCULATION PROCEDURE

The steps of calculation procedure are as follows:

1) The annual or monthly precipitation data for stations in or near the watershed are prepared.
2) Using geographic information system, a grid is established over the watershed.
3) The kriging weights are calculated to be used for each grid cell using linear semivariogram.
4) The linear regression between average annual precipitation and station elevation is calculated.
5) The linear precipitation elevation trend is subtracted from the precipitation observations to obtain residuals.

6) For each grid cell, the estimated grid cell residual is calculated by multiplying the precipitation residuals by the kriging weights and summing.
7) For each grid cell, the linear precipitation-elevation trend is added to grid cell residuals, based on the elevations of the grid cells, to obtain the estimated grid cell precipitation.
8) For each year, grid cell precipitation is averaged aritmetically to obtain mean areal precipitation.

The idea behind detrending is that data other than the observed values of the phenomenon under study can be related to and used to estimate the statistics of the spatial process. Switzer (1979) has suggested that elevation data should be used as a covariate together with the two-dimensional spatial coordinates to estimate both the drift and the semivariogram. The form of the semivariogram and drift he suggests are,

$$2\gamma(\underline{u}_1,\underline{u}_2) = [\, c_1 + |\, e(\underline{u}_1) - e(\underline{u}_2) \,|\, c_2 \,] \cdot |\, (\underline{u}_1) - (\underline{u}_2) \,| \qquad (2.27)$$

$$m(\underline{u}) = b_o + b_1\, e(\underline{u}) \qquad (2.28)$$

where $e(\underline{u})$ = elevation of point $\underline{u}$; c_1 , c_2 = parameters of semivariogram; b_o , b_1 = parameters of drift.

Elevation data are easily obtained and there are well known relationships established between precipitation and altitude in mountanous areas. To cite a few representative studies, Whitmore (1972), using multiple curvilinear regression analysis, showed that annual precipitation increased 30 mm for every 100-m rise in altitude for different locations in South Africa.

In view of the above, it was thought that the following relationship between the drift and elevation would be reasonable:

$$m(\underline{u}) = b_o + b_1 e(\underline{u})$$

A linear relationship was introduced because it was the simplest and the avaliable studies on precipitation relationships did not seem to warrant anything more complex. Precipitation can be thought of as:

$$Z(\underline{u}) = m(\underline{u}) + Y(\underline{u}) \text{ and } Z(\underline{u}) = b_o + b_1 e(\underline{u}) + Y(\underline{u}) \qquad (2.29)$$

where $m(\underline{u})$ is a deterministic trend or drift and $Y(\underline{u})$ are the residuals. Ordinary least-square regression of $Z(\underline{u})$ on the elevation $e(\underline{u})$ gives the parameters b_o and b_1, and the residuals from the regression are the variables, $Y(\underline{u})$, the set residuals can be used to estimate their underlying variogram.

The value of the mean is as follows:

$$m(\underline{u}) = b_o + b_1 e(\underline{u})$$

2.5 COMPUTER PROGRAMS

2.5.1 SPAM

SPAtially distributed hydroMeteorological variables program (SPAM) can be used to estimate spatial fields of precipitation, temperature and snow water equivalent by interpolating among point measurements. The algorithm is based on detrended kriging. It is developed to create a better way of calculating mean areal inputs for spatially lumped hydrologic simulation models and to create a method for estimating spatial fields of these inputs for spatially distributed models.

2.5.1.1 PROGRAM DESCRIPTION

Spatial fields on a grid cell basis for precipitation, temperature and snow water equivalent are calculated by interpolating point measurements at hydrometeorological stations. Spatial interpolation is done by detrended kriging which carries out the interpolation by dividing the variability into a vertical and a horizontal component. Spatial fields can be output in the ASCII column-and-row format used by the GRASS GIS. An arithmetic average of the values for all grid cells in the region, or within a subset of this region by a GIS mask, is also given for each year.

Elevation is accounted by detrending, whereby a linear regression of elevation vs. precipitation, temperature, or snow water equivalent is to fit to each individual period's data and the residuals from this regression are used in the kriging calculations. Kriging is used to deal with the horizontal interpolation. Kriging weigths are calculated from the distances among stations and distances between stations and grid cells. This is equivalent to linear semivariogram. Alternatively, equal weighting can be used, which is equivalent to a flat semivariogram. The distance weighting by kriging gives better cross-validation accuracy than using equal weights on all stations.

Hydrometeorological input data are yearly precipitation values, and the elevation, latitude or northing and longitude or easting of each station. Grid cells are represented by latitude or northing, longitude or easting and elevation. These are easily defined by a digital elevation model.

For precipitation, the slope of the line must be positive, otherwise it is set to zero. This is to ensure that the detrending is in fact dealing with orographic influences, for which precipitation increases with elevation. By setting the slope to zero if it is negative, the detrending step is in effect not done, thereby saying no trend with elevation, and the interpolation consists only of kriging in horizontal.

For estimating the detrending line, the program can use either the usual least squares regression, or it can use least absolute deviations regression (algorithm taken from Press et. al., 1988). The latter is a robust regression technique that is less influenced by so-called "outliers", that is, values that are significantly different from most of the others in the regression data set. From the author's experience, least absolute deviations regression is preferable for daily precipitation data. For temperature, least squares generally performs fine. Either method can be successfully applied for snow water equivalent.

See SPAM User's guide for further details how to input hydrometerological data and digital elevation data and the optimal mask file data to indicate grid cells within the area to include in the areal precipitation calculations.

2.5.2 GEO-EAS

Geo-EAS (Geostatistical Environmental Assessment Software) is a collection of interactive software tools for performing two-dimensional geostatistical analysis of spatially distributed data. Programs are provided for data file management, data tranformations univariate statistics, variogram analysis, cross validation, kriging, contour mapping, post plots, and line/scatter graphs. Features such as hierarchical menus, informative messages, full-screen data entry, parameter files, and graphical displays are used to provide a high degree of interactivity, and an intimate view of results. Users may easily alter parameters and re-calculate results or reproduce graphs, providing a "what if" analysis capability.

Geostatistical methods are useful for site assessment and monitoring situations where data are collected on a spatial network of sampling locations, and are particularly suited to cases where contour maps of pollutant concentration (or other variables) are desired. Kriging is a weighted moving averaged method used to interpolate values from a sample data set onto a grid of points for contouring. The kriging weights are computed from a variogram, which measures the degree of correlation among sample values in the area as a function of the distance and direction between samples.

Estimation of the variogram from sample data is critical part of a geostatistical study. The procedure involves interpretation and judgement, and often requires a large number of "trial and error" computer runs. The lack of inexpensive, easy-to-use software has prevented many people from acquiring the experience necessary to use geostatistical methods effectively.

2.5.3 PRISM

PRISM (Parameter-elevation Regressions on Independent Slopes Model) is an expert system that uses point data and a digital elevation model (DEM) to generate gridded estimates of climate parameters (Daly et al., 1994). PRISM is well-suited to mountainous regions, because the effects of terrain on climate play a central role in the model's conceptual framework.

Although PRISM was originally developed for precipitation mapping, it was quickly recognized that the model philosophy, i.e., the topographic facet is an important climatic unit and elevation is a primary driver of climate patterns, could be extended to other climate parameters. PRISM has since been used to map temperature, snowfall, weather generator statistics, and others. Since it is only applied in UNIX system and not commercially avaliable, it is not applied to the data in this research.

2.6 VALIDATION PROCEDURE

The validity and applicability of the foregoing interpolation techniques is tested by so-called "fictitious-point" method. This is done by suppressing one station sampling point and values for that point are interpolated based on the remaining (n-1) points. Then, the interpolated values are compared with those observed for that point. The same procedure is followed for some selected points in the network.

The criteria for comparison is:

1) Comparison of the mean and variance of the interpolated and observed values.

2) The sum of squares errors between the observed and interpolated values:

$$S = \sum_{t=1}^{N} (\hat{h}_0(t) - h_0(t))^2 \qquad (2.30)$$

where N = number of observed and interpolated values, $\hat{h}_0(t)$ = interpolated value at sampling point (x_0, y_0) and $h_0(t)$ = observed value at sampling point (x_0, y_0)

3) The proportion of the variance of the observed values accounted by the interpolator, called the coefficient of efficiency, is:

$$E = 1 - \frac{S}{S_0} \qquad (2.31)$$

where S_0 , the sum of square differences between the observed values and the mean at point (x_0, y_0) is given by,

$$S_o = \sum_{t=1}^{N} (h_0(t) - m_0(t))^2 \qquad (2.32)$$

4) Another measure of association between the observed and interpolated values is the coefficient of determination (r^2) obtained by single regression.

5) The standart deviation of the error of the interpolation is also computed using Equation 2.13.

The validation procedure is applied to the precipitation records using the first three steps . The comparison of two methods discussed in Section 2.3 and 2.4 is given in Chapter 3.

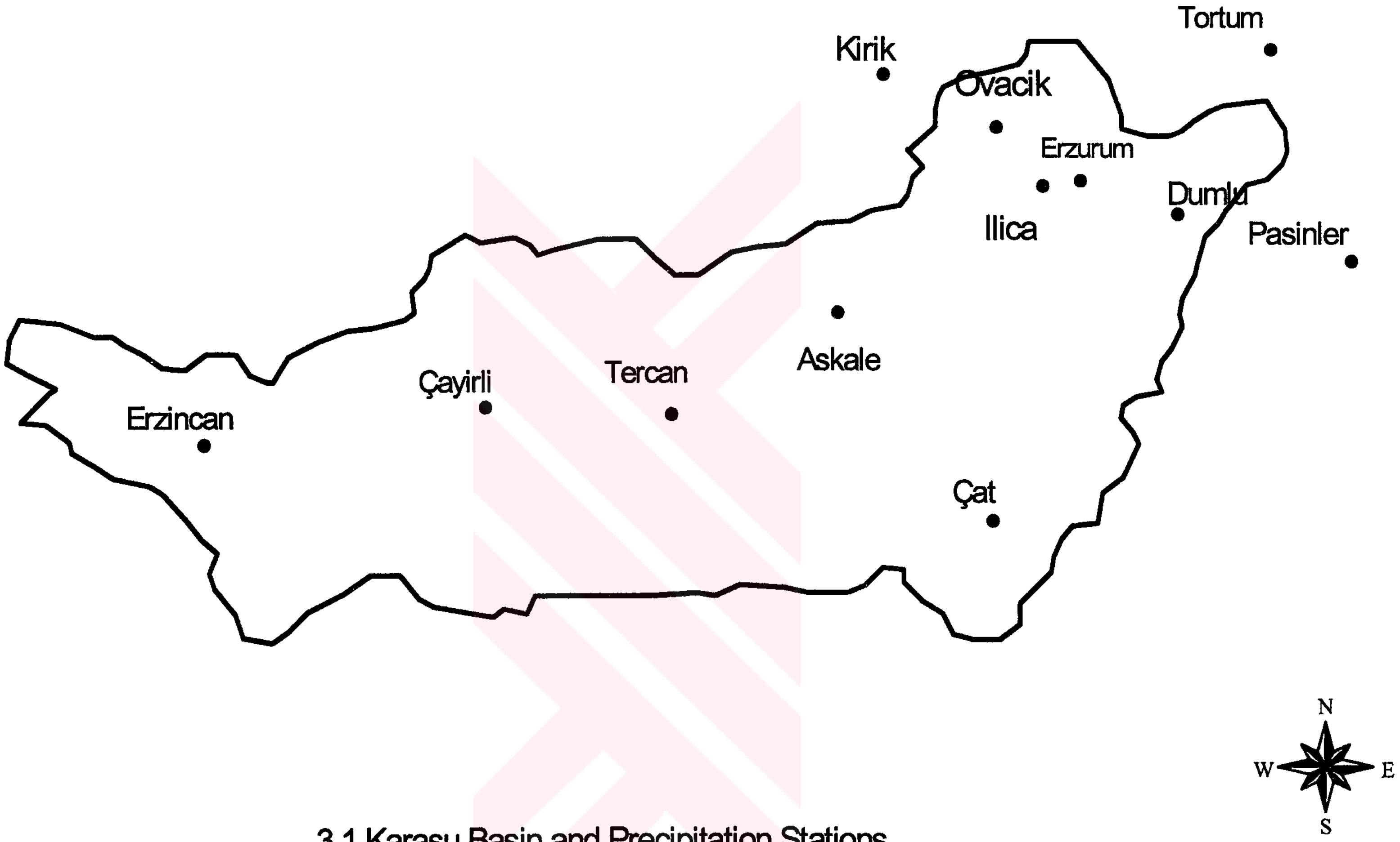
CHAPTER 3

APPLICATION OF SPATIALLY DISTRIBUTED PRECITATION MODELS

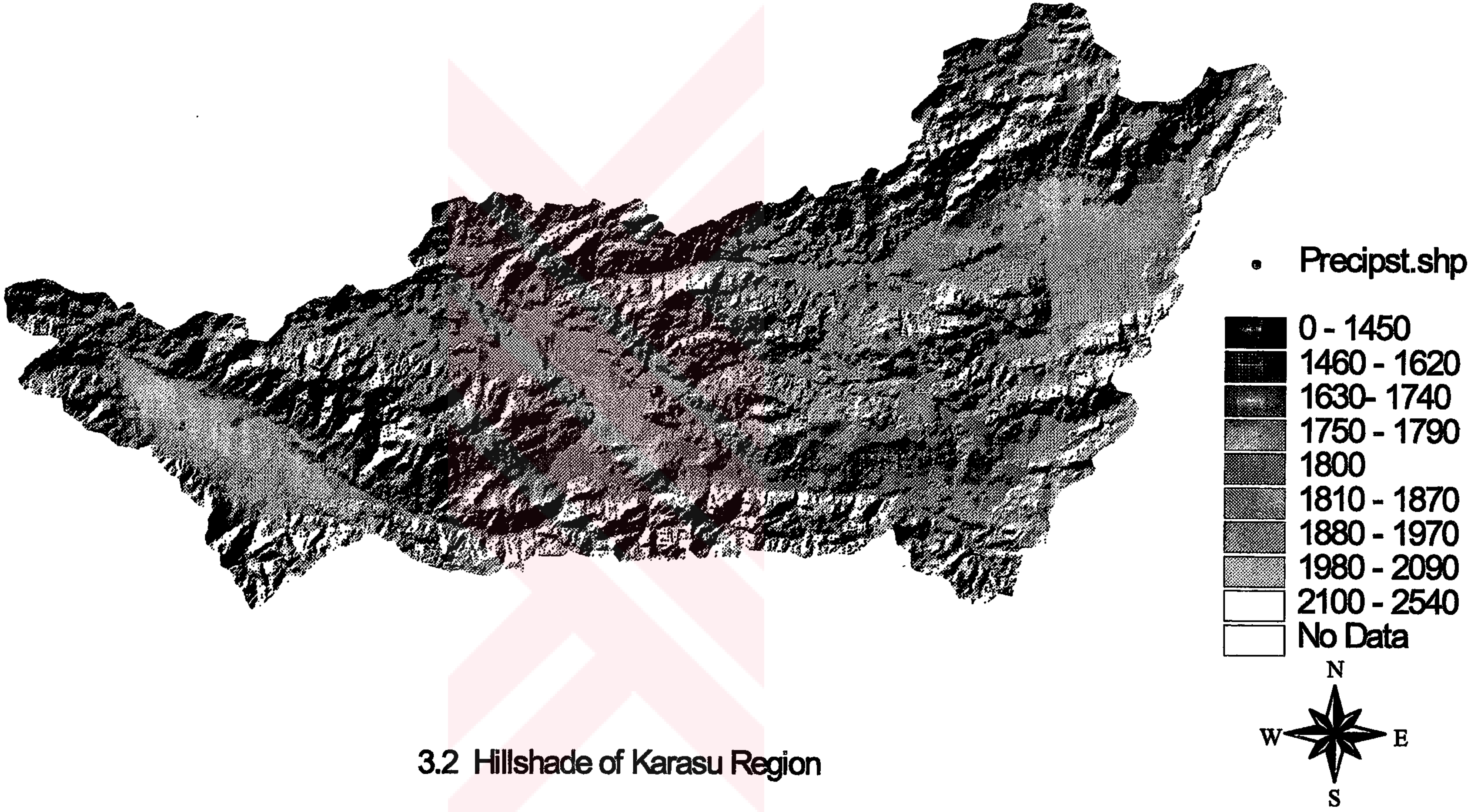
3.1 GENERAL

This part of the thesis covers an illustration of the analysis of spatial distribution techniques using annual precipitation data in Karasu Basin located in Eastern Part of Turkey. The recording precipitation stations are selected around and within this basin and spatial distribution analyses are carried out based on varying records between 1970-1995.

Kriging and detrended kriging models are applied to Karasu Basin in Eastern Anatolia. Karasu Region has 12 precipitation stations. 11 precipitation stations are used while Askale is eliminated because of its limited data. The map of the region and the location of the precipitation stations are shown in Figure 3.1. The hillshade of Karasu Region obtained from digital elevation model is given in Figure 3.2. The selected stations have 26 years of annual precipitation depths in millimetres (mm) for the period 1970-1995. The coordinates and the altitudes of the selected stations are given in Table 3.1. The historical annual records mean and standard deviation of each station based on 26 years of record are given in Table 3.2. The precipitation records of the selected stations are given in Table 3.3. Stations Ilıca and Ovacık have had missing precipitation data for the period 1984-1995, the missing data is filled using stepwise regression analysis and Kırık station



3.1 Karasu Basin and Precipitation Stations



3.2 Hillshade of Karasu Region

records are used for extending Ovacik station from 1984 to 1995 and Ovacık records are used for Ilıca because of their high correlation.

Table 3.1 UTM Coordinates and Altitudes of the 11 Meterological Stations

	Easting(m)	Northing(m)	Altitude(m)
KIRIK	653015	4460760	2075
OVACIK	671645	4451906	2200
ILICA	679393	4424319	1700
PASİNLER	729119	4429356	1660
ERZURUM	685089	4424456	1758
TORTUM	716723	4464175	1602
ERZINCAN	542835	4400130	1218
ÇAT	670246	4387092	1920
ÇAYIRLI	588463	4406070	1525
DUMLU	701831	4437841	1825
TERCAN	618455	4404625	1425

Table 3.2 Mean and Standard Deviations of the Annual Precipitation Based on 26 Years of Record for 11 Stations

	MEAN(mm)	STD.DEV(mm)
KIRIK	525.20	83.17
OVACIK	557.50	78.25
ILICA	353.30	77.96
PASİNLER	381.10	90.02
ERZURUM	406.10	63.44
TORTUM	460.20	93.4
ERZİNCAN	364.40	66.44
ÇAT	446.50	97.26
ÇAYIRLI	384.90	67.39
DUMLU	396.60	75.22
TERCAN	439.30	79.89

Table 3.3 The Annual Precipitation Based on 26 Years of Record for 11 Precipitation Stations of the Study Region

	KIRIK	OVACIK	PASIN.	ILICA	ERZURU.	TORTUM	ERZIN.	CAT	CAYIRLI	DUMLU	TERCAN
1970	441.9	470.4	196.1	235.5	291.1	350.1	225.7	270.9	312.6	288.3	375
1971	612.5	687.1	338	482.7	364.4	575.4	399.3	372.4	376.1	449.9	436
1972	543.1	575.4	408.9	336.5	445.2	628.2	352.1	362.3	356.4	412.8	388.5
1973	432.3	507.1	269.5	311.7	375.7	552.7	230	402.8	321.9	354.4	436.6
1974	401.7	434.6	206.2	285	392.6	311.6	300	371.6	356	290.2	369.8
1975	623.9	572.2	290.1	242.6	377.2	412.2	250	367.1	373.4	294.2	407.6
1976	636.9	662.3	478.8	475.5	509.7	481.7	524.5	591.1	416.4	387.4	538.6
1977	504.4	497.8	330.4	345.2	373.7	499.7	364.2	362.3	433.9	334	444.6
1978	469.4	539.2	381	396.8	398.6	413.6	400	482.6	342.3	361.5	413.4
1979	643.1	703.2	459	532.6	592.9	652.9	573.5	620.4	608.1	524.3	684.2
1980	475.1	500.2	297.3	291.9	372.4	360.4	374	369.6	409	247.4	409
1981	533.6	560.6	413.5	350.4	439	458	381.7	440.0	377.7	404.8	427.1
1982	414.2	463.8	350	296.2	388.3	251.3	318.8	362.1	367.7	321.2	404.6
1983	509.4	537.8	374	312	416.2	431.3	345.1	443.8	423.8	521.5	406.5
1984	403.2	447.1*	405.5	260.3*	475.2	413.9	318.5	338.5	360.2	389.9	377.1
1985	537.8	569.1*	329.1	359.6*	396.1	383.2	357.2	441	336.5	452.5	406.5
1986	547.3	577.6*	423.8	366.7*	502.4	490.5	415.9	549.2	401.5	468.1	512.6
1987	622.8	643.6*	372	423.9*	440.5	499	425.4	412.8	387.3	446.8	528.2
1988	713.4	721.2*	582.2	493.7*	435	492.5	468.7	508.1	516.8	542.9	600.3
1989	499.5	535.0*	317.8	331.0*	348.6	401.9	313.3	549.9	258.3	411.5	322.9
1990	432.7	474.3*	364.8	281.7*	344	452.2	278.5	595.4*	340.7	375.9	373.2
1991	485.2	522.1*	493.6	320.3*	373.7	475	319.1	517.4*	421.4	404.3	478.1
1992	614.1	636.1*	435.4	417.3*	423.1	523.7	411.0	570.1*	429.4	451.4	488.5
1993	525.2	557.3*	440.9	350.1*	324	390	312.0	548.2*	338.1	356.9	369.9
1994	519.3	552.7*	489.9	345.7*	381.8	556.2	340.4	319.9*	355	412	391.8
1995	513.8	547.2*	459.8	341.6*	377.5	508.7	335.4	440.6*	385.9	407.9	431
MEAN	525.223	296.604	381.062	188.254	406.112	460.227	359.011	331.481	384.862	396.615	439.292

* Interpolated Precitation Values

Figure 3.3 gives the graphical relationship between the altitudes of the precipitation stations and mean annual precipitation of the stations. The regression equation is fitted to get the best-fit line with the regression coefficient of 0.52. The equation of the line is determined as:

$$\mathrm{MAP} = 142.3 + 16.67 \times \mathrm{Altitude} \qquad (3.1)$$

MAP is in millimetres and altitude is the height in 100m.

When the mean elevation of the region is 1950m whereas the arithmetic mean of the station elevations is 1719m. When the former is substituted into the equation above, it gives 467.37mm for the areal mean elevation.

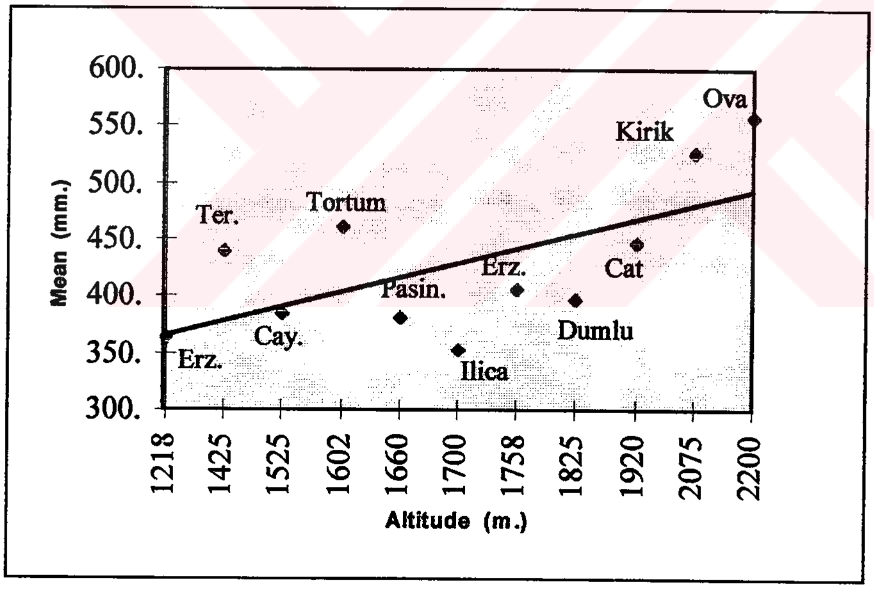


Figure 3.3 Mean Annual Precipitation vs. Elevation

3.2 TIME-SERIES ANALYSIS OF PRECIPITATION DATA

For time-series analysis of the annual rainfall data, the normalization procedure proposed by Turkes (1996) is followed. The normalized annual rainfall (A_{sy}) for a given station is derived first:

$$A_{sy} = (R_{sy} - R_s) / \sigma_s \qquad (3.2)$$

where R_{sy} is the annual total rainfall for the stations during the year y; R_s and σ_s are the mean and the standard deviation of the annual rainfall (Table 3.2) for that station respectively. The area averaged normalized annual rainfall for a given region A_{ry} is defined next:

$$A_{ry} = (1 / N_s) \sum_{s=1}^{N_s} A_{sy} \qquad (3.3)$$

where N_s is the number of areal stations operating in year y.

The precipitation data of the 11 stations in the region using 26 years of data are analyzed for wetness and dryness characteristics and presented in Table 3.4. The total normalized annual rainfall, A_{sy} using Eq. 3.2 and the area averaged normalized annual rainfall, A_{ry} using Eq. 3.3 are given in Table 3.5. Figure 3.4 shows the dry and wet years variations of the region graphically in time scale. The wetness-dryness characteristics of the precipitation stations are shown in Figure 3.5. A_{ry} values above the X-axis show that the year is wet, the values below the line show that the year is dry. As a result of the values shown in Figure 3.4, the wettest year is 1979, the dryest year is 1970.

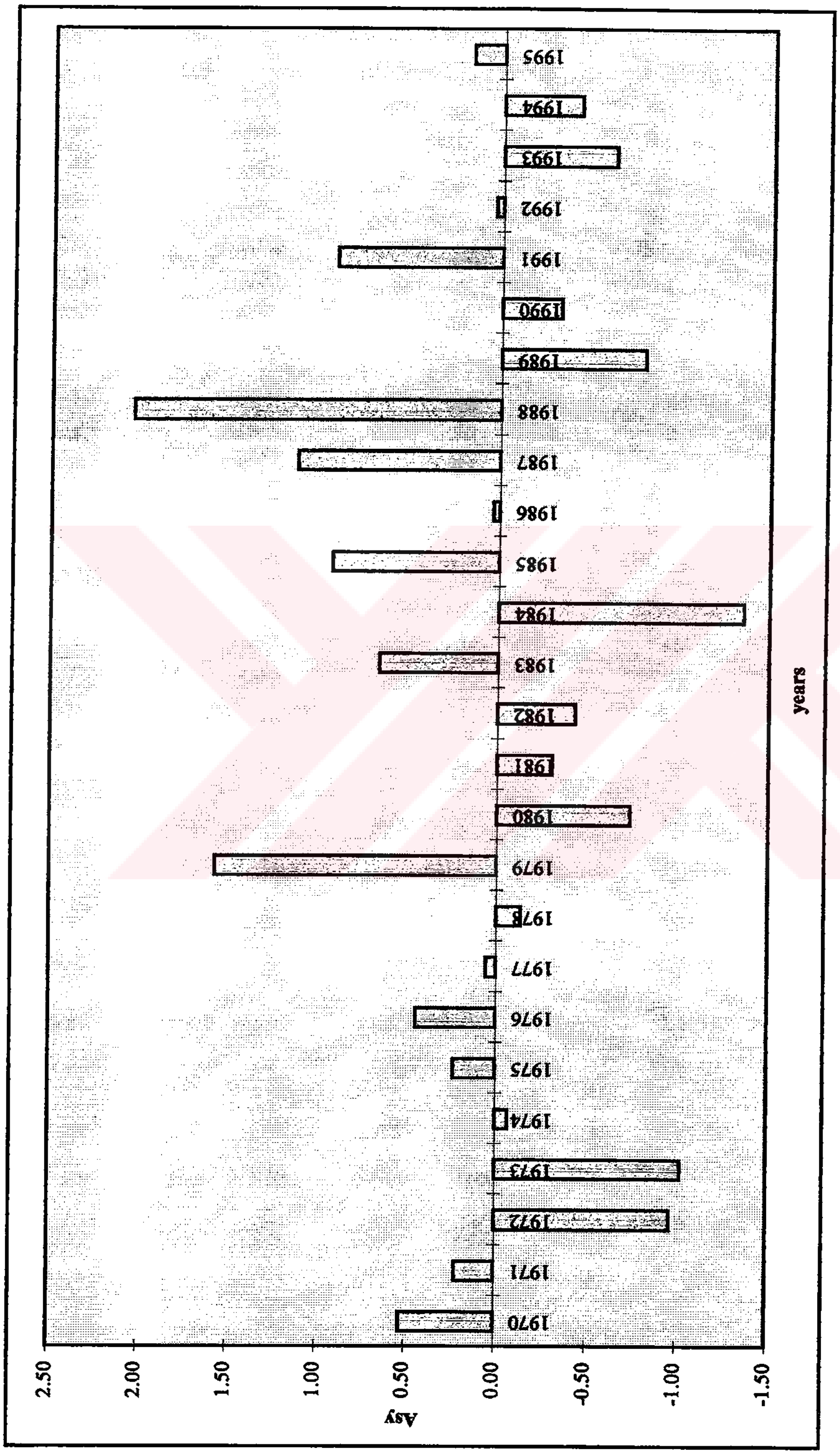


Figure 3.4 Normalized Annual Rainfall over the Basin

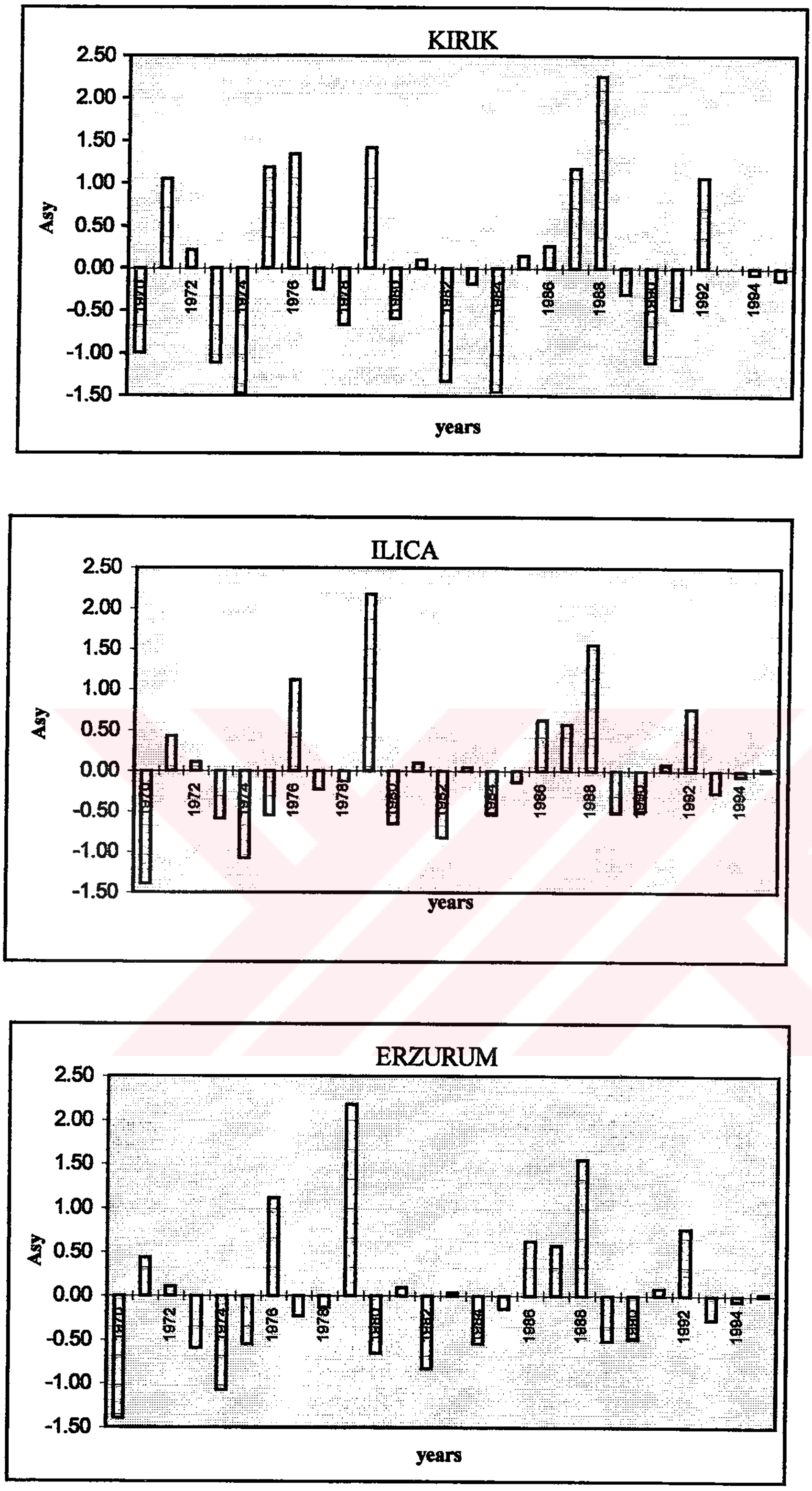
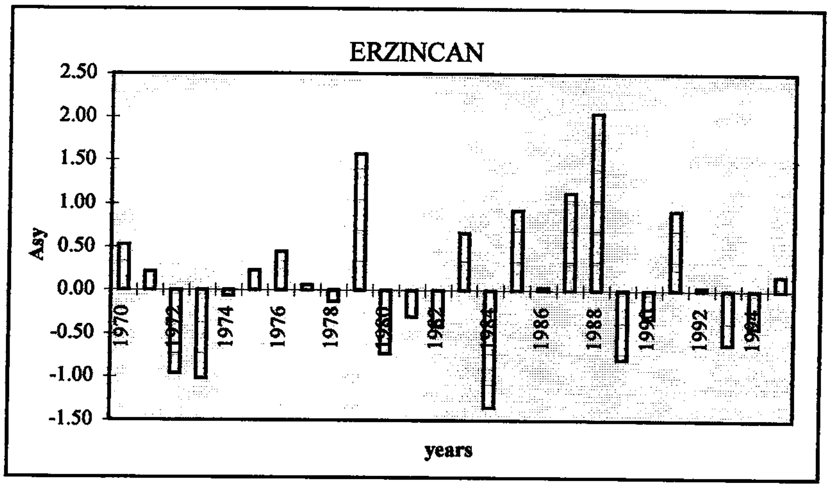
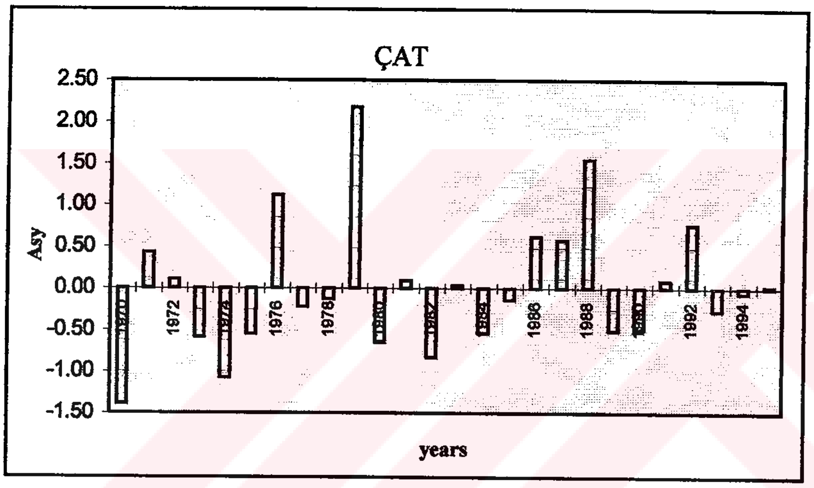


Figure 3.5 The Normalized Annual Rainfall of The Stations





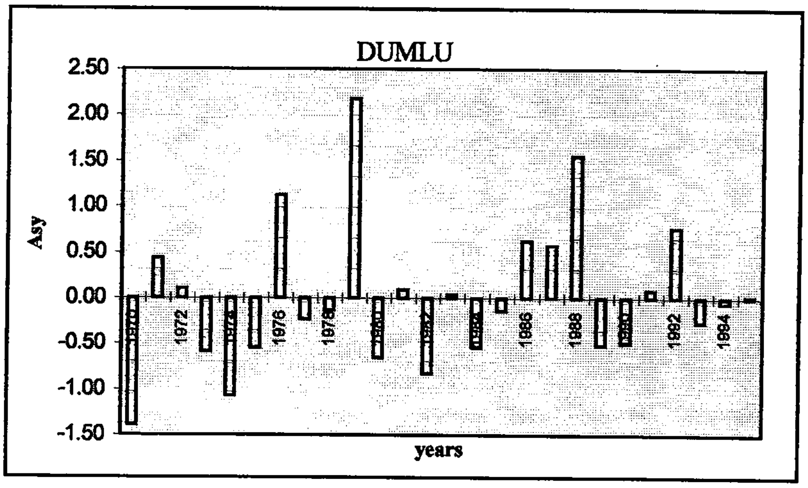


Figure 3.5 (continued)

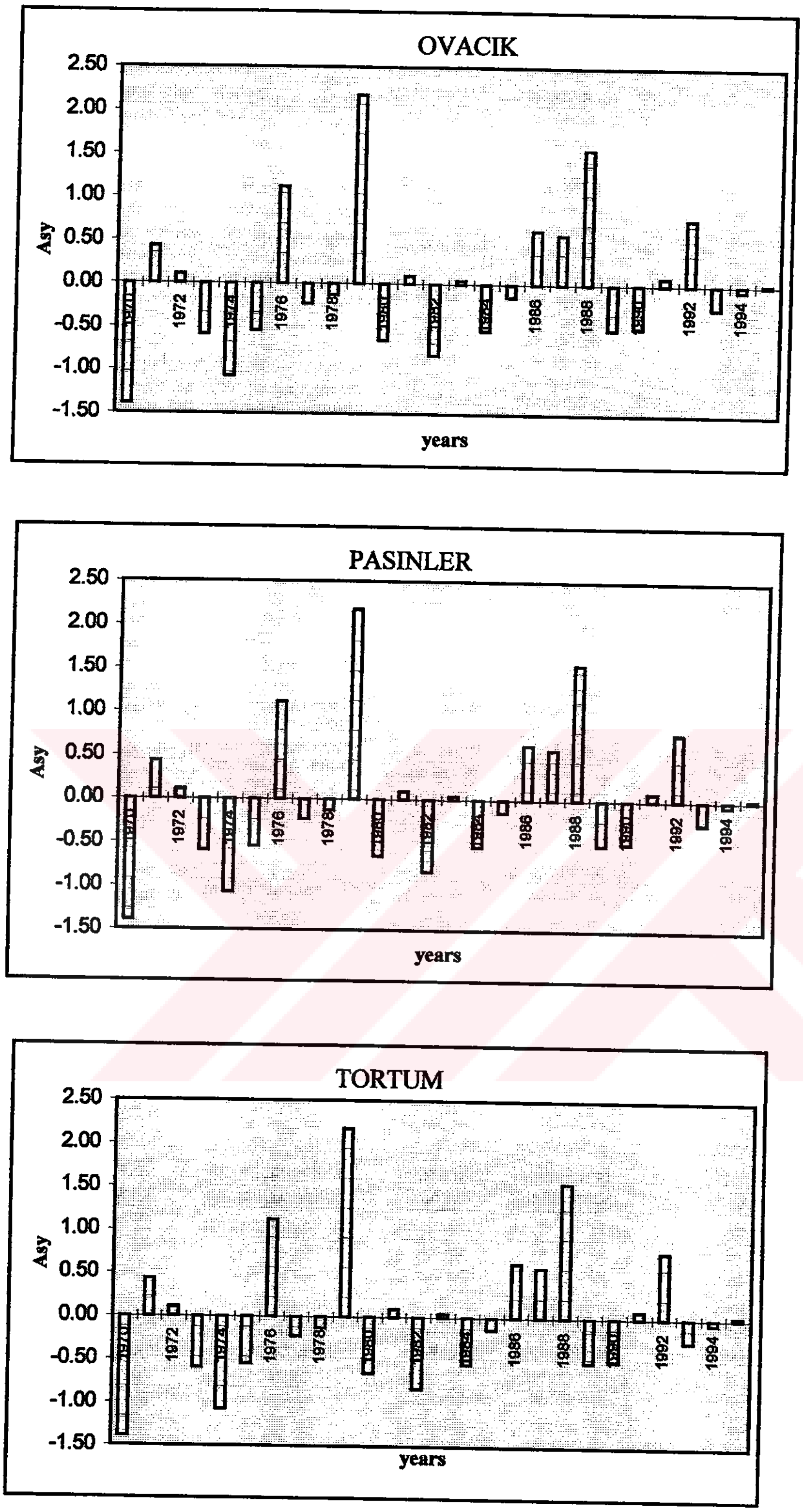
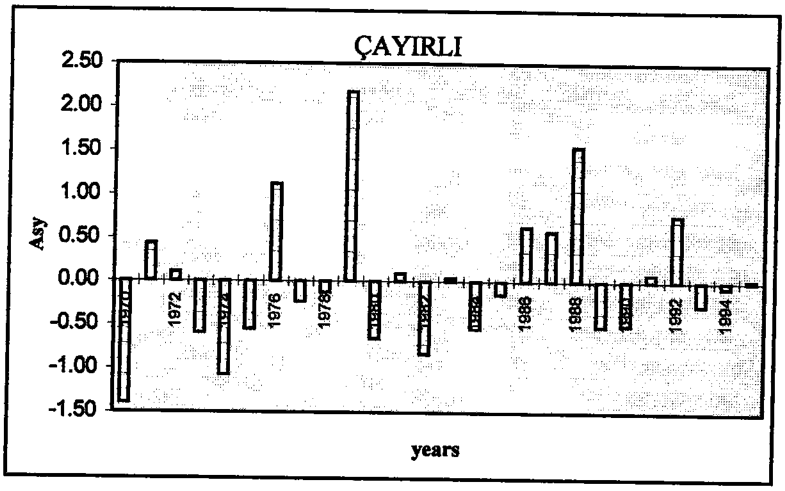


Figure 3.5 (continued)



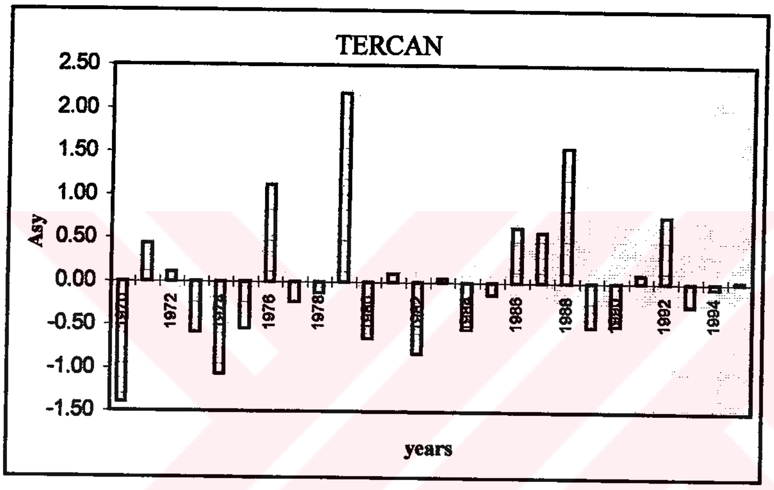


Figure 3.5 (continued)

Table 3.4 The Normalized Annual Rainfall of The Precipitation Stations

	KIRIK	OVAC.	ILICA	PASİN.	ERZUR	TORTU	ERZIN.	ÇAT	ÇAYIR	DUMLU	TERCAN
1970	-1.00	-1.11	-1.51	-2.05	-1.81	-1.18	0.53	-1.81	-1.07	-1.44	-0.80
1971	1.05	1.66	1.66	-0.48	-0.66	1.23	0.22	-0.76	-0.13	0.71	-0.04
1972	0.22	0.23	-0.22	0.31	0.62	1.80	-0.97	-0.87	-0.42	0.22	-0.64
1973	-1.12	-0.64	-0.53	-1.24	-0.48	0.99	-1.03	-0.45	-0.93	-0.56	-0.03
1974	-1.48	-1.57	-0.88	-1.94	-0.21	-1.59	-0.07	-0.77	-0.43	-1.41	-0.87
1975	1.19	0.19	-1.42	-1.01	-0.46	-0.51	0.23	-0.82	-0.17	-1.36	-0.40
1976	1.34	1.34	1.57	1.09	1.63	0.23	0.44	1.49	0.47	-0.12	1.24
1977	-0.25	-0.76	-0.10	-0.56	-0.51	0.42	0.06	-0.87	0.73	-0.83	0.07
1978	-0.67	-0.23	0.56	0.00	-0.12	-0.50	-0.14	0.37	-0.63	-0.47	-0.32
1979	1.42	1.86	2.30	0.87	2.94	2.06	1.57	1.79	3.31	1.70	3.07
1980	-0.60	-0.73	-0.79	-0.93	-0.53	-1.07	-0.74	-0.79	0.36	-1.98	-0.38
1981	0.10	0.04	-0.04	0.36	0.52	-0.02	-0.31	-0.07	-0.11	0.11	-0.15
1982	-1.33	-1.20	-0.73	-0.35	-0.28	-2.24	-0.43	-0.87	-0.25	-1.00	-0.43
1983	-0.19	-0.25	-0.53	-0.08	0.16	-0.31	0.66	-0.03	0.58	1.66	-0.41
1984	-1.47	-1.41	-1.19	0.27	1.09	-0.50	-1.36	-1.11	-0.37	-0.09	-0.78
1985	0.15	0.15	0.08	-0.58	-0.16	-0.82	0.93	-0.06	-0.72	0.74	-0.41
1986	0.27	0.26	0.17	0.47	1.52	0.32	0.03	1.06	0.25	0.95	0.92
1987	1.17	1.10	0.91	-0.10	0.54	0.42	1.12	-0.35	0.04	0.67	1.11
1988	2.26	2.09	1.80	2.23	0.46	0.35	2.04	0.63	1.96	1.95	2.02
1989	-0.31	-0.29	-0.29	-0.70	-0.91	-0.62	-0.80	1.06	-1.88	0.20	-1.46
1990	-1.11	-1.06	-0.92	-0.18	-0.98	-0.09	-0.33	1.53	-0.66	-0.28	-0.83
1991	-0.48	-0.45	-0.42	1.25	-0.51	0.16	0.92	0.73	0.54	0.10	0.49
1992	1.07	1.00	0.82	0.60	0.27	0.68	0.04	1.27	0.66	0.73	0.62
1993	0.00	0.01	-0.04	0.66	-1.29	-0.75	-0.63	1.05	-0.69	-0.53	-0.87
1994	-0.07	-0.06	-0.10	1.21	-0.38	1.03	-0.44	-1.30	-0.44	0.20	-0.59
1995	-0.14	-0.12	-0.15	0.87	-0.45	0.52	0.17	-0.06	0.02	0.15	-0.10

Table 3.5 The Area Averaged Normalized Annual Rainfall of Precipitation Stations

YEARS	ΣA_{sy}	A_{ry}
1970	-13.27	-1.21
1971	4.46	0.41
1972	0.27	0.02
1973	-6.03	-0.55
1974	-11.23	-1.02
1975	-4.54	-0.41
1976	10.72	0.97
1977	-2.62	-0.24
1978	-2.15	-0.20
1979	22.89	2.08
1980	-8.19	-0.74
1981	0.43	0.04
1982	-9.12	-0.83
1983	1.26	0.11
1984	-6.91	-0.63
1985	-0.69	-0.06
1986	6.21	0.56
1987	6.63	0.60
1988	17.78	1.62
1989	-5.99	-0.54
1990	-4.90	-0.45
1991	2.32	0.21
1992	7.76	0.71
1993	-3.09	-0.28
1994	-0.95	-0.09
1995	0.70	0.06

3.3 MEAN ANNUAL PRECIPITATION WITH VARIOUS TOPOGRAPHIC GRID SIZE

To obtain an indication of the differences due to topographic grid cell size, the precipitation data is examined for the basin with 3000 m, 5000 m, and 10000 m grid cell size using the SPAM model results. This makes an indication how cell size affects on the mean annual precipitation using detrended kriging method. The number of rows and the columns of Digital Elevation Model (DEM) of three mashes are 34 x 70, 20 x 42, and 9 x 18, respectively. The origin of coordinates in Y and X direction of the DEM is located at latitude 510770m (north) and longitude 4366730m (east) in UTM system.

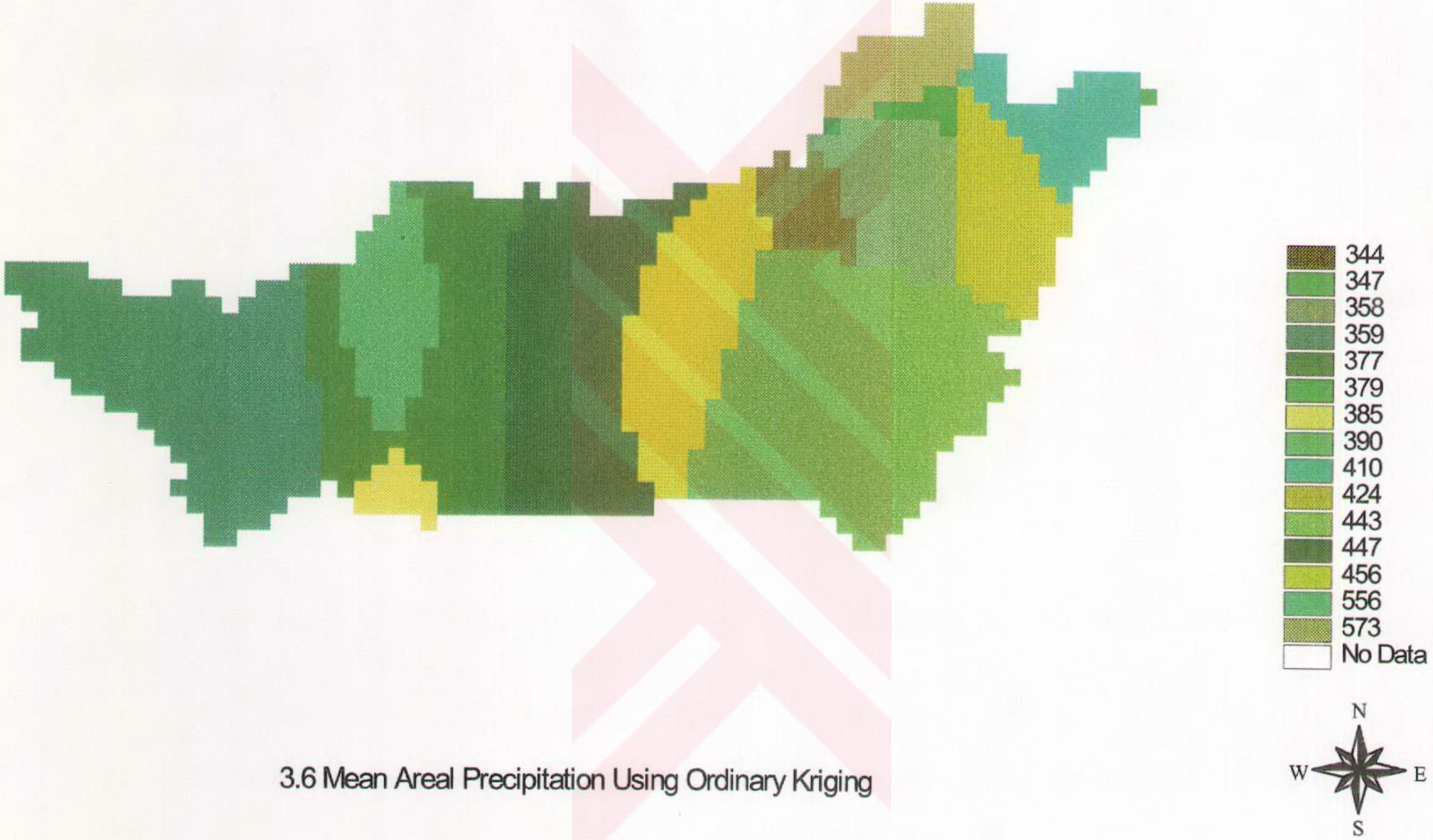
The mean annual precipitation maps of the region using ordinary and detrended kriging are shown in Figures 3.6 and 3.7. The figures are obtained from ARCVIEW program which gives the grid cell precipitation estimations in a graphical way. The figures also give the incremental precipitation depth due to the change in precipitation estimation methods.

The DEM, elevation of each grid cell at mid point, for these grid cell size and input data for SPAM are given in Appendix A.1. and A.2, respectively. The results of the detrended kriging with 3000 m, 5000 m and 10000 m grid cell are given in Tables 3.6, 3.7, and 3.8, respectively. The values given in tables are used to calculate the annual areal average of precipitation for each year of grid cell (Equation 2.28).

There are constraints placed on the detrending regression lines. For precipitation, the slope of the line must be positive, otherwise it is set to zero. This is to ensure that the detrending is in fact dealing with orographic influences, for which precipitation increases with elevation. By setting the slope to zero if it is negative, thereby saying that there is no trend with elevation, and the interpolation consists only of kriging in the horizontal (Section 2.5.1). The regression intercept is constant for the precipitation equation and the slope is given as mm per 1000 m of elevation.

For estimating the detrended line, the program uses either the usual least squares or it can use least square deviation regression. The latter one is a robust regression technique that is less influenced by extreme values called outliers. It is suggested by Garen (1994) to use least absolute deviation regression for precipitation data.

The mean absolute error (MAE) in the following tables is defined as the average of sum of squares of the difference between the observed and the estimated precipitation of the basin.



3.6 Mean Areal Precipitation Using Ordinary Kriging

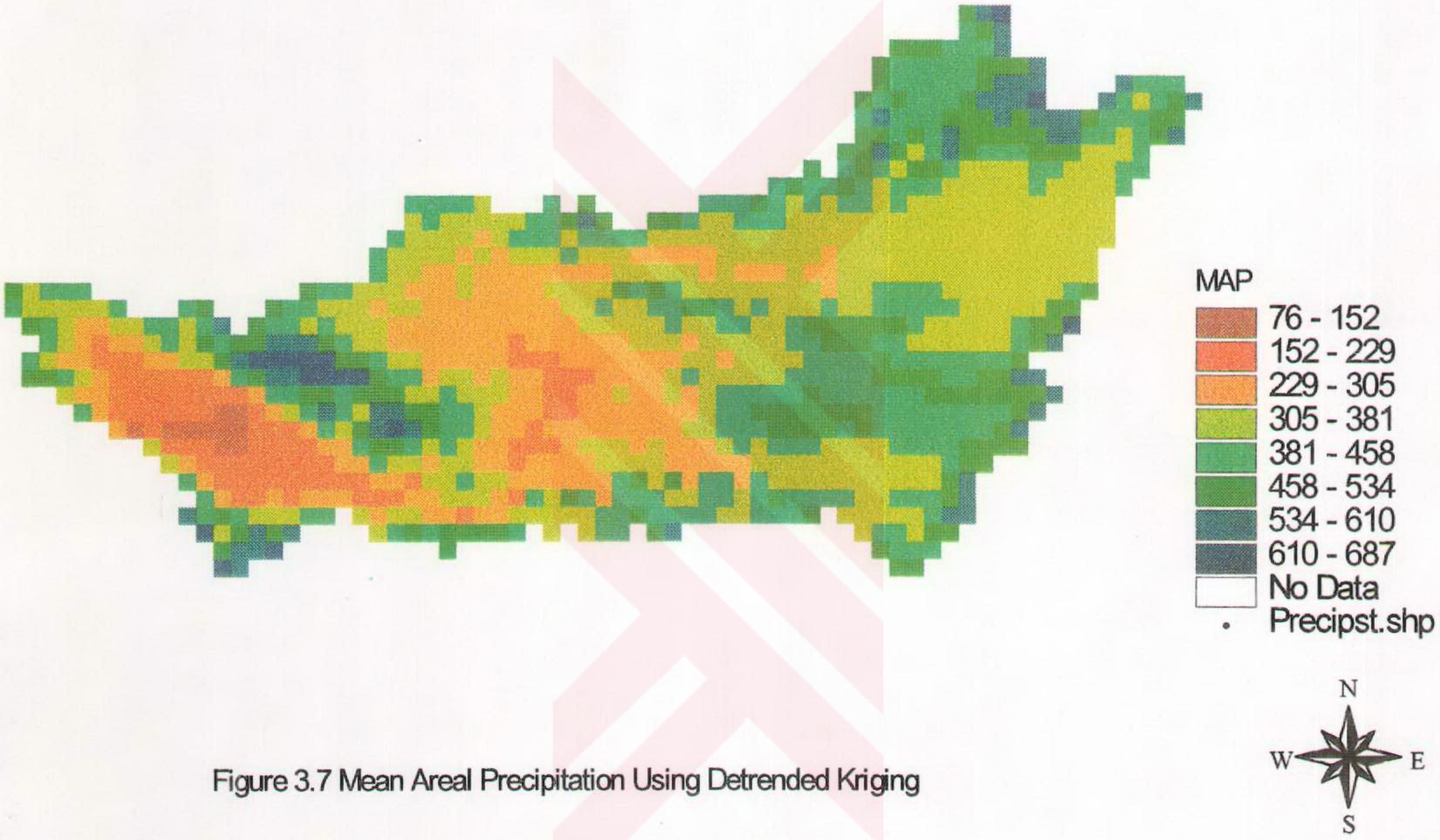


Figure 3.7 Mean Areal Precipitation Using Detrended Kriging

Table 3.6 SPAM Results for Grid Cell Size 3000 m

YEAR	INTERCEPT	SLOPE	MAE (mm^2)	MAP (mm)
1970	0.00	0.00	0.00	307.3
1971	109.14	219.75	68.80	495.8
1972	-86.74	300.99	57.02	520.6
1973	50.93	183.86	47.88	488.3
1974	229.64	82.89	32.88	366.9
1975	0.00	0.00	0.00	382.1
1976	-2.59	302.26	42.43	605.9
1977	196.91	136.83	54.65	441.3
1978	175.29	141.70	30.17	480.1
1979	293.78	170.13	47.25	660.5
1980	102.73	160.79	50.86	396.4
1981	96.20	195.03	34.18	483.7
1982	195.29	105.50	40.83	344.4
1983	180.90	158.32	32.63	475.5
1984	209.06	99.10	45.62	382.9
1985	-114.64	310.76	41.01	492.7
1986	93.90	219.90	36.36	565.7
1987	0.00	0.00	0.00	446
1988	384.37	86.85	63.65	524.5
1989	-64.63	271.90	39.52	541.6
1990	188.75	117.52	51.31	551.1
1991	360.16	60.34	45.28	508.8
1992	22.35	278.99	41.56	602.4
1993	-59.34	280.53	42.97	538.4
1994	146.14	145.62	55.97	438.1
1995	255.93	96.16	44.10	481.5

Table 3.7 SPAM Results for Grid Cell Size 5000 m

YEAR	INTERCEPT	SLOPE	MAE (mm^2)	MAP (mm)
1970	0.00	0.00	0.00	307.3
1971	109.14	219.75	68.80	497.2
1972	-86.74	300.99	57.02	522.8
1973	50.93	183.86	47.88	489.6
1974	229.64	82.89	32.88	367.4
1975	0.00	0.00	0.00	382.1
1976	-2.59	302.26	42.43	607.7
1977	196.91	136.83	54.65	442.2
1978	175.29	141.70	30.17	480.9
1979	293.78	170.13	47.25	661.6
1980	102.73	160.79	50.86	397.4
1981	96.20	195.03	34.18	484.9
1982	195.29	105.50	40.83	345
1983	180.90	158.32	32.63	476.5
1984	209.06	99.10	45.62	383.6
1985	-114.64	310.76	41.01	495
1986	93.90	219.90	36.36	567.1
1987	0.00	0.00	0.00	446
1988	384.37	86.85	63.65	525
1989	-64.63	271.90	39.52	543.3
1990	188.75	117.52	51.31	551.8
1991	360.16	60.34	45.28	509.2
1992	22.35	278.99	41.56	604.2
1993	-59.34	280.53	42.97	540.1
1994	146.14	145.62	55.97	439.1
1995	255.93	96.16	44.10	482.2

Table 3.8 SPAM Results for Grid Cell Size 10 000 m

YEAR	INTERCEPT	SLOPE	MAE (mm^2)	MAP (mm)
1970	0.00	0.00	0.00	307.30
1971	109.14	219.75	68.80	501.10
1972	-86.74	300.99	57.02	527.60
1973	50.93	183.86	47.88	492.80
1974	229.64	82.89	32.88	368.90
1975	0.00	0.00	0.00	382.10
1976	-2.59	302.26	42.43	613.10
1977	196.91	136.83	54.65	444.70
1978	175.29	141.70	30.17	483.40
1979	293.78	170.13	47.25	664.60
1980	102.73	160.79	50.86	400.30
1981	96.20	195.03	34.18	488.40
1982	195.29	105.50	40.83	346.90
1983	180.90	158.32	32.63	479.30
1984	209.06	99.10	45.62	385.30
1985	-114.64	310.76	41.01	499.60
1986	93.90	219.90	36.36	571.00
1987	0.00	0.00	0.00	446.00
1988	384.37	86.85	63.65	526.50
1989	-64.63	271.90	39.52	548.10
1990	188.75	117.52	51.31	553.90
1991	360.16	60.34	45.28	510.30
1992	22.35	278.99	41.56	609.10
1993	-59.34	280.53	42.97	545.00
1994	146.14	145.62	55.97	441.70
1995	255.93	96.16	44.10	483.90

The results of the detrended kriging for different grid sizes are given in Table 3.9. The averaged values for the intercept, slope and mean absolute error (MAE) are the same for each grid size. But the mean areal precipitation (MAP) changes gradually. The reason for that is the lack of the altitudes as grid size increases.

Table 3.9 Averaged Results of Detrended Kriging For Different Grid Size

CELL SIZE (m)	INTERCEPT	SLOPE	MAE (mm^2)	MAP (mm)
3000	128.85	179.38	45.52	481.43
5000	128.85	179.38	45.52	482.66
10000	128.85	179.38	45.52	485.42

Mean areal precipitation using ordinary and detrended kriging are given in Table 3.10 as discussed in Section 2.6. Two methods are used for different grid cell size to estimate the long-term mean areal precipitation. Table 3.10 also shows the arithmetical mean annual precipitation (428.7 mm) for 26 years of precipitation records of 11 precipitation stations. The Thiessen polygon method gives 410. 6 mm for areal precipitation. The mean precipitation should be corrected to take elevation factor into account. The mean elevation of the stations is 1719 m and the mean elevation of the area, obtained from hypsometric curve, is determined as 1950 m. Multiplying the difference by the average slope from SPAM will give the elevation effect to the areal mean precipitation when arithmetic, Thiessen or ordinary kriging is used. Since the slope over the basin in

Table 3.9 is 18 mm/100m, the corrected mean areal precipitation is shown for arithmetic procedure:

$$428.7 + \frac{1950 - 1719}{100} \times 18 = 470 \text{ mm}$$

Above equality gives the estimated mean of the areal precipitation taking the elevation parameter into account and gives close estimation value (467.37 mm) using the regression Equation 3.1.

Table 3.10 Observed and Estimated Mean Areal Precipitation Obtained From Two Methods for 26 Years

CELL SIZE(m)	D.KRIGING*	O.KRIGING*	ARITH.MEAN*	THIESSEN*
3000	481.43	414.00	428.7	410.6
5000	482.66	415.37	428.7	410.6
10000	485.42	428.70	428.7	410.6

* All are in millimeters.

3.4 SPAM RESULTS WITH VARIOUS STATION NUMBERS

In this part of the thesis, some selected precipitation stations are excluded from the study to find the effect of the absence of the precipitation data. The change of the parameters in the regression such as intercept, slope and mean areal precitation is examined in three (3) cases using 3000 m cell grid size. It is important to conclude how the lack of the precipitation station changes the overall results.

For the first case, Ilıca station is omitted as the first station due to its coordinates and the characteristics of the precipitation data. It has the lowest precipitation mean, 353.30 mm, and the precipitation data is extrapolated by regression from 1984-1995 using Ovacık records. There are three stations in the vicinity of Ilıca such as Dumlu, Ovacık and Erzurum. The results of SPAM are given in Table 3.11.

For the second case, meteorological records of Ilıca, Dumlu and Ovacık stations are omitted from the input precipitation data. Dumlu has two precipitation stations nearby which are Erzurum and Tortum. Records of the last precitation station, Ovacık, are extracted because it has the highest precipitation data (557.5 mm) of the region. The outcomes of SPAM are given in Table 3.12.

Additionally, in the last case, Kırık and Tortum records are excluded from the precipitation analysis due to their locations in the basin. They are close to the boundary of the region, but out of the region. Table 3.13 shows the resulting values of SPAM analysis with five stations disregarding after these five precipitation stations.

The overall results of these 3 cases are summarized in Table 3.14. This table shows the average values of intercept, slope, mean absolute error (MAE) and mean areal precipitation (MAP) when extracting one (Case 1), three (Case 2) and five stations (Case 3) out of total 10 precipitation stations.

Table 3.11 Mean Annual Precipitation (mm) Results With SPAM Without Precipitation Station ILICA (Case1)

YEAR	INTERCEPT	SLOPE	MAE(mm^2)	MAP (mm)
1970	0.00	0.00	0.00	307.30
1971	42.52	274.45	74.78	510.40
1972	-85.77	300.53	53.53	522.70
1973	51.07	183.85	47.43	489.60
1974	284.01	56.72	26.23	361.20
1975	268.58	89.65	64.40	403.30
1976	63.26	272.29	42.91	600.60
1977	290.10	94.30	50.89	432.20
1978	174.87	141.97	31.35	481.00
1979	338.53	146.81	46.57	656.00
1980	48.05	205.52	46.55	408.00
1981	52.04	231.16	28.30	493.50
1982	195.57	105.36	36.65	345.00
1983	181.18	158.18	20.92	476.50
1984	208.95	99.18	37.66	383.60
1985	-115.11	311.02	39.58	495.00
1986	93.84	220.00	29.18	567.10
1987	297.12	126.01	63.52	475.90
1988	383.91	87.14	66.47	525.10
1989	-64.25	271.68	36.50	543.30
1990	188.69	117.60	45.13	551.90
1991	361.13	59.79	34.48	509.10
1992	22.73	278.81	37.36	604.20
1993	-17.81	261.69	40.09	535.60
1994	44.52	228.81	54.31	458.80
1995	173.11	164.12	38.27	498.30

Table 3.12 Mean Annual Precipitation (mm) Results With SPAM Without Precipitation Station ILICA, DUMLU and OVACIK (Case2)

YEAR	INTERCEPT	SLOPE	MAE(mm^2)	MAP (mm)
1970	0.00	0.00	0.00	308.10
1971	0.00	0.00	0.00	446.40
1972	-93.61	306.66	60.98	527.40
1973	52.05	183.26	48.99	492.90
1974	283.73	56.85	16.15	362.20
1975	0.00	0.00	0.00	384.20
1976	55.33	279.04	29.93	605.50
1977	239.03	127.78	46.10	442.80
1978	175.15	141.81	22.52	482.80
1979	511.20	63.54	38.09	638.90
1980	101.86	161.45	33.12	400.30
1981	96.63	194.75	25.96	486.30
1982	238.54	84.66	32.30	339.70
1983	346.55	50.66	13.95	449.40
1984	241.79	77.79	44.29	378.70
1985	307.22	69.67	39.25	436.30
1986	44.57	260.45	29.74	578.10
1987	0.00	0.00	0.00	446.50
1988	0.00	0.00	0.00	503.60
1989	-63.60	271.37	43.85	544.60
1990	188.72	117.58	50.27	554.60
1991	361.05	59.83	30.70	510.90
1992	4.98	293.55	33.81	610.10
1993	-1.88	254.01	36.50	536.10
1994	190.92	108.77	60.23	431.90
1995	256.18	96.05	37.05	484.00

Table 3.13 Mean Annual Precipitation (mm) Results With SPAM Without Precipitation Station ILICA, DUMLU, OVACIK, KIRIK AND TORTUM (Case3)

YEAR	INTERCEPT	SLOPE	MAE(mm^2)	MAP(mm)
1970	0.00	0.00	0.00	287.6
1971	0.00	0.00	0.00	370.6
1972	-23.23	248.94	36.06	422.2
1973	53.00	182.26	27.07	416.7
1974	321.03	26.34	8.34	380.4
1975	0.00	0.00	0.00	370.8
1976	55.67	278.76	37.26	601.3
1977	0.00	0.00	0.00	365.5
1978	113.74	192.12	28.65	482
1979	560.50	31.20	42.60	607
1980	0.00	0.00	0.00	364.3
1981	149.90	151.09	17.62	457.4
1982	232.76	88.47	20.61	381.6
1983	369.60	35.54	7.12	439.9
1984	-197.38	365.66	49.88	433.8
1985	0.00	0.00	0.00	428.2
1986	36.85	266.79	28.27	567.5
1987	0.00	0.00	0.00	423.6
1988	0.00	0.00	0.00	489.6
1989	121.63	141.19	51.43	497.9
1990	87.99	200.15	54.30	539.5
1991	288.66	119.13	38.61	492
1992	2.06	295.68	37.55	564.4
1993	-58.71	300.78	47.48	519.7
1994	197.79	103.13	25.14	355.3
1995	255.66	96.32	20.45	434.6

Table 3.14 Averaged SPAM Results for 3 Cases

	INTERCEPT	SLOPE	MAE (mm^2)	MAP (mm)
N=10	128.85	179.38	45.52	481.43
CASE 1 (N=9)	142.64	173.53	43.72	485.97
CASE 2 (N=7)	168.40	155.22	36.85	482.71
CASE 3 (N=5)	139.23	179.47	32.14	449.85

The tabulated values in Table 3.14 indicate that MAE and MAP values seem to decrease when the station number decreases. The reason is that with 9 stations as in Case 1, the number of years (N) included in regression analysis is 25 and this number decreases down to 18 when five stations left. When someone compares the MAE values of the years eliminated for Case 3 (1971, 1975, 1987, 1988), in these years, it is noticed that MAE values are higher than average MAE; so, the mean of 25 years of records decreases from 43.72 to 32.14 when there are 5 stations remain in the network analysis.

Setting the slope of the detrended regression line to zero means that there is no trend in precipitation with elevation, interpolation is done only using kriging technique in which MAP values start decreasing from 485.95 mm to 449.75 mm getting closer to arithmetic mean or Thiessen polygons methods.

3.5 ANALYSIS OF ANNUAL AND SEASONAL DATA USING SEMIVARIOGRAM AND SPAM

In this part of the thesis, the precipitation data are examined with respect to the seasonal characteristics of the precipitation periods. Various semivariogram models are tested to see the change in nugget (γ_n) which is the discontinuity in the origin of the variogram. The model uses ordinary kriging method of analysis and represents phenomena with a high scale of fluctuations wide persistance over large distances. It also utilises a distance (h) called range representing the maximum length in meters over which observations are correlated. There is a maximum asymptotic value called the sill (γ_r) which equals the calculated variance. The semivariogram is analyzed with these three values (γ_n. γ_r and h) which indicates the characteristics of each period. GEO-EAS is used to analyze the precipitation data. Input and output data of annual precipitation data for GEO-EAS are given in Appendix A.3 and A.4, respectively.

The annual precipitation data are used for the first step. The second step is dividing the annual precipitation data into two seasons to see the effect of the wet and dry seasons. First season, Season 1 and Season 2 have the precipitation data of October to March and is April to September, the precitation data of the seasons are given in Table 3.15 and 3.16, respectively. Since the second season has two precipitation periods, namely snow melt period in spring and dry period in summer months, the data are analyzed for these two different periods. The change of the semivariogram values, nugget, sill and range are analyzed. The results are given in Table 3.19. The change in sill and range of the semivariogram apperently shows that the second period of the Season 2 has a noticable fall in precipitation values. So they are analyzed separately. The precipitation data of Season 2 is divided into two different periods as April to June and July to September. First period, April to June, has higher precipitation records than the second period, July to September. The precipitation records are given in Table 3.17 and 3.18, respectively. The results of the semivariogram values for these 2 Seasons and 2 subseasons are given in Table 3.19.

Table 3.15 Precipitation (mm) of October-March of 11 Precipitation Stations

	KIRIK	OVACIK	ILICA	ERZURUM	TORTUM	PASIN.	ERZINCAN	CAT	CAYIRLI	DUMLU	TERCAN
1970	268.1	230.7	140.9	106.2	117.9	106.2	261.3	160.7	185.1	162.7	257.9
1971	294.9	303.4	188.2	166.3	172.3	166.3	183.8	193.5	178.4	218.6	218.1
1972	162.3	203.4	100.3	129.4	110.7	129.4	127.1	143.6	115.1	123.2	144.6
1973	248.7	275	167.7	163.2	194.2	163.2	158.8	249.9	176.4	197.9	259.2
1974	153.3	171.8	110.2	78.9	149.8	78.9	162.6	168.4	176.2	90.7	215.3
1975	296.2	237.1	84.5	122	131.5	122.0	146.7	161.9	163.2	119.2	203.5
1976	340.7	348	220.5	145	195.9	145.0	225.8	276.8	196.4	123.8	264.1
1977	194.9	244.3	108.6	174.4	126.3	174.4	220.2	141.5	243.2	114.4	204.7
1978	242.7	303.4	196.8	207.8	174	207.8	209.1	232.3	208.5	168.7	235.9
1979	407.9	488.7	298.3	254.3	287.3	254.3	333.8	309	361.2	245.2	394.6
1980	271	281.8	161.4	180	231.2	180.0	158.1	171.2	236.7	138.7	250.8
1981	233.7	243.7	123	137.2	155.2	137.2	159.7	178.7	158.9	123.8	215.7
1982	152.3	156.2	86.9	127.3	135.7	127.3	97.1	155.3	94.4	76.3	131.8
1983	269.7	356.1	186.8	172.9	155.8	172.9	194.9	219.4	198.5	210	227.1
1984	159.5	150.3	109.1	188.2	156	188.2	75.1	109.7	134.7	183.6	130.7
1985	318	323.4	169.9	212.9	232.2	212.9	258	245.9	159.5	282	230.8
1986	251.6	276.3	162.3	218.9	249.5	218.9	190.3	309.6	226.9	232.8	279.2
1987	396.4	429	217.9	266.9	234.9	266.9	341.6	272.6	291.5	291.2	382
1988	379.3	397.3	200.3	253.5	191.8	253.5	354.5	233.3	266.2	250.2	365.3
1989	298.9	346.2	208.1	205.1	197.2	205.1	180.2	444.8	174.8	276.6	203.5
1990	208.3	241.4	132.1	192.9	173.8	192.9	154.9	304	159.6	29.3	227.5
1991	217.8	225.9	149	293.9	171.1	293.9	254.9	245.7	217.6	142.4	268.7
1992	322.4	360.5	198.4	206.5	180	206.5	234.5	211.6	216	165.4	255.2
1993	194.6	215.8	129.1	160.6	75.2	160.6	125	169.6	135.1	75.8	158.1
1994	250.5	249.2	142.6	285	168.1	285.0	217.5	158.4	188.4	152.2	217.6
1995	242.2	267.3	164.9	245.9	200.5	245.9	205.8	215	190	180.4	227.9
MEAN	260.6	281.8	159.9	188.3	175.7	188.3	201.2	218.6	194.3	168.3	237.3

Table 3.16 Precipitation (mm) of April-September of 11 Precipitation Stations

	KIRIK	OVACIK	ILICA	ERZURUM	TORTUM	PASIN	ERZINCAN	CAT	CAYIRLI	DUMLU	TERCAN
1970	173.8	325.4	94.6	89.9	173.2	89.9	140.9	110.2	127.5	125.6	117.1
1971	317.6	298.2	294.6	172.3	215.1	172.3	193	197.2	197.7	231.4	217.9
1972	380.8	359.4	236.2	279.5	334.5	279.5	152.8	218.8	241.3	289.6	243.9
1973	183.6	287.9	172	138.8	201	138.8	116.2	164.7	172.9	196	177.4
1974	248.4	218.4	174.8	127.4	242.8	127.4	190.5	203.2	193	199.5	154.5
1975	327.8	324.7	158.1	168.3	245.7	168.3	231.2	205.2	222.3	175	214.8
1976	296.2	294.3	255.8	333.8	313.8	333.8	169.4	314.3	220	282.4	274.5
1977	309.5	295.3	236.6	156	247.4	156.0	143.5	220.8	202.9	219.6	239.9
1978	226.7	222	200	231.8	224.6	231.8	138.7	250.3	146	192.8	188.2
1979	235.2	312.6	247.8	204.8	305.6	204.8	153.4	311.4	246.9	299.8	289.6
1980	204.1	233.8	130.5	187.6	141.2	187.6	140.4	198.4	172.3	108.7	158.2
1981	299.9	284.7	227.4	276.3	283.7	276.3	174.1	261.4	230.9	281	211.4
1982	261.9	299.3	209.3	285.5	252.6	285.5	226.7	206.8	273.3	244.9	272.8
1983	239.7	229.5	208.4	222.4	260.4	222.4	218	224.4	225.3	311.5	179.4
1984	244.8	231.5	156.5	208.7	342.2	208.7	172.9	246.9	240.8	225.1	246.4
1985	219.8	226.3	159.2	185.4	163.9	185.4	176.6	195.1	177	189.3	175.7
1986	296.2	324.3	240.3	230.3	252.9	230.3	171.5	251.3	174.7	278.6	233.4
1987	226.4	203	120.2	186.5	205.6	186.5	109	140.3	95.8	155.6	146.2
1988	334.1	321.1	236.5	328.7	243.2	328.7	171	274.8	250.6	292.7	235
1989	200.6	217	146.6	112.2	151.4	112.2	113.4	123.4	112.7	134.9	130.1
1990	224.4	240.2	161.9	171.4	170.2	171.4	176.9	291.5	199.9	64.5	156.4
1991	267.4	282	177	199.7	202.6	199.7	178.9	289.9	198.8	188.2	209.4
1992	291.7	275.4	178.7	228.9	243.1	228.9	127.7	358.5	227.2	207.7	233.3
1993	278.6	284.4	187.4	280.3	248.8	280.3	182.7	396.9	204	228.5	211.8
1994	268.3	274.6	172.1	204.9	213.4	204.9	105.9	161.5	172	204.9	174.2
1995	276.6	266.9	183.9	214.5	223.8	214.5	167.2	227.1	198.1	194.1	204
MEAN	262.9	274.3	191.0	208.7	234.7	208.7	163.2	232.5	197.1	212.4	203.7

Table 3.17 Precipitation (mm) of April-June of 11 Precipitation Stations

YEAR	KIRIK	OVACIK	CAYIRLI	CAT	DUMLU	TERCAN	PASINLER	TORTUM	ERZURUM	ERZINCAN	ILICA
1970	83.9	116.1	84	74.5	64.7	84.7	31	91.8	103.3	79.5	60.0
1971	208.8	262.8	131.5	140.4	168.2	165.3	104.8	195.9	134.2	137.0	215.1
1972	280.9	298.3	209.9	179.6	228.5	216.6	216.6	286.4	241	136.6	197.4
1973	162.5	167.6	139.6	140.7	113.8	173.5	92.7	212.8	139.9	104.8	117.3
1974	174.6	154.2	142.9	112.3	100.1	124	71.5	127.2	104.9	151.2	94.4
1975	232.4	222.8	137.9	154.3	115.4	168	137.5	136.3	187.2	181.6	128.6
1976	245.8	215.8	189.7	216.6	196.3	233.6	212.6	182	206.3	142.6	201.8
1977	259.4	241.5	185.8	206.6	172.3	234.3	117.6	226.4	194.7	126.4	193.4
1978	203.8	183.8	126.1	224.8	159.7	163.6	182.9	178.1	185.5	117.8	163.5
1979	201.2	260.8	209.2	267.8	239.5	223.7	182.6	253.8	258.1	119.7	207.3
1980	177.3	200.5	138	165.1	78.5	149.7	147.4	130.8	89.3	119.2	110.6
1981	207.8	220.4	181.7	223.8	220.8	190.8	195.8	222.4	202.8	144.4	177.5
1982	224.5	256.1	239.5	159	180.6	260.9	253.6	125.3	186.2	201.3	181.8
1983	169.9	162.5	183	170.1	247.2	144.7	155.8	177.6	178.3	181.9	167.3
1984	163.6	183.4	190.1	191.5	153.8	194.9	155.8	229.7	208.5	155.6	123.6
1985	160.9	169.4	150.8	169.1	150.2	134.1	164.4	140.6	134.3	155.4	118.0
1986	260	277.8	167.4	218.9	203.6	217.2	184.7	219.3	204.9	165.2	193.9
1987	143.2	147.1	64.1	84.5	112.4	78.2	155.8	108.3	144.8	56.5	103.7
1988	240	249.4	184.8	196.1	193.9	156.9	226.5	183.3	144.6	140.2	178.7
1989	163.3	168.9	97.6	69.7	96.1	87.6	68.5	122.7	102.8	85.3	119.4
1990	190.3	201.3	165.6	257.6	45.6	125.5	159.3	134.9	126.8	152.2	140.5
1991	202	220.2	155.4	224.2	135.1	165.9	119.9	147	141	156.1	149.7
1992	194.1	191.4	159.4	242.6	153.0	171.5	148.2	161.9	178.4	106.0	143.3
1993	214.8	225.6	181.5	355.4	187.8	202.4	219.9	196.6	217.3	162.4	159.3
1994	196.9	222.1	144.9	130.9	161.8	150.6	184.3	198.7	176.9	74.9	147.1
1995	212.2	208.0	157.6	177.5	140.6	167.3	161.2	182.2	161.3	134.4	157.5
MEAN	199.0	208.8	158.4	182.8	154.6	168.7	155.8	175.8	167.4	134.2	151.9

Table 3.18 Precipitation (mm) July-September of 11 Precipitation Stations

YEAR	KIRIK	OVACIK	CAYIRLI	CAT	DUMLU	TERCAN	PASINLER	TORTUM	ERZURUM	ERZINCAN	ILICA
1970	89.9	209.3	43.5	35.7	60.9	32.4	58.9	83.3	69.9	61.4	34.6
1971	108.8	35.4	66.2	56.8	63.2	52.6	67.5	140.2	80.9	56.0	79.5
1972	99.9	61.1	31.4	39.2	61.1	27.3	62.9	148.3	93.5	16.2	38.8
1973	21.1	120.3	33.3	24.0	82.2	3.9	46.1	50.9	61.1	11.4	54.7
1974	73.8	64.2	50.1	90.9	99.4	30.5	55.9	52.9	137.9	39.3	80.4
1975	95.4	101.9	84.4	50.9	59.6	46.8	30.8	74.6	58.5	49.6	29.5
1976	50.4	78.5	30.3	97.7	86.1	40.9	121.2	75.4	107.5	26.8	54.0
1977	50.1	53.8	17.1	14.2	47.3	5.6	38.4	70.7	52.7	17.1	43.2
1978	22.9	38.2	19.9	25.5	33.1	24.6	48.9	37.9	39.1	20.9	36.5
1979	34.0	51.8	37.7	43.6	60.3	65.9	22.2	70.0	47.5	33.7	40.5
1980	26.8	33.3	34.3	33.3	30.2	8.5	40.2	52.8	51.9	21.2	19.9
1981	92.1	64.4	49.2	37.6	60.2	20.6	80.5	49.3	80.9	29.7	49.9
1982	37.4	43.1	33.8	47.8	64.3	11.9	31.9	42.5	66.4	25.4	27.5
1983	69.8	67.0	42.3	54.3	64.3	34.7	66.6	78.7	82.1	36.1	41.1
1984	81.2	48.0	50.7	55.4	71.3	51.5	52.9	100.0	133.7	17.3	32.8
1985	58.9	56.9	26.2	26.0	39.1	41.6	21.0	54.8	29.6	21.2	41.2
1986	36.2	46.5	7.3	32.4	75.0	16.2	45.6	31.9	48.0	6.3	46.4
1987	83.2	55.9	31.7	55.8	43.2	68.0	30.7	116.3	60.8	52.5	16.5
1988	94.1	71.7	65.8	78.7	98.8	78.1	102.2	104.7	98.6	30.8	57.9
1989	37.3	48.1	15.1	53.7	38.8	42.5	43.7	57.4	48.6	28.1	27.2
1990	34.1	38.9	34.3	33.9	18.9	30.9	12.1	94.2	43.4	24.7	21.3
1991	65.4	61.8	43.4	65.7	53.1	43.5	79.8	94.9	61.6	22.8	27.3
1992	97.6	84.0	67.8	115.9	54.7	61.8	80.7	132.0	64.7	21.7	35.5
1993	63.8	58.8	22.6	41.5	40.7	9.4	60.4	51.8	31.5	20.3	28.1
1994	71.4	52.5	27.0	30.6	43.1	23.6	20.6	118.2	36.5	31.0	25.0
1994	64.4	58.9	40.5	49.6	53.5	36.7	53.3	74.5	62.5	32.8	26.4
MEAN	63.8	65.6	38.7	49.6	57.8	35.0	52.9	79.2	67.3	29.0	39.1

Table 3.19 Semivariogram Results for Different Periods

	TYPE	NUGGET(γ_n) (mm^2)	SILL(γ_r) (mm^2)	DISTANCE(h) (m)
ANNUAL	Spherical	2000	10000	40500
OCT.-MAR.	Spherical	1000	5500	42000
APR.-JUNE	Spherical	1000	2600	41000
JULY- SEP.	Spherical	0	850	37000
APR.-SEP.	Spherical	2000	4100	27000

Various semivariogram models are tested to find the best fit to the spatially distributed data. Spherical semivariogram model type is chosen. The discontinuity in the origin of the semivariogram, nugget (γ_n) mm^2, using Equation 2.10, is found as 2000 for annual and April-September precipitation data and 1000 for October-March and April-June. The sill values as the calculated variance, also called sample variance (γ_r), mm^2, using Equation 2.10, are computed as 10000 for annual, 5500, 4100, 2600, 850 for October-March, April-September, April-June and July-September precipitation data, respectively. A high scale of fluctuations appears over wide persistance over large distances, range representing the maximum length over which observations are correlated. The range, distance h in meters, decreases with decreasing precipitation.

The SPAM results for the given periods are given in Tables 3.20 to 3.23 for different time periods.

Table 3.20 SPAM Results for October-March

YEAR	INTERCEPT	SLOPE	MAE (mm^2)	MAP (mm)
1970	0.00	0.00	0.00	152.30
1971	-25.76	133.89	28.82	217.00
1972	4.89	72.25	17.15	147.30
1973	9.98	115.02	24.30	250.10
1974	0.00	0.00	0.00	160.00
1975	120.19	21.74	43.55	154.50
1976	-114.19	203.65	48.67	289.50
1977	0.00	0.00	0.00	140.70
1978	116.47	60.34	24.18	223.10
1979	0.00	0.00	0.00	301.70
1980	4.77	125.91	41.10	219.80
1981	82.85	49.90	31.20	179.70
1982	24.04	60.04	17.75	157.00
1983	117.49	53.10	32.06	207.70
1984	66.22	44.93	23.36	135.50
1985	-12.01	152.45	35.55	277.80
1986	83.66	87.56	27.72	299.60
1987	0.00	0.00	0.00	264.20
1988	0.00	0.00	0.00	226.90
1989	-6.06	147.01	37.78	371.80
1990	78.77	62.45	43.05	257.80
1991	0.00	0.00	0.00	218.10
1992	0.00	0.00	0.00	201.10
1993	-30.13	108.32	25.82	157.00
1994	50.92	90.14	40.08	186.20
1995	59.17	88.21	22.92	229.00

Table 3.21 SPAM Results for April-June

YEAR	INTERCEPT	SLOPE	MAE(mm^2)	MAP (mm)
1970	0.00	0.00	0.00	80.70
1971	74.22	51.51	30.14	172.30
1972	12.81	129.22	23.95	245.80
1973	30.08	62.49	23.87	177.90
1974	0.00	0.00	0.00	119.80
1975	-54.19	125.93	29.77	179.20
1976	85.66	68.21	15.39	215.50
1977	8.07	106.13	28.69	232.80
1978	75.60	61.77	17.09	214.90
1979	135.65	56.89	28.01	266.30
1980	33.32	68.64	19.84	164.70
1981	132.75	39.84	11.80	227.60
1982	168.45	27.00	36.59	156.70
1983	0.00	0.00	0.00	175.00
1984	0.00	0.00	0.00	201.80
1985	122.75	18.39	9.12	162.20
1986	72.15	76.42	17.60	233.40
1987	-48.70	89.02	17.71	113.10
1988	4.97	111.08	14.61	214.30
1989	45.87	32.38	21.34	97.40
1990	18.50	82.81	32.30	223.30
1991	26.15	84.74	23.37	211.10
1992	52.76	68.12	17.47	220.00
1993	119.39	48.25	24.10	295.60
1994	-29.14	114.18	20.93	179.00
1995	43.02	75.00	12.19	193.40

Table 3.22 SPAM Results for July-September

YEARS	INTERCEPT	SLOPE	MAE (mm^2)	MAP (mm)
1970	-82.02	82.87	24.46	74.70
1971	27.14	23.72	19.79	91.70
1972	-73.98	74.03	24.08	94.20
1973	-76.17	71.91	20.06	51.80
1974	-15.72	43.15	17.29	84.70
1975	29.64	16.41	15.95	63.20
1976	-91.93	97.53	22.57	108.80
1977	-29.69	38.44	12.56	44.10
1978	-0.28	17.47	6.73	33.80
1979	11.30	18.42	11.75	56.90
1980	0.00	0.00	0.00	39.30
1981	-32.38	50.98	13.59	54.00
1982	-7.90	27.34	10.47	51.30
1983	-11.68	39.25	10.08	71.20
1984	-33.78	55.41	20.67	82.20
1985	-14.78	29.53	9.77	43.10
1986	-39.73	39.23	11.26	40.90
1987	46.91	4.62	16.87	77.60
1988	43.10	24.57	15.68	91.00
1989	28.75	8.79	8.24	55.10
1990	22.21	6.09	11.94	55.50
1991	-4.35	33.60	11.38	80.90
1992	-16.62	55.04	18.53	127.30
1993	-47.33	48.25	9.30	55.40
1994	-27.35	36.31	15.65	70.10
1995	-8.70	34.08	6.68	65.40

Table 3.23 SPAM Results for April-September

YEAR	INTERCEPT	SLOPE	MAE (mm^2)	MAP (mm)
1970	0.00	0.00	0.00	134.5
1971	115.67	63.44	30.84	218.5
1972	-38.64	180.94	30.97	298.3
1973	143.23	19.46	26.17	179.4
1974	153.82	25.71	23.40	222.1
1975	0.00	0.00	0.00	220.4
1976	181.23	55.42	29.35	316.9
1977	-5.67	136.79	28.25	256.7
1978	78.77	71.30	19.99	249.4
1979	98.05	97.56	36.33	321.5
1980	39.59	82.74	19.18	192
1981	17.57	136.05	16.90	295.3
1982	220.84	19.80	23.84	229.4
1983	203.69	11.74	19.97	241
1984	0.00	0.00	0.00	275
1985	107.11	45.83	9.91	193.5
1986	-5.88	145.60	17.10	280.9
1987	-7.70	95.79	26.34	183.5
1988	76.49	111.20	19.81	283.1
1989	29.32	69.01	19.71	148.7
1990	6.81	104.91	34.30	261.4
1991	10.53	123.42	20.87	278.7
1992	117.87	71.64	34.64	316.8
1993	46.34	111.94	29.45	353.8
1994	-72.55	157.81	18.92	213.7
1995	44.74	100.55	14.18	244.6

The average of the results of the SPAM analysis are given in Table 3.24. The mean areal precipitation and also the parameters of the precipitation equation during the time period July-September are the smallest values compared to the other time periods, while it is the dryest period of the year. The time period April-September is divided into two periods, while the difference of mean areal precipitation between April-June, rain season, and July-September, dry season, is extremely high.

Table 3.24 Average SPAM Results For Various Seasons

	INTERCEPT	SLOPE	MAE (mm^2)	MAP (mm)
OCT-MAR.	35.07	93.16	31.4	216.4
APRIL-JUNE	51.40	72.60	21.60	191.31
JULY-SEP	16.21	39.1	14.60	67.85
APR-SEP.	67.80	88.6	23.93	246.5

3.6 COMPARISON OF ORDINARY AND DETRENDED KRIGING FOR VALIDATION

As mentioned in Section 2.6, the validation of the suggested interpolation techniques is made by suppressing one sample point at a time. Six stations are chosen regarding their location, altitude and mean values for this purpose. For each of the six sampling points selected, 26 years of annual precipitation totals in millimetres are estimated by using two suggested interpolation techniques. The selected sampling points are Dumlu and Ovacık which are located east and northeast of the area respectively, Tercan is located near the centroid of the study area. The results and the discussion are given in Chapter 4.

The stations are selected due to the following reasonings. Ovacık has the highest mean (557.5 mm) and Ilıca has the lowest mean (353.3 mm) of the precipitation depths. The effect of the highest and lowest precipitation depths over the area is examined by two methods expressed in Sections 2.3 and 2.4. Erzurum, Dumlu and Ilıca have 3 more precipitation stations nearby. The effect of the closest station to the estimated precipitation is seen using the two estimation methods. Tercan and Çayırlı have the means which are close to the areal mean of the region.

CHAPTER 4

DISCUSSION OF RESULTS

This chapter summarizes the results presented in tabular form and discussions of the previous chapter presentations in order to represent the annual and seasonal variations of the spatially distributed precipitation over Karasu Basin and explain the reason of the changes in mean areal precipitation and mean absolute error.

4.1 ANNUAL AND SEASONAL VARIATION OF MAE FOR DRY AND WET PERIODS

4.1.1 ELEVATION EFFECT WITH VARIOUS NUMBER OF RAINGAGES

The effect of elevation is considered with various number of precipitation stations. The elevation effect is also taken into account using tabulated results of dry and wet years. The detrended kriging results are used to show how the mean absolute error changes over the basin with decreasing number of precipitation stations.

Table 4.1 shows the effect of decreasing number of precipitation station for four years. They are compared with the overall values including 26 years of precipitation records. No trend is noticed with elevation and the interpolation consist only with ordinary kriging techniques in horizontal plane. The mean areal precipitation in millimeters decreases when elevation effect is not taken into account.

The mean absolute error is high in wet or dry years with ten(10) precipitation stations, there is no trend also with elevation when the number of precipitation stations decreased down to seven.

Table 4.1 Elevation Effect With Various Number of Precipitation Stations

	N = 10	N = 9	N = 7
1971 MAE	68.80	74.78	0.00
MAP	495.80	510.40	446.40
1975 MAE	0.00	64.40	0.00
MAP	382.10	403.30	384.20
1987 MAE	0.00	63.52	0.00
MAP	446.00	475.90	446.50
1988 MAE	63.65	66.47	0.00
MAP	524.50	525.10	503.60
MEAN MAE	45.52	43.72	36.85
MAP	481-485	485.95	476.24

Table 4.2 summarizes the results of wet years and shows that the mean absolute error decreases with decreasing number of stations. When the station number decreases, the number of years also decreases down to 18 years, eliminating the years with high mean absolute errors found with 10 stations. The overall results for 26 years with no distriction of dryness and the wetness of the years are presented earlier in Tables 3.11, 3.12 and 3.13.

Table 4.2 Wet Year Effect with Various Number of Precipitation Stations

	N = 10	N = 9	N = 7
1976 MAE	42.43	42.91	29.93
MAP	605.90	600.60	605.50
1979 MAE	47.25	46.47	38.09
MAP	660.50	656.00	638.90
1992 MAE	41.56	37.36	33.81
MAP	602.40	604.20	610.10

Table 4.3 shows that the change in mean absolute error for dry years is less than the determined average error for overall basin and, MAE decreases also with decreasing number of precipitation stations.

Table 4.3 Dry Year Effect with Various Number of Precipitation Stations

	N = 10	N = 9	N = 7
1970 MAE	0.00	0.00	0.00
MAP	307.30	307.3	308.10
1974 MAE	32.88	26.23	16.15
MAP	366.90	361.20	362.20
1982 MAE	40.83	36.65	32.30
MAP	344.40	345.00	339.70

4.1.2 SEASONAL VARIATIONS OF MAE AND MAP FOR WET AND DRY YEARS AND THEIR COMPARISONS

Annual and seasonal precipitation records are analyzed separately for comparison. The total seasonal results are compared with the annual results. Seasonal results are characterised with dry and wet seasons.

Table 4.4 and Table 4.5 give the results of the wet and dry seasons compared with the annual results. For dry years, there is no trend with elevation, so the mean absolute error term is obtained as zero.

When the annual precipitation results are compared with seasonal results, the mean annual precipitation depth decreases, whereas the mean absolute error increases.

The seasonal and annual precipitation depth estimates, shown in Table 4.4 columns 4 and 5, are obtained from the equations:

Seasonal MAP = 102.68 + 20.49 x Elevation (h) (4.1)

Annual MAP = 128.9 + 17.94 x Elevation (h) (4.2)

where the slope of the equation represents the change in precipitation in 100 m.

For the elevation 1028, the above equations have the equal mean areal precipitation. With increasing elevation, the sum of seasonal precipitation gives higher values for depth of precipitation compared to the mean areal precipitation estimates increases, the differences in MAP are 5 % and 7.5 % for 2000 m and 3000 m, respectively, when equations 4.1 and 4.2 are applied.

The seasonal mean areal precipitation equations for the time periods, October-March, April - June and July - September shown in Table 4.5 are as follows:

October-March MAP = 35.07 + 9.32 x Elevation (h) (4.3)

April - June MAP = 51.40 + 7.26 x Elevation (h) (4.4)

July - September MAP = 16.21 + 3.91 x Elevation (h) (4.5)

The slopes of the equations now give the precipitation change in 100 m as 9.3 mm for October-March, 7.3 mm for April-June, and 3.9 mm for July-September in four months. Sum of the three time periods is 20.5 mm per 100 m. It is determined to be 17.94 mm per 100 m for annual precipitation.

October-March has no trend with elevation for the wet and dry years. So ordinary kriging techique is alternative to distribute the point precipitation to the area. For dry years, the time period which has no trend with elevation is wider covering the months from October to June. The results indicate that the snow season is localized and the precipitation stations must be distributed uniformly in the project area. The claster analysis is an alternative solution for subgrouping the number of stations and the station number must be increased for the time period October to June in the west side of the region which has limited point station records.

Table 4.4 Wet Years Precipitation Variation

	OCTOBER-MARCH	APRIL-JUNE	JULY-SEPTEM.	TOTAL	ANNUAL
1976 MAE	48.67	15.39	22.57	86.63	42.43
MAP	289.50	215.50	108.80	613.8	605.9
1979 MAE	0.00	28.01	11.75	39.80	47.25
MAP	301.70	266.30	56.90	624.9	660.50
1992 MAE	0.00	17.47	18.53	36.0	41.56
MAP	201.00	220.00	127.30	584.4	602.40
MEAN MAE	31.40	21.60	14.60	67.6	45.52
MAP	216.40	191.30	67.85	475.6	481-485
INTERCEPT	35.07	51.40	16.21	102.7	128.9
SLOPE	93.16	72.60	39.10	204.9	179.4

Table 4.5 Dry Years Precipitation Analysis

	OCTOBER-MARCH	APRIL-JUNE	JULY-SEPTEM.	TOTAL	ANNUAL
1970 MAE	0.00	0.00	24.46	24.46	0.00
MAP	152.30	80.70	108.80	613.8	605.9
1974 MAE	0.00	0.00	17.29	17.29	32.88
MAP	160.00	119.80	84.70	364.5	366.90
1982 MAE	17.75	36.59	10.47	64.81	40.83
MAP	157.00	156.70	51.30	584.4	344.40

4.2 SEMIVARIOGRAM ANALYSIS

Table 4.6 shows ordinary kriging results with different time periods. October - March has a sample variance of 5500 mm^2 with the radius of influence about 42 km. The sample variances decrease for April - June (2600 mm^2) and July- September (850 mm^2).

The square root of sample variance of annual precipitation data, standard deviation, is 100 mm which is similar to the values observed in Table 3.19. The standart deviations in Table 3.19 are computed as 102 mm using ordinary kriging and 66.5 mm using detrended kriging. The standard deviations obtained using ordinary kriging are higher than the observed values. This shows that the number of stations is not sufficient considering the time period, October to March. The stations must be closer to each other with higher density and be uniformly distributed to have more accurate result.

The nugget value of the semivariogram which shows the uncontrolled variance and obtained from the annual precipitation is the sum of that of the three periods. It shows a consistency between the periods. The range of influence (h) decreases from 42 km to 37 km with decreasing precipitation depth (216 to 67.85 mm) which varies with various seasonal time periods.

Table 4.6 Semivariogram Parameters with Ordinary Kriging

	TYPE	NUGGET(γ_n) (mm^2)	SILL(γ_r) (mm^2)	DISTANCE(h) (m)
ANNUAL	Spherical	2000	10000	40500
OCT.-MAR.	Spherical	1000	5500	42000
APR.-JUNE	Spherical	1000	2600	41000
JULY- SEP.	Spherical	0	850	37000
APR.-SEP.	Spherical	2000	4100	27000

4.3 RESULTS OF COMPARISON FOR VALIDATION

The criteria for comparison of two techniques, namely ordinary and detrended kriging, is followed as discussed in Section 2.6. As the first criteria for comparing two techniques, means and standard deviations were computed as stated in Section 2.6. Table 4.7 shows the mean of the interpolated values corresponding to each technique at six meteorological stations, including those of the observed values for each station suppressed. Table 4.8 shows the standard deviations of interpolated and observed values corresponding to each technique. These tables also show the differences in percentage of these techniques with respect to the observed value characteristics namely mean annual precipitations and the standard deviations.

The standard deviations changed -20~+20 percent (%) using ordinary kriging and deviations ranged in between -17 to +25 % using detrended kriging for the mean annual precipitation differences (Table 4.7).

The standard deviations of the estimated values as the second moment parameter using kriging were higher but the values estimated by the second technique are much closer to the observed value of standard deviation (Table 4.8).

Table 4.7 Observed and Estimated Mean Annual Precipitation Obtained from the Two Interpolation Techniques For Six Stations Data

	ILICA	OVACIK	TERCAN	ERZUR	CAYIR.	DUMLU
Ord. Kriging[1]	438.8	535.6	364.2	363.0	444.0	447.9
Detr. Kriging[2]	441.9	477.5	364.2	450.1	410.3	470.3
OBSERVED	353.3	557.5	439.3	406.1	384.9	396.6
Difference[1] (%)	+24	-4	-17	-20	+15	+13
Difference[2] (%)	25	-14	-17	+11	+7	+18

Table 4.8 Observed and Estimated Standard Deviations of Annual Precipitation Obtained From The Two Interpolation Techniques For Six Stations Data

	ILICA	OVACIK	TERCAN	ERZUR.	CAYIR	DUMLU
Ordinary Kriging	116.9	81.37	110.6	81.9	129.1	91.6
Detrended Kriging	61.92	83.83	52.07	64.02	60.39	76.80
OBSERVED	77.96	78.25	79.89	63.4	67.4	75.22
Difference[1] %	+50	+4	+38	+29	+91	+22
Difference[2] %	-20	+7	-34	+1	-10	+2

The sum of square errors is also computed using the respective equations in Chapter 2 (Equations 2.31, 2.32 and 2.33) in order to compare the techniques. The square error is square of the difference of interpolated mean areal precipitation of each year obtained from detrended kriging and the observed annual precipitation of stations for each year for the sampling points. For ordinary kriging, since the interpolated annual precipitation is the same for each year, the square error is the difference of the interpolated annual precipitation and the observed for each year at the interpolated station. The results presented in Table 4.9 for six stations and the mean of six points indicated that annual precipitation at these selected stations can be estimated with less error using special precipitation algorithm for interpolation of annual rainfall by considering elevation and location of measuring stations over Karasu Basin.

Table 4.9 Sum of Square of Errors between the Observed and Estimated Annual Precipitation By Two Techniques

	ILICA	OVACIK	TERCAN	ERZUR.	CAYIR.	DUMLU	*
Ord. Kriging	341916	165530	306032	211067	204370	209844	239793
Detr. Kriging	228297	267542	190493	122882	61373	2446311	185869
OBSERVED	151925	153066	159578	100622	212313	141435	153156

* Mean of root of sum of square errors for each technique

Similarly the coefficient of efficiency is determined at six meteorological stations in Table 4.10, their efficiency(+) / inefficiency(-) magnitudes in percentage changes between +4 % and -125 % for ordinary kriging and +71 % and -75 % for detrended kriging (Table 3.27). The ineffiency mean is -63 % for former and -28 % for the latter. The values stated above show that detrended kriging gives more efficient results than ordinary kriging.

Table 4.10 Coefficient of Efficiency(in percent) For Two methods and Selected Stations

	ILICA	OVACIK	TERCAN	ERZUR.	CAYIR.	DUMLU	*
Ord. Kriging	-125.1	-8.1	-91.8	-109	4	-48.4	-63.1
Detr. Kriging	-50	-75	-19.4	-22	71	-73.0	-28.1

* Mean of coefficient of efficiency(in percent) for each technique

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The kriging procedure provides the basis for improving the estimation of areal average watershed precipitation input in that it accounts for spatial correlation and variability of precipitation fields and determines the station weights. The procedure provides the basis for estimating the time series of spatial distribution fields needed for spatially distributed hydrologic modelling.

Detrended and ordinary kriging are applied to Karasu region. Detrended kriging provides spatially distributed estimates of precipitation which take into account precipitation elevation relationships. The inclusion of these relationships leads to improved accuracy of precipitation estimates. Detrended kriging gives more reasonable results compared with ordinary kriging in mountainous terrain. The mean areal precipitation found by ordinary kriging is close to those of Thiessen polygon and arithmetical mean. As the mean areal precipitation is corrected by the elevation factor, it is near to the value of mean areal precipitation obtained from detrended kriging.

The mean areal precipitation is obtained with 3000, 5000 and 10000 grid cell size using SPAM. The equations of mean annual precipitation are the same for the given grid cell size, whereas the value of the mean areal precipitation changes with different grid cell size. This is due to the absence of altitudes as the grid cell size increases. The results will be more accurate with smaller grid cell size.

The annual point precipitations of 11 stations using the time period, 1970-1995, are analyzed for wetness and dryness. The wet years and dry years are obtained as 1979 and 1988, 1970 and 1974, respectively. With various number of stations, detrended kriging is applied annual precipitation. It is observed that the mean absolute error decreases with decreasing number of stations for wet and dry years. But with 7 stations, relationship between the elevation and precipitation cannot be obtained for the years which has high mean absolute error with 10 stations.

Detrended kriging does not give good relationship with elevation due to large terrain and elevation fluctuations in the terrain. The seasonal and annual mean areal precipitation obtained using detrended kriging begins to increase over the altitude, 2000 m. The relationship between the elevation and the precipitation is assumed to be linear, so the precipitation equation for higher altitudes gives higher values. In fact, the mean altitude obtained from the hypsometric curve is 1950 and the relationship should be spherical or exponential.

For the season October to March, precipitations have no trend with the elevation due to the localization of the precipitation in high altitudes and number of stations in eastern side of the basin.

The distance between the stations is an important factor to obtain accuracy in the precipitation estimation. The range of the influence in the semivariogram is a good indicator to arrange the distance between the stations within the terrain. The number of stations is insufficient in the westside of the region whereas most of the stations are located in the northeast part of the region.

5.2 RECOMMENDATIONS

Precipitation-elevation relationship weakens at larger scale. So the watershed must be divided into subzones and the stations in the watershed need to be grouped for different orograhic regimes and must be uniformly distributed with its location and elevation.

The kriging can also be applied to daily precipitation values. Daily precipitation is not used in this study, due to the lack of precipitation data and insufficient number stations with continous precipitation records.

Microclimatological effects can be taken into account and precipitation records of Tercan can be analyzed separately due to its microclimatological characteristics.

The procedure can be used other hydometeorological variables such as temperature and snow water equivalent.

SPAM for detrended kriging has limited capacity of solving larger system of equations and can be used only for 10 stations in the watershed. So, it must be improved to work with more number of stations and small grid cell size.

The new version of GEO-EAS for ordinary kriging should be supplied to study with Windows 95.

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APPENDIX A

DATA FILES OF THE PROGRAMS

The program, SPAM, use the two input files for the estimation of precipitation. One is the elevation of each grid cell, size of 3000 m. The other one is the precipitation records of the meteorological stations.

GEOEAS requires one input file containing precipitation records of the stations and the location of the precipitation records. The output file of GEOEAS gives the estimated precipitation for the grid cell size chosen.

```
north:  4466329.5
south:  4366729.5
east:   718870.6875
west:   510770.6875
rows:   34
cols:   70
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2100 2139 2322 2100 2000 0 0 0 2300 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2003 2123 1800 2025 1800 2027 1900 2125 2163 2460
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2114 1893 1839 1897 1742 1700 1992 2119 2209 2139 2000
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2180 1919 1954 1867 1800 1689 1869 1716 1940 2028 1773 2085
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2175 1937 1774 1700 1665 1848 1650 1636 1658 1593 1500 1506
0 2433 2000 2200 2314 2300 0 0 0 0 0 0 0 0 0 0 0 0 2615 2250 2068 2000 1914 1800 1673 1672 1600 1800 1518 1626 1577 1700 1773 1812
0 2052 1800 1844 1801 1900 2000 2100 0 0 0 2229 2532 0 0 0 2430 2221 2100 1939 1885 1799 1700 1749 1800 1629 1505 1600 1500 1500 1600 1604 1700 1900
0 0 2444 2240 1911 1500 1700 1855 2000 2300 2259 2000 2225 2685 0 2383 2300 2200 2009 2076 1900 1815 1791 1680 1600 1600 1600 1500 1500 1500 1481 1500 1525 1608
0 0 0 2304 1903 1636 1400 1499 1548 1887 2187 1854 2353 2334 2635 2594 2747 2877 2686 2551 2115 2000 1800 1700 1601 1612 1543 1500 1500 1481 1416 1457 1493 1600
0 0 2057 1815 1660 1500 1350 1319 1323 1525 1582 1794 1764 2426 2800 2961 3089 3238 3039 3018 2466 2489 2228 1899 1843 1628 1589 1500 1500 1500 1420 1411 1423 1491
0 0 2388 2383 2062 1800 1500 1268 1241 1245 1259 1348 1424 1622 2112 2597 2810 2677 3034 3000 2991 2951 2591 2328 2142 1711 1800 1809 1688 1794 1545 1500 1400 1404
0 0 0 0 1982 1600 1587 1276 1204 1200 1207 1199 1213 1175 1385 1697 2078 2262 2545 2509 2302 2365 2604 2522 2036 2029 2165 1800 2019 1863 1600 1522 1400 1400
0 0 0 0 0 2107 1644 1294 1175 1151 1145 1141 1139 1125 1125 1244 1464 1774 2065 2661 2220 2007 2737 2640 2603 2481 2098 2223 1782 1600 1700 1500 1400 1400
0 0 0 0 0 0 0 1552 1125 1144 1125 1125 1125 1125 1125 1140 1279 1337 1641 2088 1997 2418 2712 3023 2676 2500 2306 2276 2000 1600 1507 1400 1450 1575
0 0 0 0 0 0 0 0 0 1767 1414 1200 1138 1125 1125 1145 1150 1150 1372 1618 1738 2242 2509 2491 2241 1951 2048 1800 1674 1496 1400 1400 1427 1500
0 0 0 0 0 0 0 0 0 0 1790 1508 1199 1197 1160 1150 1150 1150 1177 1300 1538 1719 2064 2000 1821 1700 1934 1802 1644 1566 1400 1491 1553 1500
0 0 0 0 0 0 0 0 0 0 0 2222 1577 1300 1264 1212 1188 1150 1196 1244 1200 1300 1515 1600 1431 1781 1900 2108 2027 1839 1599 1698 1715 1689
0 0 0 0 0 0 0 0 0 0 0 0 2184 1589 1377 1400 1604 1432 1500 1674 1558 1300 1325 1300 1461 1713 1777 1865 1993 1677 1432 2168 1957 2459
0 0 0 0 0 0 0 0 0 0 0 2893 2313 2380 2080 2000 2028 2032 2044 2081 0 1844 1557 1943 1769 1500 1479 1400 1490 1562 1879 1839 1848 1961
0 0 0 0 0 0 0 0 0 0 0 0 3221 2002 2472 2744 2595 2813 0 0 0 0 1882 2100 2400 2295 2380 2339 2347 2429 2275 0 2009 0
0 0 0 0 0 0 0 0 0 0 0 0 0 2490 2653 2800 2963 0 0 0 0 0 0 0 0 0 0 2596 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 3082 2797 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
```

A.1 Elevation at Midpoint of Each Grid Cell

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2514	2889	3000	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2267	2506	2830	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2590	2385	2363	2200	2200	2324	2713	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2533	2202	2200	2176	2200	2202	2368	2500	2564	2797	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2379	2200	2155	2136	2269	2300	2548	2732	2690	2769	0	0	0	0	2810	2200	2146	2300	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2617	2216	2471	2327	2228	2100	2434	2742	2700	2900	3030	0	0	0	2712	2184	2028	2186	2527	2799
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2334	2698	2304	2100	2241	2390	2500	2631	2674	2518	2708	2700	2677	2457	2264	2107	2076	2493	2581	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2431	2471	2300	2637	2105	2700	2477	2608	2600	2551	2370	2723	2823	2330	2200	1903	2300	2373	2785	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2451	2638	2868	2445	2039	2341	2741	2429	2205	2293	2227	2607	2408	2461	1921	1926	1936	2094	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	2398	0	2242	2586	2092	1937	2349	2449	2221	2033	2000	1967	2000	2053	2089	1888	1797	1872	2200	2326	0	0	0
0	0	0	0	0	0	0	0	0	0	0	2315	2397	2161	2202	2451	2313	1919	2155	2284	2076	1963	1872	1860	1847	1878	2108	1783	1767	1769	1928	2300	0	0	0	0
2400	0	0	0	0	0	0	2308	2334	2100	2393	2335	2000	2100	1929	2200	2200	1867	2103	2000	1900	1865	1844	1810	1788	1789	1764	1763	1763	1763	1900	0	0	0	0	0
2651	2569	0	0	2599	2348	2100	1843	1900	2106	2176	2078	1900	1968	2000	1900	1800	1911	1886	1879	1839	1827	1800	1772	1763	1763	1763	1763	1763	1763	1774	0	0	0	0	0
2100	2258	2277	2200	2000	1993	1900	1829	1752	1868	1939	1884	1985	1800	1842	1800	1800	1850	1850	1850	1796	1782	1771	1763	1763	1763	1763	1763	1763	1777	2000	0	0	0	0	0
1997	2009	1811	1690	1615	1600	1612	1700	1783	1769	1800	1760	1763	1751	1707	1800	1792	1800	1837	1750	1750	1805	1770	1763	1763	1764	1773	1794	1864	1900	0	0	0	0	0	0
1600	1600	1752	1872	2036	1787	1900	1737	1800	1700	1700	1700	1757	1726	1703	1750	1750	1800	1818	1836	1945	2000	1883	1766	1772	1792	1827	1871	2000	2000	0	0	0	0	0	0
1908	1945	2493	2247	2370	2082	1944	1875	1900	1800	1800	1821	1750	1748	1730	1750	1863	2205	2266	2101	2114	2000	1969	1791	1793	1836	1901	1967	2070	2368	0	0	0	0	0	0
2040	2267	2000	1936	2183	2296	2400	2400	2100	1996	2086	2040	1903	2000	2072	1983	2000	2139	2300	2100	2200	2133	1881	1816	1837	1884	2000	2350	2408	0	0	0	0	0	0	0
1874	2000	1848	1800	1946	2047	1948	1900	2208	2100	2000	2000	2132	2342	2400	2432	2600	2572	2357	2200	1900	1902	1850	1890	1895	2155	2498	2513	3033	0	0	0	0	0	0	0
1656	1616	1717	1993	1992	1831	1700	1900	1875	1900	1831	1944	2105	2281	2400	2429	2400	2301	2300	2000	1926	1883	1850	1920	2000	2200	2500	2649	0	0	0	0	0	0	0	0
1567	1500	1549	1735	1674	1614	1835	1800	1740	1800	1800	1872	1924	2120	2171	2267	2200	2433	2308	2226	2207	2100	2079	2168	2300	2504	0	0	0	0	0	0	0	0	0	0
1410	1564	1500	1500	1600	1800	2041	2031	2000	2000	1966	1954	2060	2100	2235	2300	2245	2439	2559	2400	2362	2235	2251	2520	2591	2760	2763	0	0	0	0	0	0	0	0	0
1455	1600	1798	1480	1537	1789	1698	2004	2044	2300	2233	2254	2300	2400	2227	2300	2300	2200	2208	2276	2500	2375	2367	2376	2352	2436	2509	2757	0	0	0	0	0	0	0	0
1454	1500	1525	1601	1518	1616	1700	1907	2123	2247	2475	2444	2483	2550	2500	2483	2400	2213	2300	2300	2300	2239	2108	2122	2159	2600	2736	0	0	0	0	0	0	0	0	0
1600	1658	1600	1600	1700	1579	1800	1961	2150	2231	2239	2439	2550	2372	2374	2300	2345	2200	2296	2300	2125	2103	2134	2180	2370	2728	0	0	0	0	0	0	0	0	0	0
1800	2022	1963	1669	1800	1652	1500	1635	1800	2090	1986	2218	2281	2082	1991	1984	1932	1998	2100	2139	2200	2176	2390	2400	2636	2625	0	0	0	0	0	0	0	0	0	0
1626	1895	1932	1834	1744	1676	1600	1600	1600	1600	1800	1957	1910	1900	1816	1800	1800	1807	1906	1900	2000	2146	2488	2576	0	0	0	0	0	0	0	0	0	0	0	0
1718	1687	2239	2444	2000	2340	1726	2085	2156	1633	2076	1943	1933	2037	1815	1777	1850	1850	1911	1931	2014	2400	2751	0	0	0	0	0	0	0	0	0	0	0	0	0
2041	1628	2100	2332	2121	1988	1949	2321	2047	1757	2335	2357	2140	2111	2308	2067	1871	1809	2100	2073	2233	2427	2669	0	0	0	0	0	0	0	0	0	0	0	0	0
2014	2186	2298	2433	2295	2100	2298	2332	2000	1900	2076	2300	2289	2500	0	1900	1813	1900	1878	1979	2307	2733	2754	0	0	0	0	0	0	0	0	0	0	0	0	0
1911	2196	2112	0	2513	2774	0	0	0	0	0	0	0	0	0	0	2000	2068	2042	1996	2359	2600	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2500	2322	2300	2100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2500	2447	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

A.1 (continued)

10	1	1	26								
KIRIK	2075	653015	4460760								
OVACIK	2200	671645	4451906								
ILICA	1700	679393	4424319								
ERZURUM	1758	685089	4424456								
TORTUM	1602	716723	4464175								
ERZINCA	1218	542835	4400130								
CAT	1920	670246	4387092								
CAYIRLI	1525	588463	4406070								
DUMLU	1825	701831	4437841								
TERCAN	1425	618455	4404625								
95	1	441.9	470.4	235.5	291.1	350.1	402.2	270.9	312.6	288.3	375
95	2	612.5	687.1	482.7	364.4	575.4	376.8	372.4	376.1	449.9	436
95	3	543.1	575.4	336.5	445.2	628.2	279.9	362.3	356.4	412.8	388.5
95	4	432.3	507.1	311.7	375.7	552.7	275	402.8	321.9	354.4	436.6
95	5	401.7	434.6	285	392.6	311.6	353.1	371.6	356	290.2	369.8
95	6	623.9	572.2	242.6	377.2	412.2	377.9	367.1	373.4	294.2	407.6
95	7	636.9	662.3	475.5	509.7	481.7	395.2	591.1	416.4	387.4	538.6
95	8	504.4	497.8	345.2	373.7	499.7	363.7	362.3	433.9	334	444.6
95	9	469.4	539.2	396.8	398.6	413.6	347.8	482.6	342.3	361.5	413.4
95	10	643.1	703.2	532.6	592.9	652.9	487.2	620.4	608.1	524.3	684.2
95	11	475.1	500.2	291.9	372.4	360.4	298.5	369.6	409	247.4	409
95	12	533.6	560.6	350.4	439	458	333.8	440	377.7	404.8	427.1
95	13	414.2	463.8	296.2	388.3	251.3	323.8	362.1	367.7	321.2	404.6
95	14	509.4	537.8	312	416.2	431.3	412.9	443.8	423.8	521.5	406.5
95	15	403.2	447.1	260.3	475.2	413.9	248	338.5	360.2	389.9	377.1
95	16	537.8	569.1	359.6	396.1	383.2	434.6	441	336.5	452.5	406.5
95	17	547.3	577.6	366.7	502.4	490.5	361.8	549.2	401.5	468.1	512.6
95	18	622.8	643.6	423.9	440.5	499	450.6	412.8	387.3	446.8	528.2
95	19	713.4	721.2	493.7	435	492.5	525.5	508.1	516.8	542.9	600.3
95	20	499.5	535	331	348.6	401.9	293.6	549.9	258.3	411.5	322.9
95	21	432.7	474.3	281.7	344	452.2	331.8	595.4	340.7	375.9	373.2
95	22	485.2	522.1	320.3	373.7	475	433.8	517.4	421.4	404.3	478.1
95	23	614.1	636.1	417.3	423.1	523.7	362.2	570.1	429.4	451.4	488.5
95	24	525.2	557.9	350.1	324	390	307.7	548.2	338.1	356.9	369.9
95	25	519.3	552.7	345.7	381.8	556.2	323.4	319.9	355	412	391.8
95	26	513.8	547.8	341.6	377.5	508.7	373	440.6	385.9	407.9	431

A.2 Input Data of SPAM for Annual Precipitation Distribution

A.3 Input Data File of GEO-EAS

```
PRECIPITATION.DAT Geostatistical    Environmental Assessment Software
     3
Easting   M          F8.1      Columns 31-80 can be used for comments
Northing M           F8.1
Yagis     MM         G16.9
 653015     4460760      441.9           'Sample   1'          KIRIK
 653015     4460760      612.5           'Sample   2'
 653015     4460760      543.1           'Sample   3'
 653015     4460760      432.3           'Sample   4'
 653015     4460760      401.7           'Sample   5'
 653015     4460760      623.9           'Sample   6'
 653015     4460760      636.9           'Sample   7'
 653015     4460760      504.4           'Sample   8'
 653015     4460760      469.4           'Sample   9'
 653015     4460760      643.1           'Sample   10'
 653015     4460760      475.1           'Sample   11'
 653015     4460760      533.6           'Sample   12'
 653015     4460760      414.2           'Sample   13'
 653015     4460760      509.4           'Sample   14'
 653015     4460760      403.2           'Sample   15'
 653015     4460760      537.8           'Sample   16'
 653015     4460760      547.3           'Sample   17'
 653015     4460760      622.8           'Sample   18'
 653015     4460760      713.4           'Sample   19'
 653015     4460760      499.5           'Sample   20'
 653015     4460760      432.7           'Sample   21'
 653015     4460760      485.2           'Sample   22'
 653015     4460760      614.1           'Sample   23'
 653015     4460760      525.2           'Sample   24'
 653015     4460760      519.3           'Sample   25'
 653015     4460760      513.8           'Sample   26'
 671645     4451906      470.4           'Sample   27'         OVACIK
 671645     4451906      687.1           'Sample   28'
 671645     4451906      575.4           'Sample   29'
 671645     4451906      507.1           'Sample   30'
 671645     4451906      434.6           'Sample   31'
 671645     4451906      572.2           'Sample   32'
 671645     4451906      662.3           'Sample   33'
 671645     4451906      497.8           'Sample   34'
 671645     4451906      539.2           'Sample   35'
 671645     4451906      703.2           'Sample   36'
 671645     4451906      500.2           'Sample   37'
```

671645	4451906	560.6	'Sample 38'	
671645	4451906	463.8	'Sample 39'	
671645	4451906	537.8	'Sample 40'	
671645	4451906	447.1	'Sample 41'	
671645	4451906	569.1	'Sample 42'	
671645	4451906	577.6	'Sample 43'	
671645	4451906	643.6	'Sample 44'	
671645	4451906	721.2	'Sample 45'	
671645	4451906	535	'Sample 46'	
671645	4451906	474.3	'Sample 47'	
671645	4451906	522.1	'Sample 48'	
671645	4451906	636.1	'Sample 49'	
671645	4451906	557.9	'Sample 50'	
671645	4451906	552.9	'Sample 51'	
671645	4451906	547.8	'Sample 52'	
679393	4424319	235.5	'Sample 53'	ILICA
679393	4424319	482.7	'Sample 54'	
679393	4424319	336.5	'Sample 55'	
679393	4424319	311.7	'Sample 56'	
679393	4424319	285	'Sample 57'	
679393	4424319	242.6	'Sample 58'	
679393	4424319	475.5	'Sample 59'	
679393	4424319	345.2	'Sample 60'	
679393	4424319	396.8	'Sample 61'	
679393	4424319	532.6	'Sample 62'	
679393	4424319	291.9	'Sample 63'	
679393	4424319	350.4	'Sample 64'	
679393	4424319	296.2	'Sample 65'	
679393	4424319	312	'Sample 66'	
679393	4424319	260.6	'Sample 67'	
679393	4424319	359.6	'Sample 68'	
679393	4424319	366.7	'Sample 69'	
679393	4424319	423.9	'Sample 70'	
679393	4424319	493.7	'Sample 71'	
679393	4424319	331	'Sample 72'	
679393	4424319	281.7	'Sample 73'	
679393	4424319	320.3	'Sample 74'	
679393	4424319	417.3	'Sample 75'	
679393	4424319	350.1	'Sample 76'	
679393	4424319	345.7	'Sample 77'	
679393	4424319	341.6	'Sample 78'	
729119	4429356	196.1	'Sample 79'	PASINLER
729119	4429356	338	'Sample 80'	
729119	4429356	408.9	'Sample 81'	

729119	4429356	269.5	'Sample 82'	
729119	4429356	206.2	'Sample 83'	
729119	4429356	290.1	'Sample 84'	
729119	4429356	478.8	'Sample 85'	
729119	4429356	330.4	'Sample 86'	
729119	4429356	381	'Sample 87'	
729119	4429356	459	'Sample 88'	
729119	4429356	297.3	'Sample 89'	
729119	4429356	413.5	'Sample 90'	
729119	4429356	350	'Sample 91'	
729119	4429356	374	'Sample 92'	
729119	4429356	427	'Sample 93'	
729119	4429356	386.2	'Sample 94'	
729119	4429356	423.3	'Sample 95'	
729119	4429356	396	'Sample 96'	
729119	4429356	582.2	'Sample 97'	
729119	4429356	317.8	'Sample 98'	
729119	4429356	364.3	'Sample 99'	
729119	4429356	493.6	'Sample 100'	
729119	4429356	435.4	'Sample 101'	
729119	4429356	440.9	'Sample 102'	
729119	4429356	489.9	'Sample 103'	
729119	4429356	459.8	'Sample 104'	
685089	4424456	291.1	'Sample 105'	ERZURUM
685089	4424456	364.4	'Sample 106'	
685089	4424456	445.2	'Sample 107'	
685089	4424456	375.7	'Sample 108'	
685089	4424456	392.6	'Sample 109'	
685089	4424456	377.2	'Sample 110'	
685089	4424456	509.7	'Sample 111'	
685089	4424456	373.7	'Sample 112'	
685089	4424456	398.6	'Sample 113'	
685089	4424456	592.9	'Sample 114'	
685089	4424456	372.4	'Sample 115'	
685089	4424456	439	'Sample 116'	
685089	4424456	388.3	'Sample 117'	
685089	4424456	416.2	'Sample 118'	
685089	4424456	475.2	'Sample 119'	
685089	4424456	396.1	'Sample 120'	
685089	4424456	502.4	'Sample 121'	
685089	4424456	440.5	'Sample 122'	
685089	4424456	435	'Sample 123'	
685089	4424456	317.8	'Sample 124'	
685089	4424456	364.3	'Sample 125'	

685089	4424456	493.6	'Sample 126'	
685089	4424456	435.4	'Sample 127'	
685089	4424456	440.9	'Sample 128'	
685089	4424456	489.9	'Sample 129'	
685089	4424456	459.8	'Sample 130'	
716723	4464175	350.1	'Sample 131'	TORTUM
716723	4464175	575.4	'Sample 132'	
716723	4464175	628.2	'Sample 133'	
716723	4464175	552.7	'Sample 134'	
716723	4464175	311.6	'Sample 135'	
716723	4464175	412.2	'Sample 136'	
716723	4464175	481.7	'Sample 137'	
716723	4464175	499.7	'Sample 138'	
716723	4464175	413.6	'Sample 139'	
716723	4464175	652.9	'Sample 140'	
716723	4464175	360.4	'Sample 141'	
716723	4464175	458	'Sample 142'	
716723	4464175	251.3	'Sample 143'	
716723	4464175	431.3	'Sample 144'	
716723	4464175	413.9	'Sample 145'	
716723	4464175	383.2	'Sample 146'	
716723	4464175	490.5	'Sample 147'	
716723	4464175	499	'Sample 148'	
716723	4464175	492.5	'Sample 149'	
716723	4464175	401.8	'Sample 150'	
716723	4464175	452.2	'Sample 151'	
716723	4464175	475	'Sample 152'	
716723	4464175	523.7	'Sample 153'	
716723	4464175	390	'Sample 154'	
716723	4464175	556.2	'Sample 155'	
716723	4464175	508.7	'Sample 156'	
645256	4421742	402.2	'Sample 157'	ERZINCAN
645256	4421742	376.8	'Sample 158'	
645256	4421742	275	'Sample 159'	
645256	4421742	353.1	'Sample 160'	
645256	4421742	377.9	'Sample 161'	
645256	4421742	395.2	'Sample 162'	
645256	4421742	363.7	'Sample 163'	
645256	4421742	347.8	'Sample 164'	
645256	4421742	487.2	'Sample 165'	
645256	4421742	298.5	'Sample 166'	
645256	4421742	333.8	'Sample 167'	
645256	4421742	323.8	'Sample 168'	
645256	4421742	412.9	'Sample 169'	

645256	4421742	248	'Sample 170'	
645256	4421742	434.6	'Sample 171'	
645256	4421742	361.8	'Sample 172'	
645256	4421742	450.6	'Sample 173'	
645256	4421742	525.5	'Sample 174'	
645256	4421742	293.6	'Sample 175'	
645256	4421742	331.8	'Sample 176'	
645256	4421742	433.8	'Sample 177'	
645256	4421742	362.2	'Sample 178'	
645256	4421742	307.7	'Sample 179'	
645256	4421742	323.4	'Sample 180'	
645256	4421742	37334	'Sample 181'	
645256	4421742	279.9	'Sample 182'	
670246	4387092	270.9	'Sample 183'	ÇAT
670246	4387092	372.4	'Sample 184'	
670246	4387092	362.3	'Sample 185'	
670246	4387092	402.8	'Sample 186'	
670246	4387092	371.6	'Sample 187'	
670246	4387092	367.1	'Sample 188'	
670246	4387092	591.1	'Sample 189'	
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670246	4387092	482.6	'Sample 191'	
670246	4387092	620.4	'Sample 192'	
670246	4387092	369.6	'Sample 193'	
670246	4387092	440	'Sample 194'	
670246	4387092	362.1	'Sample 195'	
670246	4387092	443.8	'Sample 196'	
670246	4387092	338.5	'Sample 197'	
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670246	4387092	549.2	'Sample 199'	
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670246	4387092	548.2	'Sample 206'	
670246	4387092	319.9	'Sample 207'	
670246	4387092	440.6	'Sample 208'	
588463	4406070	312.6	'Sample 209'	ÇAYIRLI
588463	4406070	376.1	'Sample 210'	
588463	4406070	356.4	'Sample 211'	
588463	4406070	321.9	'Sample 212'	
588463	4406070	356	'Sample 213'	

588463	4406070	373.4	'Sample 214'	
588463	4406070	416.4	'Sample 215'	
588463	4406070	433.9	'Sample 216'	
588463	4406070	342.3	'Sample 217'	
588463	4406070	608.1	'Sample 218'	
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588463	4406070	377.7	'Sample 220'	
588463	4406070	367.7	'Sample 221'	
588463	4406070	423.8	'Sample 222'	
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588463	4406070	336.5	'Sample 224'	
588463	4406070	401.5	'Sample 225'	
588463	4406070	387.3	'Sample 226'	
588463	4406070	516.8	'Sample 227'	
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588463	4406070	340.7	'Sample 229'	
588463	4406070	421.4	'Sample 230'	
588463	4406070	429.4	'Sample 231'	
588463	4406070	338.1	'Sample 232'	
588463	4406070	355.4	'Sample 233'	
588463	4406070	385.9	'Sample 234'	
701831	4437841	288.3	'Sample 235'	DUMLU
701831	4437841	449.9	'Sample 236'	
701831	4437841	412.8	'Sample 237'	
701831	4437841	354.4	'Sample 238'	
701831	4437841	290.2	'Sample 239'	
701831	4437841	294.2	'Sample 240'	
701831	4437841	387.4	'Sample 241'	
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701831	4437841	542.9	'Sample 253'	
701831	4437841	411.5	'Sample 254'	
701831	4437841	375.9	'Sample 255'	
701831	4437841	404.3	'Sample 256'	
701831	4437841	451.4	'Sample 257'	

618455	4404625	600.3	'Sample 279'
618455	4404625	322.9	'Sample 280'
618455	4404625	373.2	'Sample 281'
618455	4404625	478.1	'Sample 282'
618455	4404625	488.5	'Sample 283'
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618455	4404625	431	'Sample 286'

A.4 Output Data File of GEO-EAS

```
Kriging estimates produced from data fil years.grd
                         4
Easting        M         F9.1
Northing       M         F9.1
*Precipitation MM        G17.9
KSDPrecipitation         G17.9
     510770     4366730     359.5938     132.166
     510770     4371730     359.5938    131.0898
     510770     4376730     359.5938    129.6544
     510770     4381730     359.5937    127.9489
     510770     4386730     359.5938    126.1828
     510770     4391730     359.5938    124.6625
     510770     4396730     359.5938    123.7117
     510770     4401730     359.5938    123.5578
     510770     4406730     359.5938    124.2395
     510770     4411730     359.5938    125.5895
     510770     4416730     359.5938    127.3056
     510770     4421730     359.5938    129.0632
     510770     4426730     359.5938    130.6123
     510770     4431730     359.5938     131.821
     510770     4436730     1.00E+31    1.00E+31
     510770     4441730     1.00E+31    1.00E+31
     510770     4446730     1.00E+31    1.00E+31
     510770     4451730     1.00E+31    1.00E+31
     510770     4456730     1.00E+31    1.00E+31
     515770     4366730     359.5937    131.1484
     515770     4371730     359.5938    129.3968
     515770     4376730     359.5938    127.0457
     515770     4381730     359.5938     124.229
     515770     4386730     359.5938    121.2839
     515770     4391730     359.5938    118.7242
     515770     4396730     359.5938    117.1111
     515770     4401730     359.5938    116.8492
     515770     4406730     359.5938    118.0078
     515770     4411730     359.5937    120.2879
     515770     4416730     359.5938    123.1596
     515770     4421730     359.5938    126.0722
     515770     4426730     359.5938    128.6166
     515770     4431730     359.5938    130.5879
     515770     4436730     359.5938    131.9626
     515770     4441730     1.00E+31    1.00E+31
     515770     4446730     1.00E+31    1.00E+31
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525770	4371730	359.5938	124.6479
525770	4376730	359.5938	119.6188
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525770	4386730	359.5937	106.7396
525770	4391730	359.5938	100.7056
525770	4396730	359.5938	96.7806
525770	4401730	359.5938	96.13337
525770	4406730	359.5937	98.97492
525770	4411730	359.5938	104.4179
525770	4416730	359.5938	111.0295
525770	4421730	359.5938	117.5014
525770	4426730	359.5938	122.9915
525770	4431730	359.5938	127.1536
525770	4436730	359.5937	130.0131
525770	4441730	359.5937	131.8049
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525770	4451730	1.00E+31	1.00E+31
525770	4456730	1.00E+31	1.00E+31
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530770	4371730	359.5938	122.1055
530770	4376730	359.5938	115.5683
530770	4381730	359.5938	107.3875

530770	4386730	359.5938	98.33015
530770	4391730	359.5938	89.92022
530770	4396730	359.5938	84.29278
530770	4401730	359.5938	83.35077
530770	4406730	359.5938	87.45603
530770	4411730	359.5938	95.12494
530770	4416730	359.5938	104.1652
530770	4421730	359.5938	112.7875
530770	4426730	359.5938	119.9624
530770	4431730	359.5938	125.3306
530770	4436730	359.5938	128.9878
530770	4441730	359.5938	131.2676
530770	4446730	1.00E+31	1.00E+31
530770	4451730	1.00E+31	1.00E+31
530770	4456730	1.00E+31	1.00E+31
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535770	4371730	359.5937	120.0413
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535770	4381730	359.5938	102.3176
535770	4386730	359.5938	91.07597
535770	4391730	359.5937	80.29691
535770	4396730	359.5938	72.82648
535770	4401730	359.5938	71.55024
535770	4406730	359.5938	77.05583
535770	4411730	359.5938	87.01347
535770	4416730	359.5938	98.35381
535770	4421730	359.5938	108.8859
535770	4426730	359.5938	117.493
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535770	4441730	359.5938	130.8379
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535770	4451730	1.00E+31	1.00E+31
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540770	4371730	359.5937	118.9235
540770	4376730	359.5937	110.4148
540770	4381730	359.5938	99.50203
540770	4386730	359.5938	86.95116
540770	4391730	359.5938	74.64674
540770	4396730	359.5938	65.88509
540770	4401730	359.5938	64.3623
540770	4406730	359.5938	70.8744
540770	4411730	359.5938	82.35132

540770	4416730	359.5938	95.10244
540770	4421730	359.5938	106.7422
540770	4426730	359.5938	116.1518
540770	4431730	359.5938	123.0652
540770	4436730	359.5937	127.723
540770	4441730	359.5938	130.6077
540770	4446730	1.00E+31	1.00E+31
540770	4451730	1.00E+31	1.00E+31
540770	4456730	1.00E+31	1.00E+31
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545770	4371730	359.5937	119.034
545770	4376730	359.5938	110.5956
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545770	4391730	359.5937	75.2221
545770	4396730	359.5938	66.6009
545770	4401730	359.5938	65.10552
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545770	4411730	359.5938	82.82217
545770	4416730	359.5938	95.4276
545770	4421730	359.5937	106.9552
545770	4426730	359.5938	116.2846
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545770	4451730	1.00E+31	1.00E+31
545770	4456730	1.00E+31	1.00E+31
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550770	4376730	359.5937	112.7282
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550770	4386730	359.5938	92.16837
550770	4391730	359.5938	81.76944
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550770	4401730	359.5938	73.38763
550770	4406730	359.5938	78.65667
550770	4411730	359.5938	88.24163
550770	4416730	359.5938	99.22165
550770	4421730	359.5937	109.463
550770	4426730	359.5937	117.856
550770	4431730	359.5938	124.0744
550770	4436730	359.5938	128.2852
550770	4441730	359.5938	130.9006

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550770	4451730	1.00E+31	1.00E+31
550770	4456730	1.00E+31	1.00E+31
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555770	4371730	359.5937	122.5277
555770	4376730	359.5937	116.2449
555770	4381730	359.5938	108.4057
555770	4386730	359.5938	99.76354
555770	4391730	359.5938	91.78324
555770	4396730	359.5938	86.47301
555770	4401730	359.5938	85.58683
555770	4406730	359.5938	89.4547
555770	4411730	359.5937	96.71645
555770	4416730	359.5938	105.3261
555770	4421730	359.5938	113.5771
555770	4426730	359.5938	120.4664
555770	4431730	359.5938	125.6326
555770	4436730	359.5938	129.1572
555770	4441730	359.5937	131.3562
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555770	4451730	1.00E+31	1.00E+31
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560770	4371730	359.5938	125.1025
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560770	4431730	359.5938	127.4807
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560770	4441730	377.9125	131.8589
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560770	4451730	1.00E+31	1.00E+31
560770	4456730	1.00E+31	1.00E+31
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565770	4376730	359.5938	124.269

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575770	4431730	377.9124	119.1443
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575770	4446730	385.5625	130.9979
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580770	4371730	385.5625	126.562
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580770	4381730	390.4875	114.1973
580770	4386730	390.4875	104.8173
580770	4391730	390.4875	93.95413
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580770	4401730	390.4875	75.06998
580770	4406730	390.4875	72.56657
580770	4411730	390.4875	76.77219
580770	4416730	390.4875	85.87907
580770	4421730	390.4875	96.89731
580770	4426730	390.4875	107.478
580770	4431730	377.9125	116.3284
580770	4436730	385.5624	122.9997
580770	4441730	385.5624	127.5907
580770	4446730	385.5625	130.4882
580770	4451730	385.5624	132.1668
580770	4456730	1.00E+31	1.00E+31
585770	4366730	385.5624	129.51
585770	4371730	377.9125	125.9086
585770	4376730	377.9125	120.3113
585770	4381730	377.9124	112.3209
585770	4386730	390.4875	101.893
585770	4391730	390.4875	89.63402
585770	4396730	390.4875	77.18259
585770	4401730	390.4875	67.55402
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585770	4411730	390.4875	69.60308
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595770	4376730	377.9124	121.3297
595770	4381730	377.9124	113.9972
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595770	4396730	377.9125	82.54726
595770	4401730	377.9124	74.29926
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595770	4411730	377.9125	76.03468
595770	4416730	377.9124	85.30191
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595770	4426730	377.9125	107.2003
595770	4431730	377.9124	116.1519
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600770	4371730	377.9124	127.5895

600770	4376730	377.9125	123.2351
600770	4381730	377.9125	117.1059
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600770	4416730	377.9124	93.97593
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600770	4426730	377.9125	111.4912
600770	4431730	377.9124	118.8997
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600770	4446730	377.9125	130.9532
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605770	4371730	447.7561	126.6168
605770	4376730	447.7562	121.8435
605770	4381730	447.7561	115.3113
605770	4386730	447.7562	107.2443
605770	4391730	447.7562	98.46938
605770	4396730	447.7562	90.54121
605770	4401730	447.7562	85.52855
605770	4406730	447.7562	85.13194
605770	4411730	447.7562	89.50072
605770	4416730	447.7562	97.11075
605770	4421730	447.7562	105.8737
605770	4426730	447.7562	114.1257
605770	4431730	447.7562	120.9284
605770	4436730	447.7562	125.976
605770	4441730	447.7562	129.3868
605770	4446730	447.7562	131.4956
605770	4451730	1.00E+31	1.00E+31
605770	4456730	1.00E+31	1.00E+31
610770	4366730	447.7562	129.0662
610770	4371730	447.7562	125.2883
610770	4376730	447.7561	119.5804
610770	4381730	447.7562	111.686
610770	4386730	447.7562	101.7738
610770	4391730	447.7562	90.72231
610770	4396730	447.7561	80.40217
610770	4401730	447.7561	73.65036

610770	4406730	447.7562	73.10681
610770	4411730	447.7562	79.01733
610770	4416730	447.7562	88.97965
610770	4421730	447.7561	100.0683
610770	4426730	447.7562	110.2415
610770	4431730	447.7562	118.4806
610770	4436730	447.7562	124.5247
610770	4441730	447.7562	128.5803
610770	4446730	447.7562	131.0773
610770	4451730	511.3438	131.226
610770	4456730	511.3438	130.9354
615770	4366730	447.7562	128.6437
615770	4371730	447.7562	124.517
615770	4376730	447.7562	118.2577
615770	4381730	447.7562	109.5443
615770	4386730	447.7562	98.48624
615770	4391730	447.7562	85.94552
615770	4396730	447.7562	73.93631
615770	4401730	447.7562	65.84621
615770	4406730	447.7562	65.18435
615770	4411730	447.7562	72.29489
615770	4416730	447.7562	83.94141
615770	4421730	447.7562	96.56753
615770	4426730	447.7562	107.9417
615770	4431730	447.7562	117.048
615770	4436730	447.7562	123.6814
615770	4441730	447.7562	128.1137
615770	4446730	529.9936	129.7108
615770	4451730	511.3437	128.856
615770	4456730	511.3438	128.2934
620770	4366730	447.7562	128.6279
620770	4371730	447.7562	124.4881
620770	4376730	447.7561	118.2081
620770	4381730	447.7562	109.4637
620770	4386730	447.7562	98.36166
620770	4391730	447.7561	85.76245
620770	4396730	447.7562	73.68451
620770	4401730	447.7562	65.53759
620770	4406730	447.7562	64.87055
620770	4411730	447.7562	72.03236
620770	4416730	447.7562	83.7479
620770	4421730	447.7562	96.43468
620770	4426730	447.7562	107.8551
620770	4431730	447.7562	116.9942

565770	4381730	359.5938	120.2301
565770	4386730	359.5937	115.959
565770	4391730	359.5938	112.2023
565770	4396730	359.5938	109.8115
565770	4401730	359.5937	109.4215
565770	4406730	377.9125	108.8381
565770	4411730	377.9124	110.2128
565770	4416730	377.9124	113.389
565770	4421730	377.9124	117.5697
565770	4426730	377.9124	121.8994
565770	4431730	377.9125	125.7345
565770	4436730	377.9124	128.7427
565770	4441730	385.5624	130.8675
565770	4446730	385.5624	132.2302
565770	4451730	1.00E+31	1.00E+31
565770	4456730	1.00E+31	1.00E+31
570770	4366730	377.9125	131.2027
570770	4371730	377.9124	129.0441
570770	4376730	377.9125	125.7408
570770	4381730	377.9125	121.1429
570770	4386730	377.9124	115.3752
570770	4391730	377.9124	108.9843
570770	4396730	377.9124	103.0006
570770	4401730	377.9125	98.78291
570770	4406730	377.9124	97.53276
570770	4411730	377.9124	99.64786
570770	4416730	377.9125	104.4667
570770	4421730	377.9124	110.6824
570770	4426730	377.9124	116.9894
570770	4431730	377.9124	122.4819
570770	4436730	377.9124	126.7361
570770	4441730	385.5624	129.7151
570770	4446730	385.5626	131.6151
570770	4451730	1.00E+31	1.00E+31
570770	4456730	1.00E+31	1.00E+31
575770	4366730	385.5625	130.4682
575770	4371730	377.9124	127.6879
575770	4376730	377.9124	123.4054
575770	4381730	377.9124	117.3821
575770	4386730	390.4875	109.707
575770	4391730	390.4875	101.0131
575770	4396730	390.4875	92.6444
575770	4401730	390.4875	86.57726
575770	4406730	390.4875	84.747

620770	4436730	447.7562	123.6499
620770	4441730	447.7562	128.0963
620770	4446730	529.9937	126.5398
620770	4451730	511.3438	125.001
620770	4456730	511.3436	123.9835
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625770	4371730	447.7562	125.209
625770	4376730	456.3562	119.4447
625770	4381730	456.3561	111.4671
625770	4386730	456.3561	101.4398
625770	4391730	456.3561	90.24155
625770	4396730	456.3562	79.75985
625770	4401730	447.7562	72.88448
625770	4406730	447.7562	72.33022
625770	4411730	447.7562	78.351
625770	4416730	447.7562	88.47354
625770	4421730	447.7562	99.71313
625770	4426730	447.7562	110.0067
625770	4431730	447.7563	118.3337
625770	4436730	447.7562	124.438
625770	4441730	529.9937	124.7493
625770	4446730	507.0249	121.8453
625770	4451730	529.9937	119.2514
625770	4456730	529.9937	117.5228
630770	4366730	456.3562	129.7353
630770	4371730	456.3562	126.5055
630770	4376730	456.3562	121.6546
630770	4381730	456.3561	115.0105
630770	4386730	456.3561	106.7945
630770	4391730	456.3562	97.8408
630770	4396730	456.3562	89.73176
630770	4401730	456.3562	84.59283
630770	4406730	456.3562	84.18578
630770	4411730	456.3561	88.66592
630770	4416730	447.7562	96.45262
630770	4421730	447.7561	105.3973
630770	4426730	447.7562	113.8038
630770	4431730	447.7562	120.7242
630770	4436730	507.025	124.2483
630770	4441730	507.0249	120.0531
630770	4446730	507.025	115.5224
630770	4451730	529.9936	111.4151
630770	4456730	529.9937	108.6429
635770	4366730	443.8437	129.8376

635770	4371730	456.3563	128.0938
635770	4376730	456.3563	124.3386
635770	4381730	456.3562	119.2553
635770	4386730	456.3562	113.0787
635770	4391730	456.3561	106.508
635770	4396730	456.3562	100.7284
635770	4401730	456.3561	97.16354
635770	4406730	456.3562	96.88475
635770	4411730	456.3561	99.98235
635770	4416730	456.3561	105.5063
635770	4421730	447.7563	112.0417
635770	4426730	447.7562	118.3402
635770	4431730	447.7562	123.6224
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635770	4441730	507.0249	114.467
635770	4446730	507.0249	107.8663
635770	4451730	529.9937	101.7523
635770	4456730	529.9937	97.54338
640770	4366730	443.8437	127.0834
640770	4371730	443.8436	124.7553
640770	4376730	443.8438	122.572
640770	4381730	443.8437	120.972
640770	4386730	456.3561	119.1101
640770	4391730	456.3561	114.6257
640770	4396730	456.3561	110.7652
640770	4401730	456.3561	108.4271
640770	4406730	456.3561	108.2457
640770	4411730	456.3562	110.2731
640770	4416730	456.3562	113.9507
640770	4421730	456.3561	118.396
640770	4426730	447.7562	122.7671
640770	4431730	513.2562	122.8799
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640770	4441730	533.9061	108.6881
640770	4446730	507.0249	99.75755
640770	4451730	529.9936	91.2463
640770	4456730	529.9936	85.21671
645770	4366730	443.8437	123.2597
645770	4371730	443.8437	119.5285
645770	4376730	443.8437	115.986
645770	4381730	443.8437	113.3609
645770	4386730	443.8437	112.3026
645770	4391730	443.8437	113.0987
645770	4396730	443.8437	115.5315

645770	4401730	456.3562	117.4088
645770	4406730	456.3562	117.2966
645770	4411730	456.3561	118.5554
645770	4416730	456.3562	120.8636
645770	4421730	456.3562	123.694
645770	4426730	358.1937	125.2195
645770	4431730	513.2562	120.9206
645770	4436730	513.2562	113.4365
645770	4441730	513.2561	103.808
645770	4446730	533.9061	92.7241
645770	4451730	507.0249	81.82546
645770	4456730	529.9937	73.82635
650770	4366730	443.8437	118.4854
650770	4371730	443.8437	112.9051
650770	4376730	443.8437	107.5098
650770	4381730	443.8437	103.4418
650770	4386730	443.8437	101.7831
650770	4391730	443.8437	103.0319
650770	4396730	443.8437	106.81
650770	4401730	443.8437	112.0877
650770	4406730	443.8437	117.7024
650770	4411730	344.0062	122.6014
650770	4416730	344.0062	120.5117
650770	4421730	344.0062	119.3049
650770	4426730	344.0062	119.2828
650770	4431730	573.4124	119.7169
650770	4436730	513.2562	111.6563
650770	4441730	533.9061	101.0398
650770	4446730	533.9061	88.64223
650770	4451730	533.9061	76.18268
650770	4456730	507.025	66.78101
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655770	4371730	443.8437	105.4651
655770	4376730	443.8437	97.77103
655770	4381730	443.8437	91.81917
655770	4386730	443.8437	89.34842
655770	4391730	443.8437	91.21114
655770	4396730	443.8437	96.75718
655770	4401730	443.8437	104.3123
655770	4406730	443.8437	112.1498
655770	4411730	344.0062	116.2953
655770	4416730	344.0062	112.9174
655770	4421730	344.0062	110.9474
655770	4426730	344.0062	110.9112

655770	4431730	358.1937	112.8189
655770	4436730	573.4125	107.3013
655770	4441730	573.4124	100.3169
655770	4446730	533.9062	88.87456
655770	4451730	533.9062	76.50798
655770	4456730	533.9062	67.19293
660770	4366730	443.8437	108.3384
660770	4371730	443.8437	98.37481
660770	4376730	443.8437	88.20845
660770	4381730	443.8437	80.07432
660770	4386730	443.8437	76.6088
660770	4391730	443.8437	79.22687
660770	4396730	443.8437	86.84173
660770	4401730	443.8438	96.87232
660770	4406730	443.8436	106.9684
660770	4411730	344.0062	108.3794
660770	4416730	344.0062	103.2356
660770	4421730	344.0062	100.1876
660770	4426730	358.1936	100.1312
660770	4431730	358.1937	103.084
660770	4436730	573.4124	99.87278
660770	4441730	573.4124	90.41787
660770	4446730	573.4124	83.02408
660770	4451730	573.4124	80.04549
660770	4456730	513.2562	74.85361
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665770	4371730	443.8437	93.26159
665770	4376730	443.8437	81.08622
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665770	4391730	443.8437	69.94329
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665770	4436730	573.4124	93.95482
665770	4441730	573.4124	82.26869
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670770	4376730	443.8437	78.79118
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670770	4406730	358.1937	102.0379
670770	4411730	358.1937	91.36109
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670770	4421730	358.1937	75.4688
670770	4426730	358.1937	75.35251
670770	4431730	358.1937	81.29673
670770	4436730	347.0812	90.98349
670770	4441730	573.4124	78.3905
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670770	4456730	573.4124	67.22596
675770	4366730	443.8437	105.4434
675770	4371730	443.8437	94.08538
675770	4376730	443.8437	82.24892
675770	4381730	443.8437	72.51707
675770	4386730	443.8437	68.27345
675770	4391730	443.8437	71.48553
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675770	4421730	358.1937	66.54456
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675770	4431730	358.1937	73.73347
675770	4436730	347.0812	85.31511
675770	4441730	573.4124	80.30754
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675770	4456730	573.4124	69.75394
680770	4366730	443.8437	109.2807
680770	4371730	443.8437	99.75528
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680770	4386730	443.8437	79.17713
680770	4391730	443.8437	81.62992

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680770	4416730	358.1937	72.54848
680770	4421730	358.1937	64.66721
680770	4426730	358.1937	64.5146
680770	4431730	358.1937	72.17148
680770	4436730	347.0812	84.16907
680770	4441730	573.4124	87.23709
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685770	4366730	443.8437	114.3337
685770	4371730	443.8437	107.0433
685770	4376730	443.8437	99.85927
685770	4381730	443.8437	94.33583
685770	4386730	443.8437	92.05302
685770	4391730	443.8437	93.77345
685770	4396730	443.8437	98.91611
685770	4401730	443.8437	105.9641
685770	4406730	424.9124	97.61573
685770	4411730	424.9123	84.83537
685770	4416730	424.9124	72.64193
685770	4421730	424.9124	64.54652
685770	4426730	424.9124	64.15668
685770	4431730	424.4311	71.6798
685770	4436730	424.4311	83.66648
685770	4441730	410.6562	94.59153
685770	4446730	573.4123	90.80531
685770	4451730	573.4124	88.42818
685770	4456730	573.4124	90.50197