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Investigation of Monthly Pan Evaporation in Turkey with Geostatistical Technique

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ABSTRACT

The aim of this study is to evaluate the spatial variations of monthly average pan evaporation amounts throughout Turkey by applying Geostatistical methods. Monthly averages of Class A pan evaporation data are reported by the General Directorate of State Meteorological Works using series of record lengths between 20 and 45 years at about 200 stations scattered over an 814.578 km^2 surface area of Turkey. The data belonging to the summer months of June, July, and August are used in this study because the evaporation in this three-month period is greater than the sum of those of the other nine months. Monthly averages of the observed pan evaporation data are considered and the spatial variation of evaporation is analyzed. Kriging estimate maps are drawn and interpreted for the summer months. The study indicates that the spatial variation of monthly average pan evaporation values can be reasonably estimated by the geostatistical method based on observed pan evaporation data. It is suggested that this map may be used by decision-makers for accurate estimation of monthly pan evaporation in any reservoir management or irrigation projects where data availability is limited.

Keywords: Evaporation, geostatistics, kriging, semivariogram.

INTRODUCTION

Evaporation, as a major component of the water cycle, is important in water resources development and management. Accurate estimation of pan evaporation (E_{pan}) is important mainly for calculation of losses from natural or man-made lakes due to evaporation from the surface. The high rate of evaporation especially in hot summer months from water bodies in arid and semi-arid regions reduces water releases from them. Although there are theoretical–empirical formulae based on thermodynamics of evaporation, it is still difficult to obtain reliable estimates of evaporation as a function of climatic variables. There are different methods for pan evaporation like the Penman, the Priestley-Taylor, and regression models, which use such relevant meteorological events as wind speed, solar radiation, relative humidity, and temperature as the independent variables. While these methods are easy to use, they yield site-specific results which may lead to low accuracy at locations at which sufficient and reliable meteorological data do not exist.

Frequently evaporation estimates are available at several weather stations, and estimates in other areas are obtained by interpolation from those values. Several interpolation methods with various levels of complexity exist. Of these, geostatistical interpolation is becoming increasingly common in agricultural sciences [1] because it is based on the spatial variability of the variable of interest and includes estimates of uncertainty [2]. For example, ordinary kriging has been used for the spatial interpolation of evapotranspiration [3-4].

The present study is undertaken to determine the spatial variation of the monthly pan evaporation all over Turkey by using a geostatistical technique applied to pan evaporation data observed and recorded in monthly units by the General Directorate of State Meteorological Works. Monthly averages of Class A pan evaporation data are computed and reported by the General Directorate of State Meteorological Works using series of record lengths between 20 and 45 years at about 200 stations scattered over approximately 814.578 km^2 surface area of Turkey. The data belonging to the summer months of June, July, and August are used in this study because the evaporation in this three-month period is greater than the sum of those of the other nine months. Ordinary kriging is used to determine the spatial variation of the monthly pan evaporation at any point in the area under study. Kriging estimation maps for the summer months are drawn and the accuracy of the maps are discussed based on a cross-validation study.

BRIEF REVIEW OF KRIGING

There are a number of commonly used interpolation methods described in the literature such as simple average, Thiessen polygons, classical polynomial interpolation, inverse distance, multi quadric interpolation, kriging and others. In this study we used ordinary kriging method. This method includes two stages which is first identification and modeling of spatial structure. At this stage continuity, homogeneity and spatial structure of a given variable is studied using variogram. Second stage is geostatistical estimation using kriging technique which depends on the properties of the fitted variogram which affects all stages of the process. The following spatial functions were used in this study:

Semi-variogram: Perhaps the best known spatial function is the semi-variogram, which is a function or graph describing the expected squared difference between pairs of samples, X_i , X_j with a given relative orientation [5, 6]**.** The general equation for the sample semi-variogram $\gamma(d_{ij})$ of any phenomenon is given as

$$\gamma(d_{ij}) = \frac{1}{2n}\sum_1^n (X_i - X_j)^2 \qquad (1)$$

where the sum is taken over all points separated by distance d_{ij} (actually a distance class interval).

Using mean monthly evaporation from all recording periods, direct-semi-variograms of monthly evaporation were calculated.

In general, four types of models for semi-variograms: a) spherical; b) exponential; c) Gaussian; and d) linear-sill were used. Equations of these four models are described as follows:

$$\begin{aligned} \gamma(h) &= C\left[\frac{3}{2}\frac{h}{a} - \frac{1}{2}\frac{h^3}{a^3}\right] + C_o \quad h \le a \\ \gamma(h) &= C + C_o \quad h > a \end{aligned} \qquad \text{Spherical model} \qquad (2)$$

$$\gamma(h) = C\left(1 - C^{-h/a}\right) + C_o \qquad \text{Exponential model} \qquad (3)$$

$$\gamma(h) = C\left(1 - C^{-h^2/a^2}\right) + C_o \quad \text{Gaussian model} \tag{4}$$

$$\begin{aligned} \gamma(h) &= C(h/a) + C_o \quad h \leq a \\ \gamma(h) &= C + C_o \qquad\quad h > a \end{aligned} \quad \text{Linear} - \text{sill model} \tag{5}$$

In these equations a is the range, $C+C_o$ is the sill and C_o is the nugget effect. A model of semivariogram $\gamma(h)$, which is a measure of the similarity between points at a given distance h apart, is fitted. Above mentioned models are proposed in the literature where it is important to define certain parameters such as the nugget effect, which is the limit of $\gamma(h)$ when the distance (h) is zero. The range is the maximum distance at which there is no variation and the sill is the $\gamma(h)$ value at the range value. Kriging then uses the variogram $\gamma(h)$ to assign weights to neighboring observations in the interpolation process [7]. In each application we tested all the above models to find the best one according to the statistical parameters, namely, root mean square error (RMSE) and mean absolute relative error (MARE).

Ordinary kriging: Although kriging was initially introduced to provide estimates for unsampled values, it is increasingly being used to build probabilistic models of uncertainty about these unknown values. In general, kriging provides a minimum error-variance of any unsampled value. Contouring a grid of kriging estimates is the traditional mapping application of kriging.

Kriging is a method that is often associated with the best linear unbiased estimator. Ordinary kriging is linear because its estimates are weighted linear combinations of the available data; it is unbiased since it tries to have the mean residual of error (m_R) equal to 0; it is best because it aims at minimizing the variance of error (σ^2_R).

Ordinary kriging estimation is shown below[5]

$$Z^*(X_1) = \sum_1^n \lambda_j Z(x_i) \tag{6}$$

where λ_i is the weighting factor, Z is the known variable and Z^* is the estimated variable. The above estimation gives the standard kriging equation as follows:

$$\sum_{j=1}^n \lambda_j \gamma_{ij} + \mu = \gamma_{io} \quad i = 1,2,\dots,n \tag{7}$$

$$\sum_{j=1}^n \lambda_j = 1 \tag{8}$$

and the variance of estimation error is:

$$\sigma^2 = \sum_{i=1}^n \lambda_j \gamma_{io} + \mu \tag{9}$$

where γ_{ij} is a semi-variogram of variables separated by distance (i,j), γ_{io} is the value of the semi-variogram corresponding to a vector with origin in x_i and extremity in an unknown point, μ is the Lagrange multiplier, σ^2 is the variance of variable, n is the number of pairs of observation separated by a distance x_i, and i indicates the sampling point [5].

DESCRIPTION OF THE AVAILABLE DATA

The data used in this study are obtained from the General Directorate of State Meteorological Works. The average values of the monthly pan evaporation series of record lengths between 20 and 45 years obtained from about 200 stations scattered over approximately 814.578 km^2 surface area of Turkey are used in the study. The geographical coordinates of the region are 26°– 45° E and 36° – 42° N. Temperature variation in the region is high due to the rough topographical terrain of the peninsula of Anatolia surrounding the large inland plateau. The minimum temperature in Agrı station in the northeast is –42.8 °C while it reaches to higher than 46.8 °C in Şanlıurfa station in the southeast. The average annual pan evaporation varies between 435 – 2800 mm. The overall climate of the study area is semi-arid and the annual precipitation ranges from 317 mm in Konya station in the Mid-Anatolia up to 2242 mm in Rize station in the north at the sea-ward side of the Black Sea Mountains. The annual average precipitation amount of *Turkey* is about 641 mm. Figure 1 shows the distribution of gauging stations in the study area.

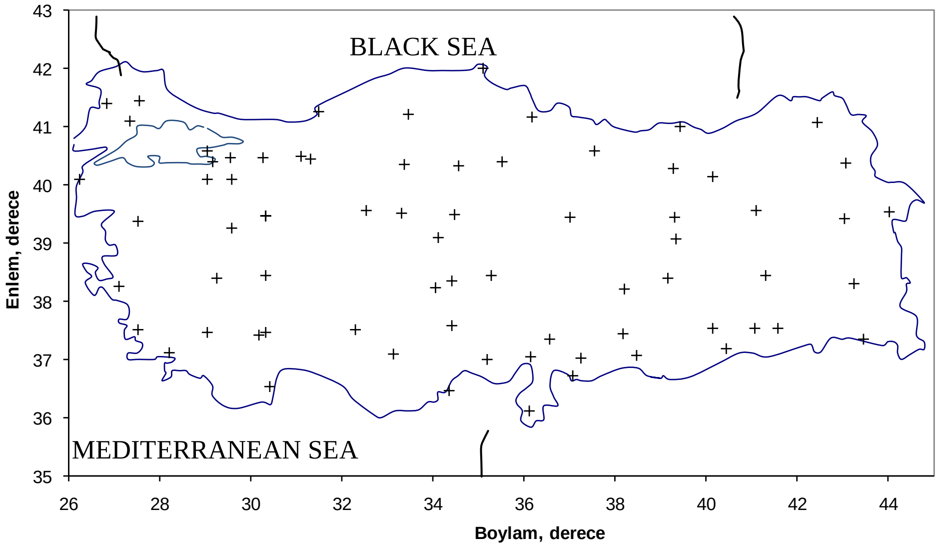

Figure 1. Locations of the pan evaporation measuring stations

APPLICATION AND RESULTS

A statistical summary of the monthly pan evaporation data is presented in Table 1. Using all the available data, the experimental variogram models of the evaporation data in June, July and August were computed. The best model for fitting the experimental variogram models were selected by the trial and error approach for four types of models for semi-variograms, which are: a) spherical; b) exponential; c) Gaussian; and d) linear-sill. These variogram models are shown in Figure 2, and Table 2 gives magnitudes of their parameters for the summer months. The nugget semi-variance, expressed as a percentage of the total semi-variance (Sill), enables comparison of the relative size of the nugget effect among the studied variables [8]. This percentage can be regarded as a criterion for classifying the spatial dependence of evaporation data. If this ratio is less than 25%, then the variable has a strong spatial dependence; if the ratio is between 25 and 75%, the variable has a moderate spatial dependence, and if it is greater than 75%, the variable shows only a weak spatial dependence. All months have moderate spatial structure. Also, the effective range of the pan evaporation data for the summer months is the same (2.5 Km).

Using the appropriate semi-variogram, the ordinary kriging method was used for the interpolations of mean monthly pan evaporations for the summer months in Turkey, which are shown in Figure 3.

Table 1. Statistical analysis on monthly pan evaporation data in summer months in Turkey

Statistics	Months		
	June	July	August
Minimum	98.60	116.30	108.10
Maximum	402.20	495.30	459.50
Mean	199.34	246.57	229.81
Std. deviation	51.18	63.04	57.72
Skewness Coef.	0.98	0.80	0.64

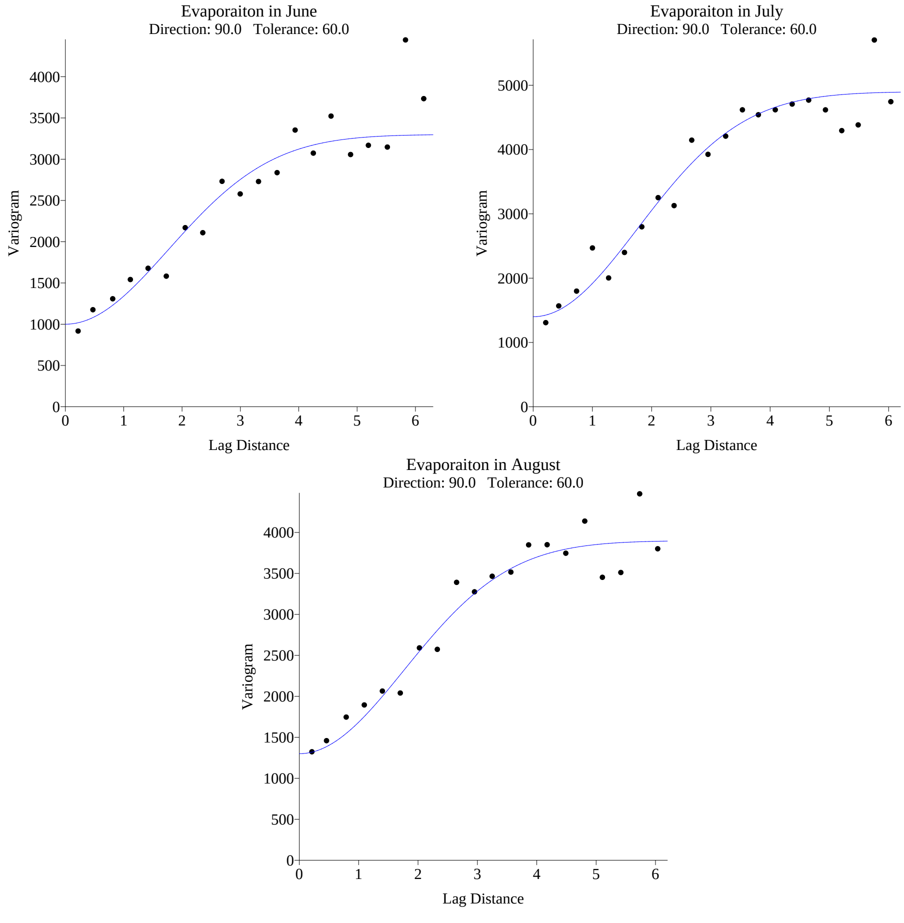

Figure 2: Variograms related to the pan evaporation data for the summer months in Turkey

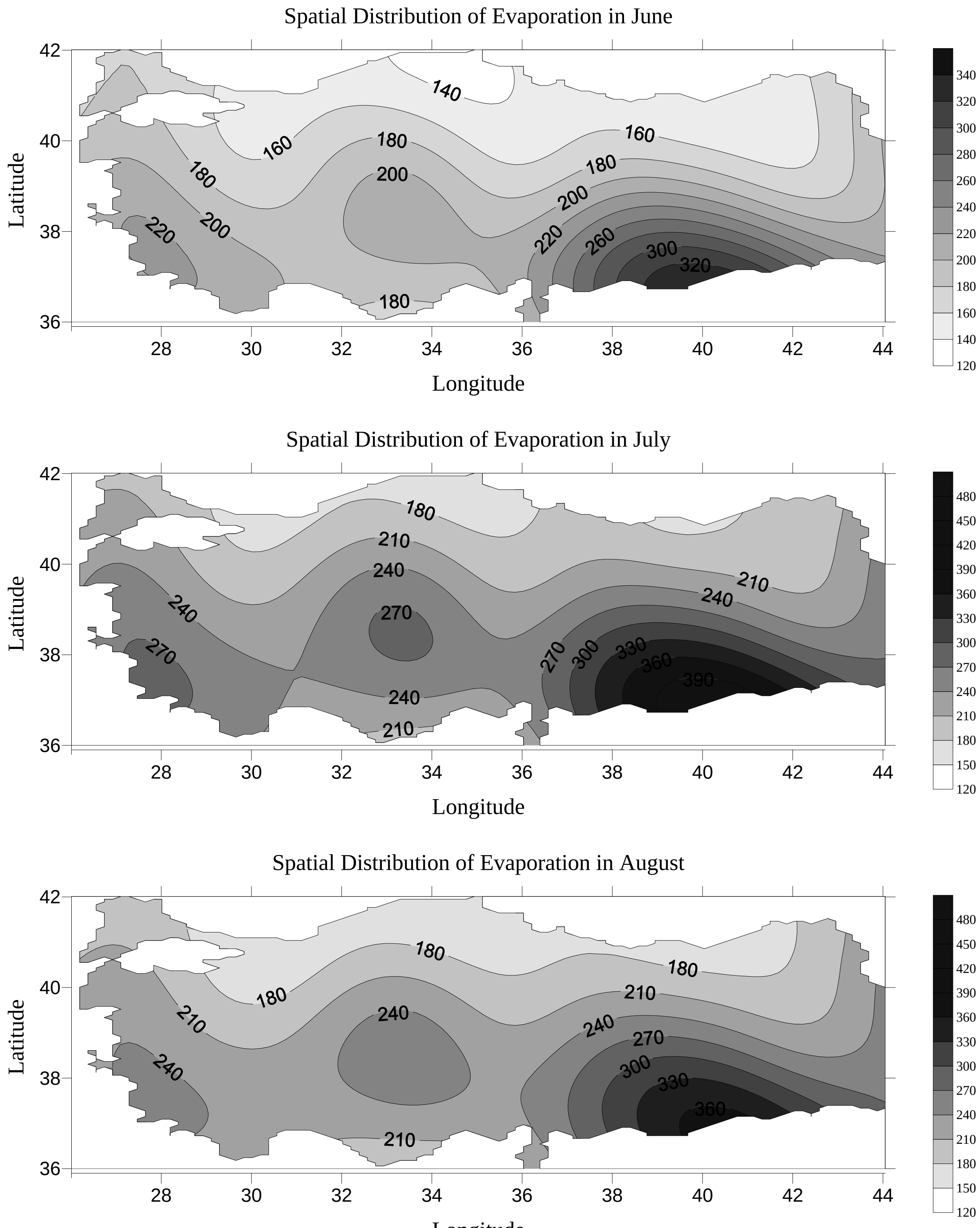

Figure 3: Spatial distribution of average pan evaporation amounts in mm/month for the summer months

Table 2. The best-fitted variogram models of monthly pan evaporation data and their parameters for the summer months

Months	Model	Nugget (C_0)	Sill (C_0+C)	Range effect, km
June	Gaussian	1000	2300	2.5
July	Gaussian	1400	3500	2.5
August	Gaussian	1300	2600	2.5

For validation of the monthly average pan evaporation estimation model, the statistics of correlation coefficient (R), root mean square error (RMSE), and mean absolute relative error (MARE) were used, whose numerical magnitudes are shown in Table 3. As seen in this table, the geostatistical technique has considerable accuracy for estimation of monthly pan evaporation.

Table 3. The magnitudes of the RMSE, MARE, and R statistics of the variogram models

Months	RMSE (mm)	MARE (%)	Correlation Coefficient (R)
June	34.76	14.31	0.730
July	42.03	14.59	0.741
August	40.66	14.99	0.700

CONCLUSIONS

As the outcome of the geostatistical analysis, it is concluded that the best theoretical semi-variogram model, which characterizes the study area and fits best to the experimental semi-variograms is the Gaussian model. The monthly point and spatial pan evaporation amounts are generated by the block kriging technique for the summer months. Using the computer plotting routines, the estimates are transformed into contour maps of monthly pan evaporations and of contour maps of kriging variance. Hence, estimation of the monthly pan evaporation without a climate station is made possible by the outcome of this study. The developed model shows a strong dependability of monthly evaporation on spatial variability. The results of this research show that the spatial variability of monthly pan evaporation over large geographical areas can be described by semivariogram models and in light of this information the monthly pan evaporation can be predicted by means of kriging maps. This procedure could be effectively used to increase the accuracy of calculation of evaporation losses during operation of reservoirs in monthly periods, which is common, for such objectives as hydroelectric energy generation, irrigation, and municipal water supply.

LITERATURE

1. Sepaskhah, A. R., Ahmadi, S. H. & Nikbakht-Shahbazi, A. R. (2005). Geostatistical analysis of sorptivity for a soil under tilled and no-tilled conditions. Soil Till. Res. (In Press).
2. Journel, A. G. & Huijbregts, C. J. (1978). Mining geostatistics. Academic Press, London, 600.

3. Cuenca, R. H. & Amegee, K. Y. (1987). Analysis of evapotranspiration as a regionalized variable. Adv. Irrig. 4, 181-220.
4. Martinez-Cob, A. & Cuenca, R. H. (1992). Influence of elevation on regional evapotranspiration using multivariate geostatistics for various climatic regimes in Oregon. J. Hydrol. 136, 353-380.
5. Clark, I. (1982). Practical Geostatistics. Elsevier Applied Science, London. 129 pp.
6. Çetin, M., 1996. Geoistatistical determination and stochastic modelling of point and areal rainfall: Application on selected basins. Cukurova Uni. Institute of Basic And Applied Sciences, PhD Thesis, Adana, Turkey.
7. Wackernagel, H., 1995. Multivariate Geostatistics. An Introduction with Applications. xiv + 256 pp. Springer-Verlag, London.
8. Trangmar, B.B., Yost, R.S. and Uehara, G., 1985. Application of geostatistics to spatial studies of soil properties. Advances in Agronomy, 38: 45-94.