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Analysis of Spatial and Temporal Precipitation Data Over a Densely Gaged Experimental Watershed

M. H. Nichols, L.J. Lane, M. ASCE, and C. Manetsch[1]

Abstract

Historical precipitation data from the densely gaged Walnut Gulch Experimental Watershed in southeastern Arizona are used to quantify watershed-scale properties of precipitation. Daily, seasonal and annual values of precipitation are analyzed using linear trend analysis, spectral density analysis, and interstation correlation. The time series analyses are used to describe temporal properties of precipitation at individual raingages and the interstation correlation analyses are used to evaluate the spatial dependence structure of the precipitation data. The particular period of record chosen for linear trend analysis greatly influences the results. The variation in mean annual precipitation over the watershed is greater from year to year than the variation of long term mean annual precipitation between gages. Daily, seasonal daily, and annual correlations decrease with distance, although they never fall below the 99% significance level for distances up to 20 km. This is in contrast to individual storm rainfall correlation-distance relations on Walnut Gulch that showed correlations were non-significant beyond approximately 5 km.

Introduction

Accurate estimates of precipitation on watersheds such as the Walnut Gulch Experimental Watershed in southeastern Arizona are important for estimating runoff and sediment yield, as well as for validating hydrologic models. The watershed comprises 150 square kilometers in the San Pedro River Valley and is representative of approximately 60 million hectares of

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[1]The authors are Hydraulic Engineer, Research Leader, and Computer Specialist, respectively, USDA-ARS, Southwest Watershed Research Center, 2000 E. Allen Rd., Tucson, AZ 85719.

brush and grass covered rangeland found throughout the semiarid southwest (Renard et al. 1992).

Dense raingage networks are an important source of data used to accurately describe rainfall input. Starting in 1954 a recording raingage network was installed to quantify and characterize precipitation on the Walnut Gulch Watershed. Currently, 85 raingages (24 hour time scale), are operating in and around the watershed to provide continuous precipitation data. Historically, as many as 95 raingages have been in operation, however, the number of gages operating within any given time period has varied. Time series analyses have been conducted to describe the temporal properties of precipitation at individual raingages and to determine the effects of length of record and the specific period of record on results.

Airmass thunderstorms characterized by extreme spatial variability, limited areal extent, and short durations dominate rainfall-runoff relationships during the summer in southern Arizona and on Walnut Gulch (Osborn, 1982). Winter precipitation results from frontal storms characterized by long duration, low intensity, and large areal coverage (Sellers, 1960). The spatial distribution of annual and seasonal daily Walnut Gulch precipitation data has been evaluated using interstation correlation analyses. Quantification of daily, seasonal, and annual precipitation characteristics will be useful in hydrologic modeling and in evaluating general circulation model output.

Precipitation data collected on Walnut Gulch have been evaluated to determine required raingage density in semiarid areas (Osborn et al., 1972, Osborn et al., 1979b). Precipitation characteristics of Arizona have been described by Sellers (1960), and precipitation characteristics of Walnut Gulch have been describe by Osborn et al. (1979b), and Osborn (1982). However, the extensive data base has primarily been used to evaluate storm data (point processes). The analyses presented in this paper are conducted to evaluate total rainfall amounts for daily, season, and annual time periods.

<u>Description of data sets</u>

Three periods of record during which continuous data are available were selected to: 1) analyze the temporal and spatial structure of precipitation and 2) quantify watershed-scale properties of precipitation. For this paper, the longest continuous records of 35, 27, and 24 years were chosen to analyze 6, 9, and 29 gage networks (Figure 1). Precipitation characteristics are presented in Table 1.

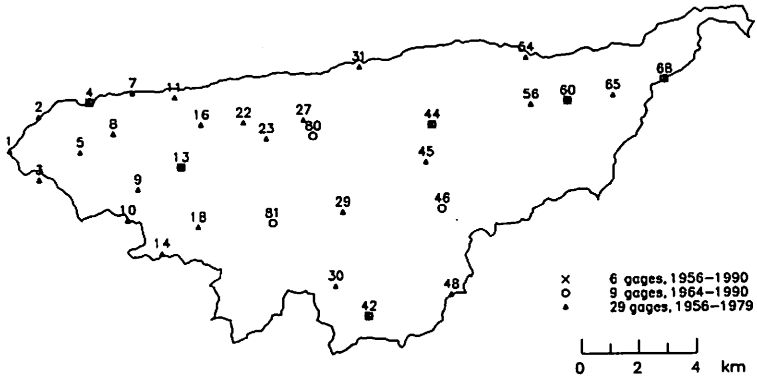

Figure 1. Raingage networks, USDA Walnut Gulch Experimental Watershed, Tombstone, Arizona.

Table 1. Summary of annual and seasonal precipitation data (mm).

Period of Record		annual (seasonal) precipitation	by time period		by gage	
			Std. Dev.	C. V.	Std. Dev.	C. V.
1956-90	annual	312.26	78.86	0.25	13.58	0.04
n=35	summer	208.62	54.31	0.26	8.12	0.04
g=6	winter	104.62	59.65	0.57	6.36	0.06
1964-90	annual	334.55	76.86	0.23	15.63	0.05
n=27	summer	222.34	52.09	0.23	9.79	0.04
g=9	winter	113.08	65.27	0.58	6.71	0.06
1956-79	annual	289.44	55.53	0.19	14.51	0.05
n=24	summer	199.37	47.23	0.24	10.8	0.05
g=29	winter	92.41	59.62	0.65	4.94	0.05

C.V. = coefficient of variation

Average precipitation, $\overline{X}$, on the watershed is calculated as:

$$\overline{X} = \frac{1}{ng} \sum_{j=1}^{g} \sum_{i=1}^{n} x_{ij}$$

where: x_{ij} = total rain for time period i at gage j,
n = number of time periods, and
g = number of gages.

There is one less winter season contributing to the average annual precipitation than the number of years in each of the three periods of record evaluated because the winter season spans portions of two calendar years. The first January through March, and the last October through December represent incomplete winter seasons. Therefore, the sum of the average summer and winter precipitation does not equal the average annual precipitation.

The standard deviation of precipitation can be calculated by time period:

$$\sigma_t = \sqrt{\frac{\sum_{i=1}^{n}\left[\left(\frac{\sum_{j=1}^{g} x_{ij}}{g}\right)-\bar{X}\right]^2}{(n-1)}}$$

or by gage:

$$\sigma_g = \sqrt{\frac{\sum_{j=1}^{g}\left[\left(\frac{\sum_{i=1}^{n} x_{ij}}{n}\right)-\bar{X}\right]^2}{(g-1)}}$$

Days lacking recorded precipitation were excluded from the calculation of means and standard deviations. The variation in mean annual precipitation over the wátershed is greater from year to year (coefficient of variation 0.19 - 0.25) than the variation of mean annual precipitation between gages (coefficient of variation 0.04 - 0.05).

Analysis of temporal properties of precipitation

Significant positive linear trends were found in the annual precipitation at the 90% level for all 6 gages evaluated for the 1956 - 1990 period of record. These trends are not found in any gage in the 27 year, 1964 - 1990 record, and trends were found in only 6 of the 29 gages in the 24 year, 1956 - 1979 record. The results of linear trend analyses for the gages common to all 3 periods of record are presented in Table 2. Figure 2 shows the linear trend at gage 4 calculated for 3 periods of record. These results indicate that conclusions regarding trends can be greatly influenced by the period of record examined. The 1956 - 1990 record includes early years of below average precipitation (drought years during the late 1950's) and later years of above average precipitation (the early 1980's). Excluding either one or both of these periods from the data influences the results of linear trend analysis.

Records that exhibited a linear trend were detrended to satisfy the condition of stationarity and to perform spectral density analysis. However, the spectral density analysis did not reveal any consistently dominant periods in the data.

Table 2. Summary of linear trend analyses for common gages in 3 periods of record.

		gage number					
Period of Record		4	13	42	44	60	68
1956-90	t prob. slope <> 0.0	0.053 *	0.127 *	0.039 *	0.0575 *	0.0010 *	0.0035 *
	slope (mm/yr)	2.617	3.553	3.253	2.669	4.823	3.884
1964-90	t prob. slope <> 0.0	0.429	0.125	0.165	0.989	0.115	0.215
	slope (mm/yr)	1.649	3.475	3.138	0.027	3.448	2.453
1956-79	t prob. slope <> 0.0	0.254	0.434	0.318	0.0229 *	0.0349 *	0.0267 *
	slope (mm/yr)	2.230	1.386	2.638	4.686	4.414	4.549

* Significant at 90% level

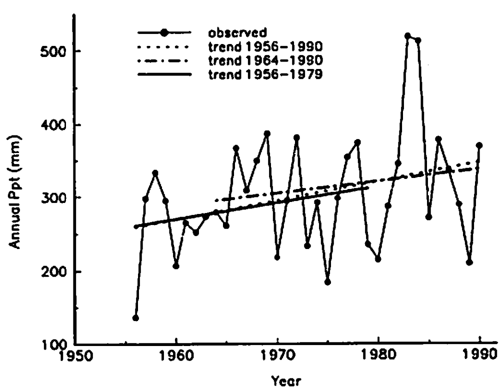

Figure 2. Linear trend for 3 periods of record, gage 4.

Analysis of spatial properties of precipitation

Airmass thunderstorms are known to be variable in space. Osborn et al. (1979a, 1979b) have presented results of spatial cross correlation analyses of dense raingage networks for storm precipitation in the Southwestern US. In contrast, the focus of this research is on total precipitation for daily, seasonal, and annual time periods. Because of the well known differences in the characteristics of summer convective storms and winter storms resulting form frontal activity, seasonal analysis is also included. The winter season includes the months of October through March and the summer season includes the months of April through September.

Correlation analysis

Daily correlation analyses included only days of rainfall. If for a pair of gages on a given day, both gages had no rain recorded, that day was not included in the analysis. These days were excluded because the absence of rain at both gages provides no information about the characteristics of precipitation, and the inclusion of these days biases the analysis toward high correlation coefficients. Cross-correlation analysis among gages for total precipitation reveals that annual correlations are higher than daily correlations (Figures 3 and 4). Similar conclusions are drawn from a plot of the 29 gage network. Seasonal results are consistent with those of Osborn et al. (1979a), with winter correlations being significantly higher than summer correlations. Daily, seasonal daily, and annual correlations decrease with distance, although they never fall below the 99% significance level for distances up to 20 km. This is in contrast to the decrease in correlation with distance on Walnut Gulch when analyzing individual storm rainfall where correlations were non-significant beyond approximately 5 km (Osborn et al. 1979b). It is instructive to note the difference between the results of analyzing storm precipitation vs. total daily precipitation. Storm precipitation is much more variable in space than daily precipitation and thus produces different correlation vs. distance relations.

Conclusions and observations

Analyses of precipitation data from Walnut Gulch Experimental Watershed suggest the following:

1) The variation in mean annual precipitation over the watershed is greater from year to year than the variation of long term mean annual precipitation between gages.

2) The particular period of record chosen for linear trend analysis greatly influences the results.

3) Daily, seasonal, and annual total precipitation are less variable in space than storm precipitation.

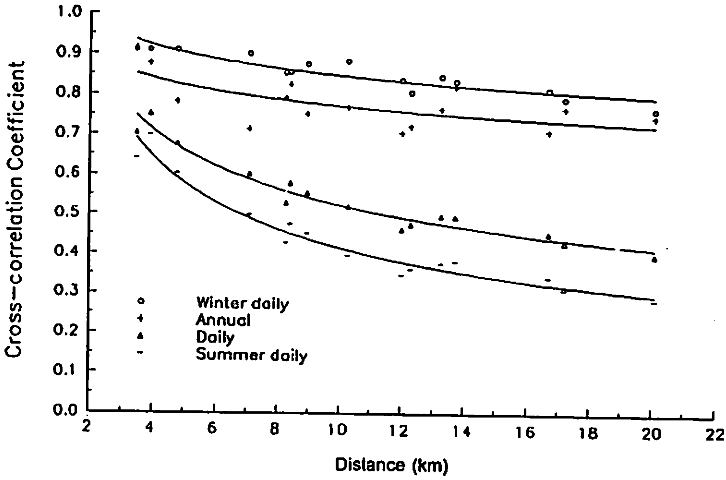

Figure 3. Correlation between precipitation amounts as a function of distance between gages for daily, winter and summer daily, and average annual precipitation, 1956-1990, Walnut Gulch.

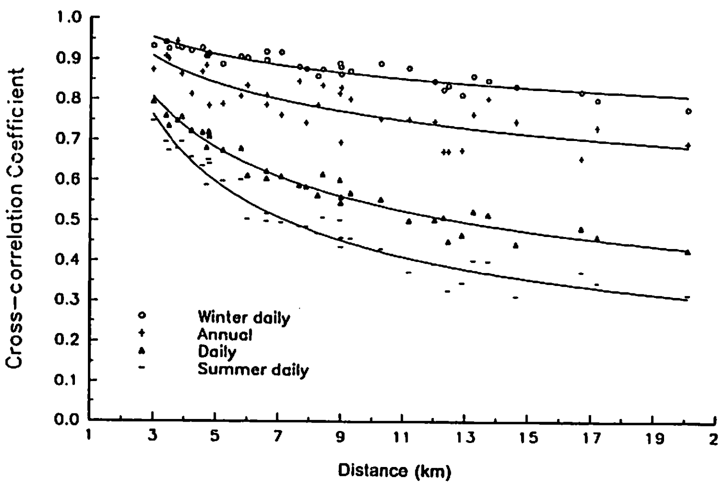

Figure 4. Correlation between gages and distance for daily, winter and summer daily, and average annual rainfall, 1964-1990, Walnut Gulch.

References

Osborn, H.B. 1982. Quantifiable differences between airmass and frontal-convective thunderstorm rainfall in the Southwest. In: Statistical Analysis of Rainfall and Runoff, International Symposium on Rainfall/Runoff, Mississippi State Univ., MS, pp. 21-32.

Osborn, H.B., R.B. Koehler, and J.R. Simanton. 1979a. Winter precipitation on a Southeastern Arizona rangeland watershed. Hydrology and Water Resources in Arizona and the Southwest, Office of Arid Land Studies, Univ. of Arizona, Tucson 9:15-50.

Osborn, H. B., L.J. Lane, and J.F. Hundley. 1972. Optimum gaging of thunderstorm rainfall in Southeastern Arizona. Water Resources Research. 8(1):259-265.

Osborn, H.B., Renard, K.G. and J.R. Simanton. 1979b. Dense Networks to Measure Convective rainfall in the Southwestern United States. Water Resources Research. 15(6):1701-1711.

Renard, K, G, , L. J. Lane, J. R. Simanton, W.E. Emmerich, J.J. Stone, M.A. Weltz, D.C. Goodrich, and D. S. Yakowitz. 1992. Agricultural Impacts in an Arid Environment: Walnut Gulch Studies. Proc. Second US/CIS Joint Conf. on Environmental Hydrology and Hydrogeology, Arlington, VA. May 16-20, 1993.

Sellers W. D. 1960. The Climate of Arizona. In: Arizona Climate, by C.R. Greene and W. D. Sellers, University of Arizona Press, Tucson, Arizona, pp. 5-64.