http://www.pjbs.org

PJBS

ISSN 1028-8880

Pakistan Journal of Biological Sciences

ANSInet

Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Pakistan Journal of Biological Sciences 9 (9): 1764-1768, 2006
ISSN 1028-8880

Analysis of Depth-area-duration Curves of Rainfall in Semi-arid and Arid Regions Using Geostatistical Methods (Case Study: Sirjan Kafeh Namak Watershed)

[1]K. Solaimani, [2]A. Abkar, [1]M. Habibnejad and [2]M.Z. Ahmadi
[1]Faculty of Natural Resources, University of Mazandaran, P.O. Box 737, Sari, Iran
[2]Former M.Sc Student, University of Mazandaran, P.O. Box 737, Sari, Iran

Abstract: Drawing isohyets maps is one of the main steps in preparation of depth-area-duration (DAD) curves. To draw these maps different methods are used such as using rainfall gradient, simple classic statistical methods and complicated Geostatistical methods like Krigging method. For this purpose, after collection of data and information related to 59 rainfall gauging stations in the study area, The dominant and maximum rainfall for durations of one to three days were selected. Then for drawing the isohyets maps, the relationship between rainfall and the elevation were investigated, but due to insignificant difference of this relationship, two methods of Geostatistical Krigging and inverse distance with powers of 1 to 3, were evaluated to draw the isohyets maps and determination of the average rainfall. To evaluate the above two methods, Mean Absolute Error (MAE) was used in this research. The results of this evaluation showed that the Krigging method is better than inverse distance method for determination of average rainfall of the region. Then, by using krigging method, the isohyets maps of one to three -day duration and DAD curves were drawn. By using this method, conversion of point rainfall to average rainfall for an area of up to 20000 km^2 of the area under study is possible. Also, the investigation of the curves shows that the ratio of the amount of rainfall at the center to the amount of rainfall at an area of 20000 km^2 is 1.98, 1.74 and 1.48 for durations of 1, 2 and 3- day, respectively.

Key words: Sijan Kafah Namak watershed, Krigging, isohyets maps, DAD curve

INTRODUCTION

One of the important parameters in design of hydraulic structures in a watershed is the average rainfall. The amount and intensity of rainfall are always two basic parameters in design of hydraulic structures and watershed management. The more precise and more scientifically-based are the prediction of the two parameters, the more successful will be the construction of the structures. In fact, rainfall is a variable which changes both in space and time. So that the intensity of a specific rainfall will not be the same from the start to the end of it. Also, it seldom occurs that a specific rainfall would be the same throughout its areas. It is more in some points and less in other points. The location with highest amount of rainfall in a watershed is the center of the rainfall. The further the distance from the center the less will be rainfall. An investigation of the decrease trend in the amount of rainfall from its center is one the important problems in the sciences of hydrology and meteorology. The rain gauge stations show the amount of rainfall at specific points in a watershed. In fact, these stations give information of a phenomenon (rainfall) which has spatial changes. So, our information about the amount of rainfall is limited to specific points in the watershed. Rain gauge stations and their amount of rainfall can not be the basis of design of hydraulic structures. This case is more serious in arid and semi-arid regions where the number of rain gauge stations more limited and the changes in rainfall is more severe. So, knowledge of rainfall changes is inevitable in design of hydraulic structures. Analysis of the relationship among Depth-Area-Duration (DAD) of the rainfall is one of the basic instruments in investigation of spatial variation of rainfall and calculations of analysis related to floods. In fact, by using these curves, one can change the point rainfall (recorded in a rain gauge station) to the average rainfall in a specific area. Also, the spatial trend of rainfall changes in a specific duration and area can be determined.

One the main steps in preparation of DAD curves is drawing isohyets maps. Several methods exist for drawing such maps: like rainfall gradient method and also complicated Geostatistical methods like kriging. Although the rainfall gradient method is fast and simple in calculation, but, unfortunately in most cases like short duration rainfall and in the relationship between elevation

Corresponding Author: K. Solaimani, Faculty of Natural Resources, University of Mazandaran, P.O. Box 737, Sari, Iran
Tel: +981524222982

and rainfall the method did not give high correlation and did not have enough precision for drawing isohyets maps. All researches in Iran were based on gradient method by omitting over 50% of data to make the relationship between rainfall and elevation significant. This is not a scientific-based work. In these cases the Geostatistical methods for considering both spatial changes of data are useful. Geostatistics investigates those variables with spatial structure. This Geostatistical Predictor is called Kriging after the name of a South African mining Engineer Krig. This method is based on moving averages and can be regarded as the Best Linear Unbiased Estimation (BLUE). Nowadays, the Geostatistical methods, despite their complexity, have several applications in different branches of science like environmental and natural resources because of using strong computer software such as GS and GIS. The studying carried out about DADA curves are as follows:

The US meteorological (1958) prepared DAD curves for durations of 0.5 to 24 h, using rain gauge stations networks and showed that by increasing the area, the amount of rainfall decreases. Leclerc and Schaake (1972) found a relationship to convert point rainfall to the average rainfall in a specific area based on meteorological data. Aghighi (1995) made the analysis of DAD curves in Jajroud-Tehran-Karaj region and concluded that most rain falls during first three days. Ahmadi (2001) made the same analysis in Kermanshah Province.

Several Geostatistical approaches have been carried out throughout the world, despite the fact that the science is young in the subject. Some are as follows:

Vankuilenberg *et al*. (1982) compared moving average and Kriging methods to determine the soil moisture capacity in the Netherlands and concluded the Kriging method is better than the moving average method. Pohlman (1993) showed that using kriging method virogram analysis for interpolation of data and design of networks in environmental investigations is useful. Mahdian (2002) showed that Spline and Kriging method to estimate rainfall and temperature in arid, semi-arid and humid climates were better than other methods.

MATERIALS AND METHODS

Study area: In this research the Sirjan Kafeh Namak watershed which is one the sub-basin of Gavekhoni Marsh watershed was investigated. The region under investigation is between 56, 26, 31 to 30, 54 East Longitude, 35, 30, 27 to 51, 46, 28 North Latitudes and includes a great section of the cities Sirjan and Shahre Babak and a small portion of the city of Baft in Kerman Province and is located in western part of Kerman Province. The area of the watershed is 2480 km^2 the highest elevation is 3800 MSL and the lowest elevation is 1500 MSL. The climate of the region is variable due to large difference between the highest and lowest points (2300 m). Mean annual rainfall 180 mm which changes from 120 to 350 mm. Over 65% of rainfall occurs in winter. Mean annual evaporation is 2185 mm and mean annual temperature is 16.1 °C.

Collection of data and information

The data sources are Water Resources Research Organization: (Tamab in Persian language) and meteorological organization. For this purpose after determination of study area on 1:25000 topographical maps, the rainfall data were collected from all stations from the beginning of construction until 1999. The number of stations was 59, out of which 33 belonged to meteorological stations and 26 were related to Ministry of Power (Energy), Tamab Organization. When the two stations existed, the data of one station was used. If the two readings were different, the average of meteorological and Ministry of Power stations were used.

Analysis of rainfall data: After collection of daily rainfall, due to high volume of data and information, the selection of dominant and maximum daily rainfall from raw data was difficult manually. That is why the daily rainfall data were incorporated into EXCEL software and information bank of the region stations were prepared in the software. The information bank can be used easily. Then by using EXCEL instructions, the dominant and maximum daily rainfall for durations of one to three-day (for each duration 4 storms and total of 12 storms) was selected.

Conversion of geographical coordinates of rain gauge stations to metric system (UTM): As the drawing of isohyets maps need GS^+ and GIS software and they work with metric system, it was needed to convert meteorological stations coordination into metric system (UTM). For this purpose the software ILWIS was used.

Drawing isohyets maps using the relationship of rainfall and elevation: This method is simple, but may not be practical, because in most cases, especially for short duration rainfall the relationship between rainfall and elevation may not be statistically insignificant. In these cases the drawing of isohyets maps are not recommended. In this research the geostatistical methods was used, because the relationship between elevation and rainfall was not statistically insignificant.

Geostatistical methods used in this research: In this research two methods of Kriging and inverse distance with powers (1-3) were evaluated for interpolation. The isohyets maps were drawn using the most suitable method. For this purpose, for each rainfall event a table was constructed consisting of UTM coordinates and the amount of rainfall in that date. Then by using this table, suitable model of virogram with respect to spatial structure of each rainfall event was fitted in GS^+ was fitted (for the data which were not normally distributed, square root and logarithm of data were used). Then by using virogram models and its parameters (section effect, threshold, effective radius and the number of points used) interpolation was carried out using Kriging and inverse distance with powers (1-3).

Fitting virogram model: To determine the best virogram model with respect to spatial structure of data, the virogram behavior in the vicinity of the center of coordinates of residual sum of squares was used (Hassanipak, 1998; Rahimibandarabadi, 2000; Mahdavi, 2002; Groovaevts, 1997; Robertson, 2000).

Method of model evaluation: To investigate the error of each interpolation method and selection of the best method of the amount of rainfall the method of Cross Validation (CV) was used. In this method for each measured points which are the only tools for comparison, estimation can be carried out. Then the measured and estimated values are compared. In CV method one point is omitted, then by using other points and making interpolation the point is estimated. The point is returned to its place and the next point is omitted. The same procedure repeated for all points. The results are in the last two columns of tables. One column is the observed and the other is estimated values which can be compared and select the best method using different criteria.

Evaluation criterion: For evaluation of the amount of error and selection of the best method, different criteria like Residual Sum of Squares (RSS), Residual Mean Squares (RMS) and also use of statistical comparison methods such as analysis of variance, etc. exist. In this research the criterion of Mean Absolute Error (MAE) was used. The method of calculation of this method is as follows:

$$\mathrm{MAE} = \frac{1}{n}\sum_{i=1}^{n} \left| z^*(xi) - z(xi) \right|$$

Where Z^* (Xi) is the estimated variable of Xi, Z (Xi) is the observed variable of Xi, n is the number of observed variables and MAE is the Mean Absolute Error. The most suitable method has the lowest MAE. When MAE is zero shows that the model estimates the variable whatever it is.

Drawing isohyets maps: After determination of the most suitable method by using GS^+ software, it was necessary to use software which could calculate the area and overlap the maps. GS^+ software was not able to carry out these two functions. For this purpose, the isohyets maps were drawn in GIS software in ILWIS medium for each rainfall, using the suitable spatial structure and effective parameters in the model determined in GS^+ software.

Drawing primary DAD curves: After drawing of isohyets maps, the following steps were carried out to draw the primary DAD curves (It is called primary because in later steps these curves should be combined):

Determination of the area between isohyets lines: In this step the area between each two isohyets lines were specified by using GIS software. (The isohyets lines are drawn from higher to lower amounts)

Determination of cumulative area: In this step the cumulative area between isohyets lines were calculated.

Determination of rainfall volume: The average of the two isohyets multiplied by the area between them gives the volume of rainfall.

Cumulative volume of rainfall and determination of average rainfall based on the area: After determination of rainfall volume, the cumulative rainfall is obtained. Then by dividing cumulative rainfall volume to cumulative area, the average rainfall related to each area is calculated.

Drawing primary DAD curves: By drawing maximum rainfall against cumulative area in one coordinate axis, the primary DAD curves are obtained

Drawing final DAD curves: AS the maximum rainfall is under consideration in final curves, for different areas in the x-axis, the amount of rainfall is obtained from y-axis of primary DAD curves. For each area the highest amount of rainfall is obtained. If the obtained maximum rainfall is drawn against the related areas in a coordinate axis system for each duration, then the final DAD curves are obtained.

RESULTS AND DISCUSSION

Investigation of the relationship between rainfall and elevation: In Table 1 the lowest and highest correlation coefficients are 0.014 and 0.58 mm, respectively. The highest value is for the three -day storm March 6, 1998 and the lowest value is for the one-day storm March 1, 1998 Also, the coefficients of determination R^2 are lowest (0.0002) for the rainfall of March 1, 1998 and highest (0.249) for the rainfall. As it can be concluded from the table, there is no suitable correlation between rainfall

Table 1: The relationship between elevation and rainfall

Gradient equations x is elevation (m) y is rainfall (mm)	No. of stations	Coefficient of determination (R^2)	Correlation coefficient (r)	Date of raining	Duration
63.23-0.0264x = y	33	0.1127	0.0335	2.6.1998	
979.61-0.0069x = y	23	0.0042	0.064	2.4.1992	
564.30-0.0002x = y	32	0.0002	0.014	3.8.1998	One-day
13.27-0.0258x = y	28	0.1830	0.420	2.6.1994	
2612.2-0.0183x = y	33	0.0931	0.300	3.1.1998	
0538.1-0.0159x = y	29	0.1053	0.330	3.10.1993	
271.69-0.0557x = y	33	0.3106	0.580	2.5.1998	Two-day
565.50-0.012x = y	23	0.0049	0.070	2.3.1992	
8.30-0.0398x = y	33	0.2429	0.490	2.28.1998	
984.48-0.0523x = y	29	0.2120	0.460	2.6.1994	
835.29-0.0382x = y	29	0.2209	0.470	3.10.1993	Three-day
7544.6-0.0477x = y	23	0.0840	0.289	2.3.1992	

Table 2: Effective parameters in spatial structure model of each rainfall date of rainfall

Radius of search, (km)	No. of neiboring points	RSS (mm^2)	C/Co + C	Ao, km, threshold	Co+C (mm^2)	Co (mm^2) effect of section	Type of the model	Base of the distance (m)	Range of data (m)	Coefficient of skewne (ss)	Date of rainfall events
150	10	0.434	0.86	46	0.3678	0.0514	Exponential	17581.00	175810	0.12	2.4.1992
170	6	4.09	0.826	250	6.91	0.95	Spherical	13688.50	136885	0.07	2.6.1994
200	16	0.046	0.875	273	2.678	0.3340	Gussian	17961.26	179612	0.02	2.6.1998
0	10	0.0132	0.558	411	0.3074	0.136	Spherical	17961.26	179612	0.02	3.8.1998
90	6	11531	0.749	86	273	69.7	Exponential	16471.00	164710	0.05	3.10.1993
170	8	15.8	0.77	365	12.62	2.81	Spherical	17581.00	175810	0.22	2.3.1992
200	16	0.148	0.527	102	0.803	0.38	Gussian	15500.00	179612	0.07	2.5.1997
224	16	14708	0.977	143	288	6.5	Exponential	17961.26	179612	0.12	3.1.1998
219	16	3.99	0.798	366	10.2	2.05	Spherical	17581.04	175810	0.14	2.3.1992
100	5	81591	0.621	411	660.1	250	Spherical	17581.04	175810	0.25	3.10.1993
205	8	0.0976	0.956	134	0.321	0.014	Exponential	8000.00	164715	0.05	2.6.1994
224	5	56101	0.816	411	1065.7	196	Spherical	17961.00	179612	0.08	2.28.1998

Table 3: Mean absolute error in the methods

Mean by kriging`	Mean of observed values	IDW^{-3}	IDW^{-2}	IDW^{-1}	Kriging	Date of raining
47	45.860	21.170	21.00	20.950	21.440	2.4.1992
20.004	22.917	11.021	10.88	12.253	10.490	2.6.1994
30.004	33.785	11.491	11.8692	11.846	10.995	1.6.1998
27.701	27.395	11.359	11.213	10.997	7.0900	3.8.1998
37.825	40.007	8.177	8.208	8.177	8.1160	3.10.1993
65.2	70.000	32.000	30.77	9.800	32.430	2.3.1992
44.9	38.218	23.445	21.682	15.811	16.550	2.5.1998
39.806	41.064	14.455	14.512	14.869	17.076	3.1.1998
100.080	97.366	38.321	35.878	33.473	30.200	2.3.1992
49.19	48.570	24.776	23.837	22.542	12.058	2.3.1992
56	59.457	18.950	20.218	20.070	16.812	2.6.1994
51.659	50.604	20.826	20.239	22.064	22.064	2.28.1998

and elevation, so that from 12 rainfall in 12 cases (100%), the correlation coefficient is less than 0.6 and in 10 cases (83%)the coefficient is less than 0.5.

Selection of suitable models and its parameters: In this stage, by using GS+ software, fitting the best model to the spatial structure was performed. Table 2 shows the parameters related to the best fitted model to spatial structure of data for each rainfall. Based on the Table 2, from the 12 rainfall events, the models spherical, Gaussian and exponential had the highest frequency occurrence of 5, 4 and 3, respectively.

Selection of the best method and drawing isohyets maps: In this stage, interpolation was carried out by two methods of common Kriging and inverse distance with powers of 1-3 for each rainfall. To compare these two methods and selection of the suitable method the Mean Absolute Error (MAE) criterion was used. Table 3 shows MAE of each method for each rainfall event. Based on this Table 3, 7 out of 12 cases (58.30% the Kriging method had lower MAE with respect to other methods. In 3 rainfall events out of 12(25%), the inverse distance with the power (-1), in one rainfall (8.3%) the inverse method with power of (-3) and in one case (8.3%) the inverse distance method with the power (-2) has the lowest MAE. Table 3 also shows the observed and estimated amounts of samples by Kriging method. The results of this part show that in general the Kriging method is better than inverse distance method for estimation of average rainfall. So, to draw the isohyets maps in later steps the Kriging method is preferred to inverse distance method. Kriging was used for drawing isohyets maps and then by using the maps the primary DAD curves were prepared.

Table 4: The maximum rainfall (mm) for different areas and durations

Duration of 72 (h)	Duration of 48 (h)	Duration of 24 (h)	Area (km^2)
160	135.00	105.0	0
142.7	113.50	84.0	20000
132.8	107.00	80.0	4000
129.48	102.50	74.0	6000
122.84	98.50	70.0	8000
121.18	94.60	68.0	10000
117.86	92.00	66.0	12000
112.88	89.00	63.0	14000
109.56	85.00	61.5	16000
106.24	82.00	57.0	18000
102.92	78.00	53.5	20000

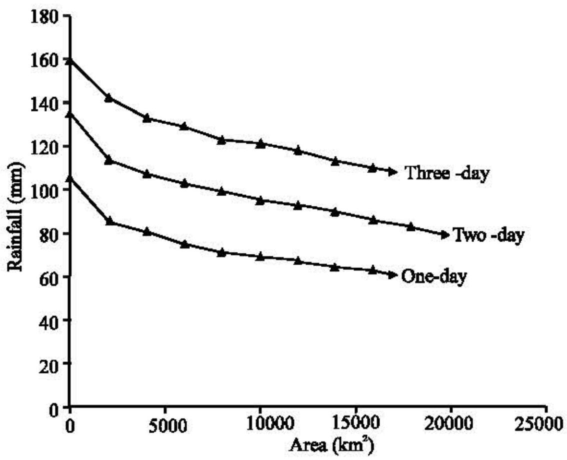

Fig. 1: Final curnes for the sequences of 1, 2 and 3 days

Drawing Final DAD curves: In this stage the primary DAD curves were combined, i.e., for each duration the maximum amount of rainfall for each area was obtained and by drawing maximum rainfall against area in each duration, the final DAD curves were obtained. Table 4 shows the maximum rainfall for different areas and Fig. 1 shows the final DAD curves.

CONCLUSIONS

- The depth-area-duration relationship for 1-3 day durations of the rainfall of the area under study is shown in Fig. 1. Based on this curves the point rainfall can be converted to average rainfall in an area of up to 20,000 km^2. The curves can be used to determine average rainfall of the watershed for studying and designing purposes.
- The ratio of point rainfall to average rainfall in an area of 20,000 km^2 in durations of 1-3 days is 1.8, 1.73 and 1.47. So, by increasing duration from 1 day to 3 days, the ratio decreases.
- In the watershed the dominant and maximum rainfall with duration of 4 days does not exist. This means that all rains occur during first 3 days.
- All dominant and maximum rainfall occurs in winter (February and March). These two months are considered as critical for flood occurrence.
- The research shows that the relationship between rainfall and elevation is not statistically significant, so it can not be used for calculation of the average rainfall.
- Comparisons of other methods show that the Kriging is better than inverse distance method.

ACKNOWLEDGMENTS

The authors would like to than the University of Mazandaran for financial support of the project.

REFERENCES

Aghighi, 1995. Analysis of DAD curves. A case study of Karaj-Tehran, Jajroud region. M.Sc. Thesis. College of Natural Resources, University of Tehran, pp: 179 (in Persian).

Ahmadi, K., 2001. DAD relationships of rainfall in Kerman shah province. Research Repot of the Natural Resources and Animal Husbandry of Kerman Shah Province, pp: 39 (In Persian).

Groovaevts, P., 1997. Geostatistics for Natural Resources Evaluation. Oxford University Press. Inc., pp: 596.

Hassanipak, A.A., 1998. Geostatistics. 1st Edn. University of Tehran Publications, pp: 314 (In Persian).

Leclerc, G. and J.C. Schaake., 1972. Derivation of hydrologic frequency curves, MAs. Inst. of Technology. Cambridge.

Mahdavi, M., 2002. Applied Hydrology. 4th End. University of Tehran Publications, pp: 364 (In Persian).

Mahdian, M.H., 2002. Determination of Suitable Interpolation Methods for Estimation of Rainfall and Temperature, in 3 Climates of Arid, Semi-arid and Humid. Final Report of Research Project of Education and Research Deputy, Soil Conservation and Watershed Management Center, pp: 196 (In Persian).

Pohlman, H., 1993. Geostatistical modeling of environmental data. Catena, 20: 191-198.

Rahimibandarabadi, S., 2000. An investigation of geostatistical methods in estimation of rainfall in arid and semi-arid regions of Southeastern Iran. M.Sc. Thesis, College of Natural Resources. University of Tehran, pp: 162.

Robertson, G.P., 2000. GS+ GeoStatistics for the Environmental Sciences. Version 5.0. Gamma Design Software, Plainwell, Michigan, USA., pp: 200.

Vankuilenberg, J., J.J. Degruijter, B.A. Marsman and J. Bouma, 1982. Accuracy of spatial interpolation between point data on soil moisture supply capacity compared with estimates from mapping units. Geoderma, 27: 377-325.