Journal of Urban and Environmental Engineering, v.8, n.2, p.218-224

ISSN 1982-3932
doi: 10.4090/juee.2014.v8n2.218224

Journal of Urban and Environmental Engineering

www.journal-uee.org

COMPARISON OF SPATIAL INTERPOLATION METHODS FOR WHEAT WATER REQUIREMENT AND ITS TEMPORAL DISTRIBUTION IN HAMEDAN PROVINCE (IRAN)

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Received 7 November 2013; received in revised form 16 October 2014; accepted 18 October 2014

Abstract: Water is the main constraint for production of agricultural crops. The temporal and spatial variations in water requirement for agriculture products are limiting factors in the study of optimum use of water resources in regional planning and management. However, due to unfavorable distribution and density of meteorological stations, it is not possible to monitor the regional variations precisely. Therefore, there is a need to estimate the evapotranspiration of crops at places where meteorological data are not available and then extend the findings from points of measurements to regional scale. Geostatistical methods are among those methods that can be used for estimation of evapotranspiration at regional scale. The present study attempts to investigate different geostatistical methods for temporal and spatial estimation of water requirements for wheat crop in different periods. The study employs the data provided by 16 synoptic and climatology meteorological stations in Hamadan province in Iran. Evapotranspiration for each month and for the growth period were determined using Penman-Mantis and Torrent-White methods for different water periods based on Standardized Precipitation Index (SPI). Among the available geostatistical methods, three methods: Kriging Method, Cokriging Method, and inverse weighted distance were selected, and analyzed, using GS+ software. Analysis and selection of the suitable geostatistical method were performed based on two measures, namely Mean Absolute Error (MAE) and Mean Bias Error (MBE). The findings suggest that, in general, during the drought period, Kriging method is the proper one for estimating water requirements for the six months: January, February, April, May, August, and December. However, weighted moving average is a better estimation method for the months March, June, September, and October. In addition, Kriging is the best method for July. In normal conditions, Kriging is suitable for April, August, December, October, and March while weighted moving average is a better method for other months. Furthermore, based on growth period scale, for normal and wet periods in both irrigated and rain-fed farming, Kriging method is suitable, while in drought condition, Kriging is suitable for irrigated farming and weighted moving average should be used for rain-fed farming.

Keywords: Geostatistical Methods, Water Requirement, Wheat, SPI, GS+, Drought

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INTRODUCTION

Limitations on soil and water resources as well as other production factors necessitate effective and optimum use of available resources and supplies. It is possible to increase the productivity of different factors involved in production with proper management, planning, allocation, and optimizing resources. Availability of adequate data on water requirements alongside with planning based on these data can help effective agriculture, improve production, and optimum use of water resources (Mozaffari, 2005).

Determining crop water requirements needs data on evapotranspiration of crops. Evapotranspiration are among key factors in regional water balance and determining factors for appropriate planning for irrigation to improve efficiency of water consumption in farms (Ki & Lyons, 2003). On the other hand, evapotranspiration plays an important role in global climate through hydrologic cycle. Estimation of these effects has significant applications in predicting runoffs, crop yields, and designing land use (Kustas & Norman, 1996), as well as in designing irrigation canals and structures for water distribution networks (Michael & Bastiaanssen, 2002). These factors also influence the occurrence of natural disasters (Ogawa, 1999). Evapotranspiration is estimated using point measurements. Since most of studies and plannings are carried out on regional scale, the data obtained by point measurements should be extended for regional scale.

Classic statistical methods like arithmetic mean, and regressions are commonly used to determine crop water requirement at regional scale. However, these methods may lack desirable accuracy due to neglecting factors such as locations and arrangement of meteorological stations. Other methods that can be applied to variable estimation at regional scale are geostatistical interpolations. Martinez Cob (1996) used multivariable geostatistical analyses to determine regional precipitation and evapotranspiration in Aragon Mountains, Spain. In this study, Kriging, Cokriging, and modified Kriging methods were evaluated as tools for long-term interpolation of total precipitation and index evapotranspiration. It was found that cokriging method outperforms the other two methods. In another study, Price *et al.* (2000) compared the performance of different thin plate smoothing spline in evaluation of spatial variations in temperature as well as monthly and annual precipitation in eastern and western Canada. They found that smoothing spline usually give better results in majority of the months; however it is easier to use smoothing spline. Mahdian *et al.* (2003) used four geostatistical methods, namely thin plate smoothing spline, kriging, cokriging, and weighted moving average methods, to study regional variations in evaporation and potential evapotranspiration in Karoun basin, Iran. Their findings suggest that for the five months January, February, September, October, and December, squared weighted moving average and nine neighborhood adjacent points is the most appropriate method, while thin plate smoothing spline with artificial variables and with the fourth power is the best method used for the other months. Noushadi & Sepaskhah (2009) calculated potential evapotranspiration using Hargreaves – Samani method and compared the results with those obtained by kriging method and cokriging method. Based on these results, cokriging method is the best approach to evaluate monthly index potential evapotranspiration (except for the months April, May and September). It is also concluded as the best method for estimation of annual evapotranspiration. The study carried out by Jeffrey *et al.* (2001) shows that no single geostatistical method can be recommended and the appropriate method should be selected based on the variable under study. Therefore, review of researches suggests that interpolation method should be chosen based on the variable of interest. Thus, more studies are needed on those variables for which no appropriate method has been reported. The present study attempts to investigate geostatistical interpolation methods that can be used for the variable, wheat water requirement. To this end, kriging, cokriging, and inverse weighted distance were evaluated and the best geostatistical methods were determined based on Mean Bias Error (MBE) and Mean Absolute Error (MAE).

MATERIALS AND METHODOLOGY

Hamedan province is located between latitude 34^o and $35^o\ 46^{'}$ N and between longitude $47^o\ 48^{'}$ and $49^o\ 28^{'}$ E. The region covers an area 19 493 km^2 equivalent to 1.2 of percent of the total area of the country (Iran). The climate is semi-arid and cold according to selyaninov classification (Zare, 2004), with an average annual precipitation of 330 mm and average annual temperature 12^oC (18).

Irrigated wheat in Hamadan cover an area of 99350 hectares where and rainfed land covers 299 160 hectare, in total 398 510 hectares (19).

The data of 11 meteorological stations of Hamadan province were collected from Meteorology Organization data base for this study. In addition, data available at 5 stations in adjacent neighboring region were used. Among these 16 stations, 10 were synoptic whose data were employed for estimation of potential evapotranspiration using Penman-Mantis method. For other stations, where required data for Penman-Mantis method were not available, the data pertaining to minimum temperature were used in Torrent-White method (1984). As FAO recommends use of Penman-Mantis over other methods, in this study two estimation methods as well as the relations between the two methods were employed to evaluate evapotranspiration. Using these relations, the equivalent values to Penman-

Mantis (1985) to comput potential evapotranspiration for those stations where only Torrent-White results were available. In order to evaluate variations in the variable under consideration at regional scale, the related index during a continuous time period in three conditions: drought (dry years), wet (wet years), and normal, were analyzed for the period of records. For this purpose, 15 stations with 30 years records were selected. Standardized Precipitation Index (SPI) was used to monitor the three conditions. SPI has been developed by McKey *et al.* (1993) to quantify the precipitation deficit for multiple time scales. These time scales reflect the impact of drought on the availability of the different water resources. McKee *et al.* (1993) originally calculated the SPI for 3, 6,12, 24, and 48–month time scales.

As mentioned earlier, due to the ability in accounting for correlation and spatial structure of data, geostatistical methods can provide estimates of variables at other points given their coordinates, Kriging method based on weighted moving average has been identified as the best unbiased estimator (Yazdani *et al.*, 2005). The general formula for this estimator is:

$$Z^*(x_i) = \sum_{i=1}^{n} \lambda_i Z(x_i) \tag{1}$$

where $Z^*(x_i)$ is estimated value at x_i location, λ_i is the weight for the ith sample, $Z(x_i)$ is the ith observed value of the variable, and *n* is the number of observations.

For using kriging method, Z must have normal distribution; otherwise, either nonlinear kriging method or some other method should be applied to obtain normal distribution (Yazdani *et al.*, 2005).

Like classic statistical multivariable methods, for cokriging method, correlation among different variables may be used to estimate the values for the unknown parameter.The cokriging estimate is a linear combination of both the variable of interest and the secondary variables and is given by (Hassani Pak, 1998):

$$Z^*(x_i) = \sum_{i=1}^{n} \lambda_i Z_i + \sum_{j=1}^{n} k_i y_i \tag{2}$$

where K_j is the weight for the slack variable *y*, Z_i is observed value for the main variable, and y_i is the observed value for the slack variable.

The value of unknown variable in inverse weighted distance is obtained by weighting the values at the adjacent points stations. The method assumes a local effect for each point of measurement (observation) and this effect weakens as moving further away from the point of measurement. The equation used in this method is similar to one shown in **Eq. (2)**, here λ_i corresponds to the distance; that is, the greater the distance, the lower the weight (Wasten, 1984). The effect of the distance is represented as (*h-a*) and hence it is called inverse weighted distance. Here, in calculations, *a* is an integer from 1 to 4 and the number of adjacent points are 6, 9, 12, and 16. Calculations for kriging and cokriging methods, using elevation as a co-variable, and inverse of weighted distance, were performed in GS+ 5.5.

Model Evaluation

The evaluation of the models is based on the following: The accuracy was measured (Kravchenko & Bullock, 1999; Schloeder *et al.*, 2001) by the mean absolute error (MAE), which is a measure of the sum of the absolute residuals and the mean bias error (MBE), provides information on the long term performance of the correlations by allowing a comparison of the actual deviation between predicted and measured values term by term. Small MAE values indicate a model with less errors, while The ideal value of MBE is (Schloeder *et al.*, 2001). The MAE was calculated as follows:

$$\mathrm{MAE} = \frac{1}{n} \sum_{i=1}^{n} \left| Z(x_i) - Z^*(x_i) \right| \tag{3}$$

$$\mathrm{MBE} = \frac{1}{n} \sum_{i=1}^{n} (Z(x_i) - Z^*(x_i)) \tag{4}$$

The parameters are defined earlier.

RESULTS AND DISCUSSION

The calculations of SPI for all the available meteorological stations in the region show that in general, for the period of records, the region has experienced drought in 1999, wet in 1992, and normal conditions in 1989.

Further, as mentioned earlier, for using geostatistical methods alongside with kriging method, the data should have normal distribution. Since this condition is not met, the logarithmic function was used to convert the data into desirable form. In cokriging method, the slack variable was assigned the height of station. Based on previous studies (Yates, 1986), the coefficient of correlation between the main variable and the slack variable should be larger than 0.5. The correlation between evapotranspiration, and elevation of station, shows that this condition is met for all months. Geometric anisotropy was observed in the data. **Table 1** and **2** shows the results of variogram analysis for kriging and cokriging interpolation methods in drought conditions. The variogram is used to express spatial relations for the variable and four factors, namely

Table 1. Results of assessment kriging & cokriging method and semivariogram analysis for drought condition

kriging method								month
MAE (mm)	MBE (mm)	r^2	C.(C0+C)	Effective range(Km)	Sill (mm^2)	C0 (mm^2)	model	
0.73	0.91	0.88	0.322	125.21	0.28.	0.001	spherical	jan
0.73	0.83	0.835	0.303	187.32	0.019	0.035	spherical	feb
1.7	1.64.	0.762	0.478	325.36	0.290	0.055	spherical	mar
0.52	1.07	0.22	0.525	312.52	0.011	0.014	Gaussian	apr
1.11	1.04	0.3	0.346	189.45	0.055	0.011	Gaussian	may
1.96	1.586	0.106	0.551	285.63	0.080	0.02	spherical	jun
0.915	1.186	0.5	0.521	154.96	0.041	0.026	spherical	jul
1.1	1.219	0.632	0.428	145.32	0.037	0.017	Gaussian	aug
1.2	1.97	0.351	0.458	112.85	0.021	0.022	Gaussian	sep
0.52	0.63	0.12	0.303	264.11	0.019	0.037	Gaussian	oct
0.915	1.186	0.62	0.421	125.24	0.031	0.016	Gaussian	Growing period of rain-fed wheat
0.92	0.230	0.234	0.587	187.32	0.038	0.078	Gaussian	Growing period of irrigated wheat

Table 2. Results of assessment cokriging method and semivariogram analysis for drought condition

Cokriging method								month
MAE (mm)	MBE (mm)	r^2	C.(C0+C)	Effective range(Km)	Sill (mm^2)	C0 (mm^2)	model	
1.554	1.342	0.687	0.322	147.01	8.2	0.100	spherical	jan
1.95	1.48	0.965	0.263	238.01	6.03	0.01	spherical	feb
1.68	1.85	0.615	0.378	156.88	2.01	0.001	spherical	mar
1.08	1.55	0.326	0.425	157.91	1.61	0.001	Gaussian	apr
1.76	2.55	0.032	0.346	229.6	0.621	0.001	Gaussian	may
1.158	1.475	0.256	0.451	173.11	-0.71	-0.001	spherical	jun
0.51	1.06	0.408	0.421	125.51	-0.77	-0.001	spherical	jul
1.82	1.58	0.764	0.428	356.21	2.01	0.001	Gaussian	aug
2.83	1.88	0.789	0.458	136.99	2.01	0.001	Gaussian	sep
1.19	1.32	0.725	0.403	211.08	2.03	0.007	Gaussian	oct
0.61	1.21	0.358	0.214	185.41	0.27	0.003	Gaussian	Growing period of rain-fed wheat
1.32	1.27	0.241	0.254	211.81	0.31	0.002	Gaussian	Growing period of irrigated wheat

nagget, sill, effective range, and ratio of structure variable to the sum of structured variable and piecewise effect (C.C0+C), are of great importance in variogram analysis.

As it can be seen in **Tables 1** and **2**, the average value for (C.C0+C) at monthly scale is 47.8 percent varying from 30.3 percent in February to 55.1 percent in June. Therefore, it can be concluded that the effect of the structure variable, evapotranspiration is more than the effect of the unstructured variable for all the months; a result that shows appropriate spatial structure for the variable of interest in the region. The effective range for the data varies from 112 km to 325 km. Gaussian model has better fit for September, October, November, April, and May, while spherical model performs well for other months. In growth period scale, (C.C0+C) is 42.1 for rain-fed wheat and the fitted model is spherical. However, for irrigated wheat, Gaussian model demonstrates better fit and (C.C0+C) is 58.7 percent.

At monthly scale, the value of (C.C0+C) obtained in cokriging method shows weak spatial structure of data. The ratio varies from 29.6 percent in February to 45.8 percent in October. The average effective range for this method is about 190 km showing a decrease in most of the months compared to kriging method. In growth period scale, (C.C0+C) for rain-fed wheat and irrigated wheat is 21.4 and 25.4 percent, respectively which again shows a reduction compared to kriging method.

In wet years, however, (C.C0+C) for monthly scale in kriging method is 46.1 percent in average, ranging from 33.6 percent in November to 58.9 percent in August. Gaussian model is appropriate for October, March, April, and May while spherical model is a better fit for other months. In addition, (C.C0+C) for kriging in normal conditions at monthly scale has an average of 43.8, ranging from 31.7 percent in January to 57.6 percent in July. Gaussian model was used as data fitting model for all months. Evaluations for cokriging method in both dry and wet years shows lower values of (C.C0+C) compared to kriging methods; a result that reveals poor spatial structure of data in this method. Similarly, evaluations were performed using inverse weighted distance with the first, second, third, and fourth powers. **Table 3** shows the results by power and number of neighborhood points in dry years.

In addition to the effect of power, number of the adjacent points influences the accuracy of estimates. Once the number of adjacent points are chosen, the effect of the power on bias and error was evaluated. The analysis of results and **Figs 1** and **2** show that number of adjacent point does not largely contribute in the error; however, the value of power has major effects on errors. In summary, using the second power and 9 adjacent points can be the best choice for evaluation of water requirement in this region for droughty conditions. The findings also suggest the sixth power and 9 adjacent points for normal conditions, and the second power and 9 adjacent points for wet years.

Table 3. Results of assessment inverse weighted distance method (WMA)

MAE (mm)				BEM (mm)				number of neighborhood points				month
Power 4	Power 3	Power 2	Power 1	Power 4	Power 3	Power 2	Power 1	Power 4	Power 3	Power 2	Power 1	
1.14	1.08	1.18	1.36	1.85	0.74	1.14	1.51	9	9	9	9	jan
1.05	1.11	1.30	0.58	0.44	0.85	0.57	1.43	9	9	9	9	feb
1.22	0.79	0.26	1.33	0.77	1.45	-0.76	1.56	6	6	6	6	mar
1.14	0.98	1.18	-1.36	0.85	0.94	1.14	1.51	9	9	9	9	apr
1.23	-1.2	1.27	1.40	1.69	1.14	1.67	1.26	9	9	9	9	may
0.64	-0.54	0.66	0.76	0.80	0.7.	0.8.	-0.13	6	6	6	6	jun
1.33	1.35	1.39	1.4	-1.13	-0.86	0.73	2.71	12	12	12	12	jul
0.24	0.24	0.23	0.22	0.90	0.91	-0.92	-0.93	16	16	16	16	aug
0.37	0.37	0.35	0.32	0.82	0.87	0.85	0.83	9	9	9	9	sep
1.31	1.28	1.25	1.22	0.91	0.94	0.97	1.00	9	9	9	9	oct

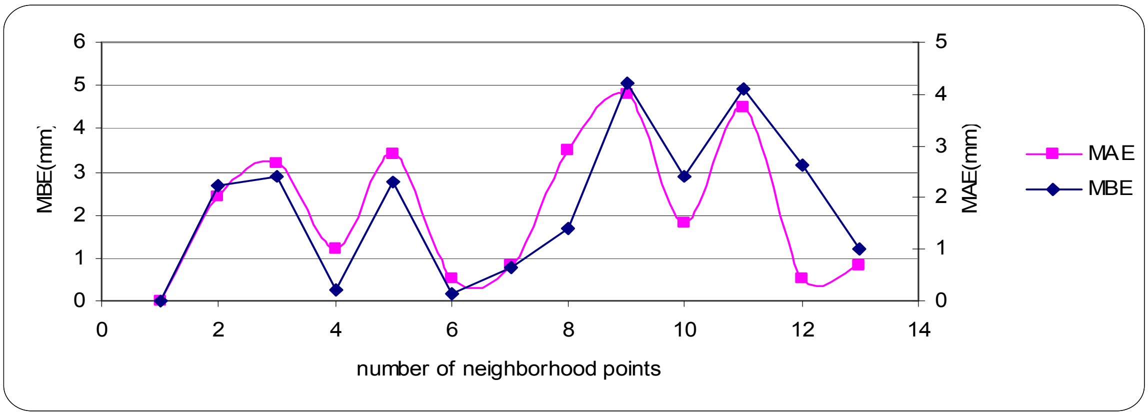

Fig. 1 Relation number of neighborhood points with mean absolute error (MAE) and the mean bias error (MBE) in WMA method for October

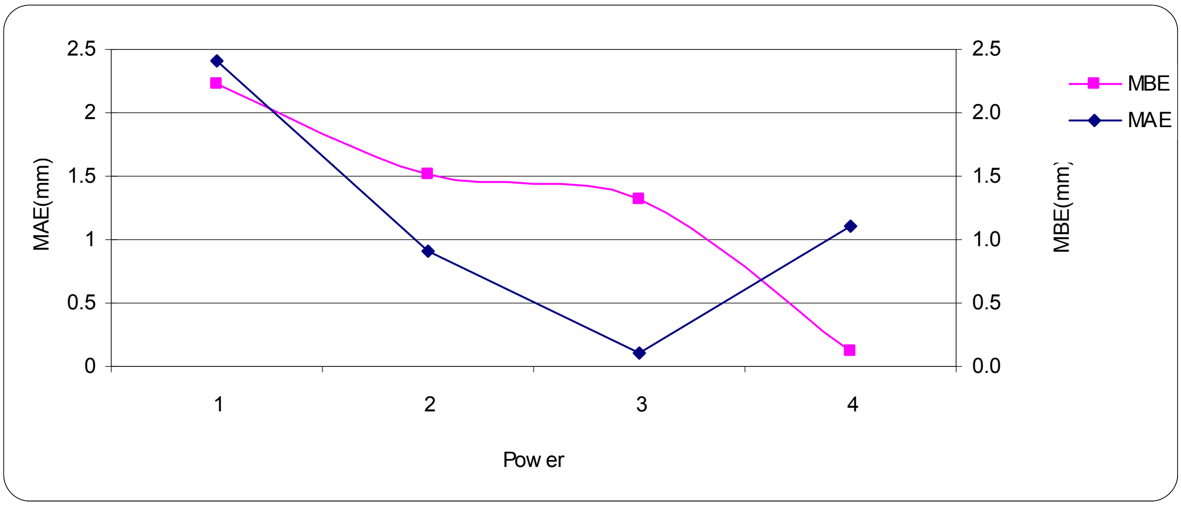

Fig. 2 Relation power with mean absolute error (MAE) and the mean bias error (MBE) in WMA method for October

Conclusion

The need for extending water requirement evaluations beyond point measurements and to regional scale can be addressed using geostatistical interpolation methods. Review of previous studies shows that choosing appropriate interpolation methods depends on the variable of interest. Therefore, additional studies are required on those variables for which no proper method has been reported. Table 4 shows the results of this study for the best methods that can be used for estimation of plants water requirements. In summary, kriging method is suitable for estimation of water requirements in January, February, April, May, August, and November in drought periods while inverse weighted distance is recommended for March, June, September, and October. Further, cokriging can be the method of choice for July. In normal conditions, kriging method can be used for April, August, November, October, and March, and inverse weighted distance is proposed for other months. In wet years, inverse weighted distance works well for January, February, and May, and kriging method can be used for the rest of the months. During the growth period in both wet and normal years, for rain-fed or irrigated agriculture, kriging method can be suggested as the method of choice while inverse weighted distance should be applied for rain-fed wheat in drought conditions and kriging can be used for irrigated wheat.

Table 4. Results of this study for the best methods that can be used for estimation of plants water requirements

Wet Year			Normal year			Dry year			month
MBE(mm)	MAE(mm)	method	MBE(mm)	MAE(mm)	method	MBE(mm)	MAE(mm)	method	
0.98	0.86	3	0.47	5.40	3	0.73	0.91	1	jan
0.49	0.52	3	5.40	0.64	3	0.73	0.83	1	feb
0.92	0.62	1	0.65	0.72	1	5.40	1.64	3	mar
0.82	0.75	1	0.44	0.64	1	0.52	5.40	1	apr
0.89	0.56	3	0.92	0.31	3	8.40	4.40	1	may
0.99	0.48	1	0.52	0.47	3	1.96	1.58	3	jun
0.54	0.85	1	0.88	0.74	3	0.91	1.86	2	jul
0.45	0.85	1	0.74	1.21	3	7.40	1.21	3	aug
5.40	0.92	2	0.71	0.63	1	5.40	1.97	3	sep
0.96	0.67	1	3.40	0.78	1	0.52	0.63	1	oct
4.40	0.67	1	0.62	0.45	1	0.84	0.61	1	rain-fed
0.45	0.88	1	0.89	0.71	1	0.55	0.72	3	irrigated

1- kriging 2- cokriging 3- WMA

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