Spatial and Seasonal Variability of Field Measured Infiltration Rates on a Rangeland Site in Utah

MOUJAHED ACHOURI AND GERALD F. GIFFORD

Abstract

This study was conducted to examine both spatial and temporal variability of infiltration rates on a rangeland site in west-central Utah. The experiment utilized a grid 20 m long and 18 m wide in both grazed and ungrazed sites with a sample spacing of 2 m within the grid. To investigate the seasonal effect on variability of infiltration rates, data were collected for 3 seasons (summer, fall, and spring). Measured infiltration rates at 10 and 30 min during all seasons and under grazed versus ungrazed conditions were all found to approximate a two-parameter log normal distribution. Regionalized variable theory was applied to the data through the development of autocorrelograms and semivariograms, revealing a complete lack of variance structure among the infiltration rates. This finding excluded the possibility of using the Kriging technique for interpolation. Seasonal effect was found to be very important in influencing infiltration rates. The difference between the measured infiltration rates at both grazed and ungrazed sites was very significant for the 3 seasons under study.

Variability is considered one of the most important aspects of the infiltration process. Many difficulties arise due to natural variability which is characteristic of all field studies. This characteristic complicates analytical expressions developed to describe and predict the infiltration process. In this matter, Vieira (1980) stated, "To estimate the infiltration rate of a given field, the variance structure of the observations throughout the field must be identified in order to appropriately analyze each set of measurements, and obtain the best estimate of the expected mean value". Also, Nielsen et al. (1973) emphasized that it is important to assess to some degree the confidence that can be attached to predictions made by models.

Though many factors contribute to variability of infiltration rates, they can often be expressed simply in terms of time and space. The variation can be attributed to source combination of experimental error, time variations, and spatial variation (Campbell 1978).

Several studies have investigated the spatial variability relationships among measured infiltration rates; however, there has been little attempt to investigate seasonal changes. In addition, most studies of spatial variability of infiltration rates have been conducted on agriculture lands.

This study examines both spatial and temporal variability on a rangeland site in Utah. The study uses regionalized variable theory to assess the spatial relationships of field measured infiltration rates on a seasonal basis. The experiment had 4 objectives: first, to study seasonal infiltration rates; second, to determine the approximate frequency distribution of measured infiltration rates on a seasonal basis; third, to determine the spatial variability relationships among measured infiltration rates by using semivariograms and autocorrelograms; and last, to compare infiltration rates from grazed and ungrazed pastures.

Authors are research assistant and professor, respectively, Watershed Science Unit, College of Natural Resources, Utah State University, Logan, 84322. Dr. Gifford is currently Head, Dept. of Range, Wildlife and Forestry, University of Nevada, Reno, 89506.

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Concept of Regionalized Variables

The term *regionalized* was proposed by Matheron (1971) to describe a phenomenon distributed in space (and/or time) which exhibits a specific structure. A variable which characterizes such a phenomenon is called a regionalized variable. Almost all variables describing subsurface water movement or atmospheric water movement may be considered regionalized variables (Delhomme 1976).

From the mathematical viewpoint, a regionalized variable is simply a function $x(z)$ which gives the value at point z (in a 1, 2, or 3-dimensional space) of a characteristic x of the natural phenomenon being studied. Regionalized variable theory is used for the analysis of the spatial variation of infiltration rates. Autocorrelograms and semivariograms are used to identify the degree of dependence (zone of influence) of infiltration rates on the distance between pairs of measurements.

The Autocorrelogram

If $x(z)$ is the value of the regionalized variable x at a point z, and $x(z+h)$ is the value of x at a point $z+h$ at a distance h from z, the autocovariance between $x(z)$ and $x(z+h)$ for a given h is (Rendu 1978):

$$\sigma(h) = E\{[x(z) - E[x(z)][x(z+h) - E[x(z+h)]]\}$$

where E denotes expected value.

The function $\sigma(h)$ is the autocovariogram of the regionalized variable x. Assuming σ_1^2 to be the variance of x(z) and σ_2^2 variance of x(z+h):

$$\sigma_1^2 = E\{[x(z) - E(x(z))]^2\}$$

$$\sigma_2^2 = E\{[x(z+h) - E[x(z+h)]]^2\}$$

The coefficient of correlation between $x(z)$ and $x(z+h)$ is:

$$\rho(h) = \sigma(h)/\sigma_1\sigma_2$$

The function $\rho(h)$ is the autocorrelogram of the regionalized variable x.

The autocorrelogram is a process of self-comparison that expresses the linear correlation between a spatial series and the same series at a further interval of space (Davis 1973). Webster and Cuanalo (1975) and Webster (1978) stated that the zone of influence corresponds to one-half the lag where the autocorrelogram flattens after a steady decay. Webster et al. (1975) defined the autocorrelation analysis as an alternative way of examining the relationships between sampling points in a spatial series. It measures the relationship as a function of the distance separating the sampling points rather than on the absolute position of them. The serial correlation of lag K is given by:

$$r_k = \frac{[1/(n-k)\sum_{i=1}^{n-k}(u_i-\overline{u_i})(u_{i+k}-\overline{u_{i+k}})}{\{[1/(n-k)]\sum_{i=1}^{n-k}(u_i-\overline{u_i})^2\,[1/(n-k)]\sum_{i=1}^{n-k}(u_{i+k}-u\,\overline{u_{i+k}})^2\}^{1/2}}$$

where:

$$\overline{u}_i = [1/n\text{-}k)]\sum_{i=1}^{n-k} u_i \quad \overline{u}_{i+k} = [1/(n-k)[\sum_{i=1}^{n-k} u_{i+k}$$

r_k is the autocorrelation at lag K
n is the number of observations
u_i is the value of the observation at the ith portion
u_{i+k} is the value of the observation at the $(i+k)^{th}$ portion

Autocorrelations can be calculated for lags k=1, 2, ..., m to give an ordered set of coefficients. A graph of these plotted as ordinate against lag is known as a correlogram. Clearly, when the lag is zero (k=0), r_k=1.0. As the value of lag k is increased, the correlation may drop possibly to zero, which means one element is changing inversely with relation to other elements being compared.

The Semivariogram

Another way of analyzing the spatial dependency between neighboring observations is the semivariogram. By definition, the value of the semivariogram (h) for a given distance h is one-half the expected squared difference between the values of the samples separated by h, as defined by Rendu (1978).

$$\gamma(h) = 1/2\ E\{[x(z) - x(z+h)]^2\}$$

If the experimental points are at a regular spacing on a line, the variogram may be calculated for values of h multiples of the step, using the formula:

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

x(z) = the data
z = the points for which the data are available both in z and z+h
n(h) = the number of pairs of points separated by a distance h.

A variogram or semivariogram is a plot of the variance $\gamma(h)$ along the ordinate against the distance measured in multiples of *h* along the abscissa. For large distances h such that *x(z)* and *x(z+h)* are not correlated, the semi-variogram $\gamma(h)$ will reach a value equal to the variance σ^2. This limiting value is called the sill of the semivariogram, and the distance at which $\gamma(h)$ reaches the sill is called the range. The range of the semi-variogram obtained from a given type of sample corresponds to the distance of influence of these samples (Rendu 1978).

The regionalized variables, by use of the variogram, characterize the spatial variability of a phenomenon. The connection with problems of estimation is done by Kriging.

Methods

Study Area

The study was conducted approximately 3.20 km southwest of Eureka, Utah, in the west-central area of the state, within Utah State University experimental pastures. In 1957, the pastures were plowed and seeded and then fenced into 24 28-ha units. Two experimental areas within a pasture seeded to crested wheatgrass *(Agropyron desertorum),* one moderately grazed (1.5 ha/AUM) for several years during parts of June, July or August by cattle and the other ungrazed for over 20 years, were utilized in this study.

Average annual precipitation for the area is 20–30 cm, most of which falls in the winter months. The taxonomic soil classification for both experimental sites is: coarse-loamy, mixed, mesic, torrifluventic hafloxeroll. Surfaces are generally free of coarse fragments and surface textures are generally loamy. Cracks 0.5 to 1.5 cm wide, 1 to 2 cm deep with pentagonal configurations 10 to 15 cm in diameter are common in relatively undisturbed areas.

Experimental Design

The experiment utilized a grid 20 m long and 18 m wide in both grazed and ungrazed sites (Fig. 1). A sample spacing of 2 m was used within the grid. The data were collected in 7 columns in the east-west direction with 10 samples per column, and 70 samples in total per sampling data per site.

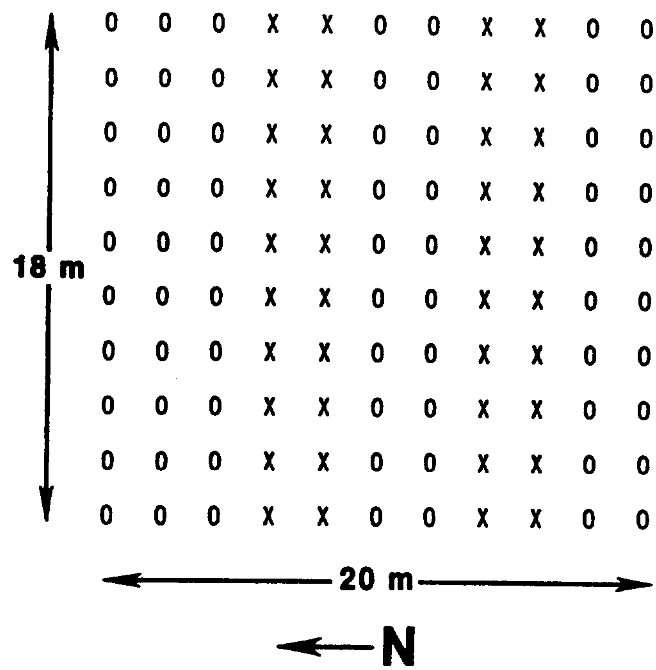

Fig. 1. *Layout of the experimental design with 0 representing measured values and X representing values to be Kriged (interpolated) later. Distance between points is 2 m.*

To investigate the seasonal effect on variability of infiltration rates, data were collected for 3 seasons (summer, fall, and spring).

Procedures

Infiltration data were collected during the months of July (during grazing) and October (after grazing) for the summer and fall of 1981, respectively, and during the month of April (before grazing) for the spring of 1982.

A double ring infiltrometer was used to minimize the effect of lateral water flow in measurement of infiltration rates. The inner ring diameter was 30.48 cm (12 inches) and the outer ring diameter was 45.72 cm (18 inches). The infiltrometer was inserted to a depth of 10 cm in the soil with a minimum of disturbance. Before measurements were taken, all plots were pre-wet with 5.08 cm (2 inches) of water and covered for a period of 3 hours to minimize confounding effects of antecedent moisture. Infiltration rates were measured using a 7.62-cm (3 inch) constant head for 32 minutes and rates were determined at 10 min (measured over the period 8-12 min) and 30 min (measured over the period 28-32 min).

Results and Discussion

Distributions

Visual (fractile diagrams) and statistical (goodness-of-fit test) methods were used to distinguish between normal and log-normal distributions in this study. Fractile diagrams were constructed for the 10- and 30-min infiltration rates measured on both grazed and ungrazed sites for 3 seasons. The fractile diagrams were constructed using the method described by Biggar and Nielsen (1976). Examination of the fractile diagrams (Fig. 2-4 are typical examples) suggests a lognormal distribution for the infiltration rates (straight-line fit). A goodness-of-fit test described by Ryan and Joiner (undated) was utilized to decide between the normal and

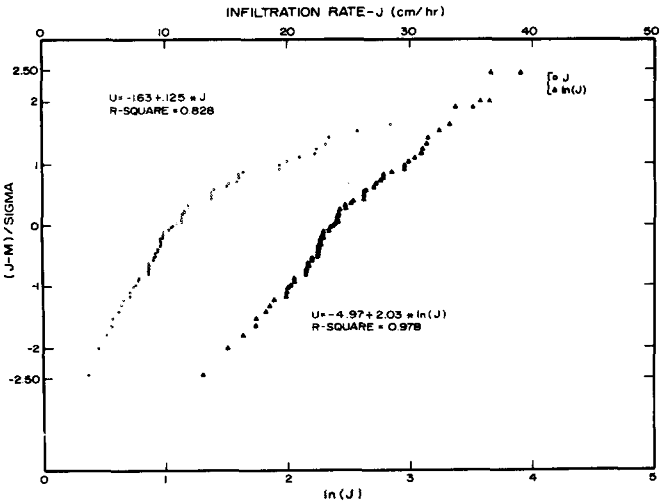

Fig. 2. *Fractile diagram of the 10 min measured data from the ungrazed pasture during the summer. Ungrazed period in excess of 20 years.*

lognormal distributions. The correlation coefficients (Table 1) indicate that measured infiltration rates closely approximate a two-paramater lognormal distribution. The statistics for the 3

Table 1. Correlation coefficients for goodness-of-fit test of measured infiltration rates from grazed and ungrazed sites at Tintic, Utah.

Season, site and time	Distribution	
	Normal	Lognormal
Summer		
Ungrazed site		
t=10 min	0.910	0.989*
t=30 min	0.919	0.994*
Grazed site		
t=10 min	0.943	0.990*
t=30 min	0.937	0.991*
Fall		
Ungrazed site		
t=10 min	0.943	0.996*
t=30 min	0.960	0.994*
Grazed site		
t=10 min	0.841	0.973**
t=30 min	0.860	0.984**
Spring		
Ungrazed site		
t=10 min	0.969	0.981**
t=30 min	0.972	0.983**
Grazed site		
t=10 min	0.974	0.995*
t=30 min	0.973	0.990*

*Data are lognormally distributed at = 0.10 level of probability.
**Data are lognormally distributed at = 0.01 level of probability.

season infiltration rates from the grazed and ungrazed sites at t=10 min and t=30 min are presented in Table 2. The parameter estimates were calculated using the formulas given by Yevjevich (1972).

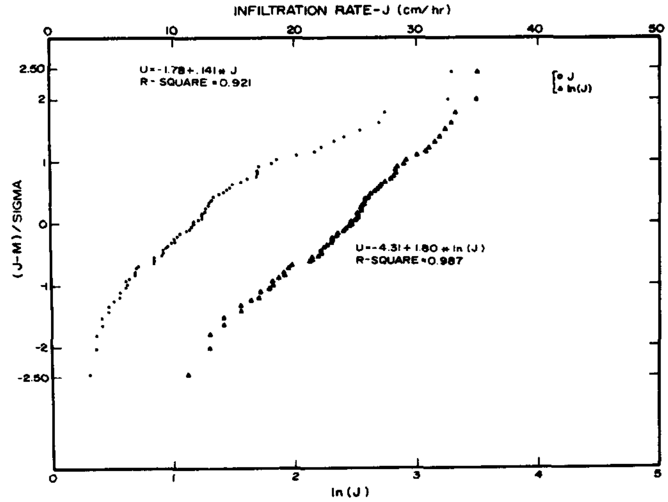

Fig. 3. *Fractile diagram of the 30 min measured data from the ungrazed pasture during the fall. Ungrazed period in excess of 20 years.*

Statistical Analyses

A 3 (seasons) by 2 (grazing treatments) by 2 (time intervals) factorial analysis of variance was performed to analyze the seasonal effects on infiltration rate, to compare ungrazed and grazed measured infiltration rates, and to differentiate between the 10-and 30-min measured infiltration rates. Season of the year (spring vs. summer, fall) was found to be very significant in influencing infiltration rates (Table 2). Pooled over sites and time intervals, the

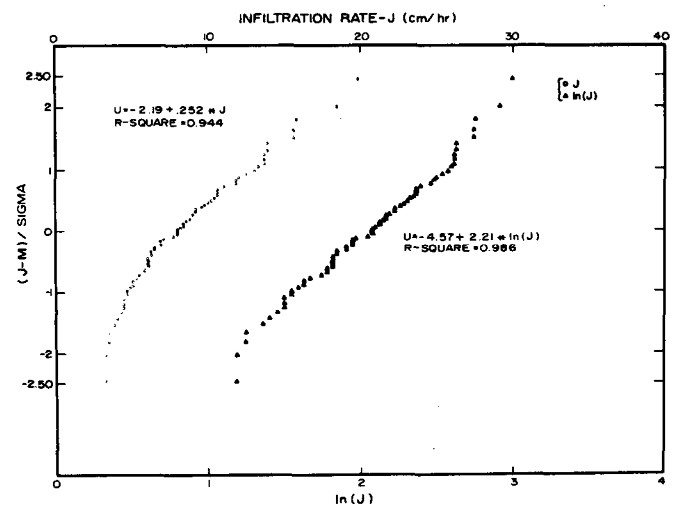

Fig. 4. *Fractile diagram of the 10 min measured data from the grazed pasture during the spring. Pasture grazed moderately for several years by cattle during late spring.*

mean infiltration rate for summer was 8.42 cm/hr, for fall 9.11 cm/hr, and for spring 15.67 cm/hr. The difference between summer and fall was not significant. These results agreed with the results found by Schumm and Lusby (1963) and Tricker (1981). In both papers, infiltration rates were reported to be maximum during early spring. Specific reasons for the seasonal changes are not known. However, field observations indicate that it is probably due to frost action and soil biological activity, which makes the soil surface more permeable. Seasonal changes should be considered an important factor in determining infiltration rates in future investigations (Gifford 1979).

The grazed and ungrazed measured infiltration rates were also

Table 2. **Statistics for three seasons infiltration rates from the grazed and ungrazed sites at t=10 min and t=30 min.**

Season, site and time	No. of samples	Log mean (μ_4)*	Log variance (σ_n^2)	Median (M)	Mode (m)	Mean (μ)	Variance (σ^2)	C.V. (n)	Skewness (γ)
Summer									
Ungrazed site									
t=10 min	70	2.42	0.23	1.25	8.93	12.63	40.74	0.50	1.64
t=30 min	70	2.32	0.26	1.29	7.84	11.62	40.12	0.54	1.77
Grazed site									
t=10 min	70	1.53	0.10	1.11	4.17	4.90	2.64	0.33	1.02
t=30 min	70	1.44	0.12	1.13	3.74	4.52	2.68	0.36	1.12
Fall									
Ungrazed site									
t=10 min	70	2.49	0.27	1.31	9.20	13.93	61.55	0.56	1.85
t=30 min	70	2.39	0.30	1.35	8.08	12.69	56.64	0.59	1.97
Grazed site									
t=10 min	70	1.44	0.26	1.29	3.25	4.94	7.07	0.54	1.77
t=30 min	70	1.47	0.22	1.24	3.49	4.87	5.86	0.49	1.58
Spring									
Ungrazed site									
t=10 min	70	2.99	0.42	1.53	13.06	24.74	326.16	0.73	2.58
t=30 min	70	2.86	0.42	1.53	11.47	21.62	248.06	0.73	2.58
Grazed site									
t=10 min	70	2.06	0.20	1.22	6.42	8.70	16.72	0.47	1.51
t=30 min	70	1.93	0.19	1.20	5.69	7.62	12.18	0.46	1.47

*μ_n, μ, M, and m in cm/hr; σ_n^2 and σ^2 in (cm/hr)^2

compared, and ungrazed site infiltration rates were significantly higher (16.21 cm/hr) than grazed site (5.92 cm/hr) infiltration rates. The high infiltration values on the ungrazed site are probably due to better soil structure, less compaction by grazing animals, and increased accumulation of litter on the soil surface.

The difference between the 10- and 30-min infiltration rates, pooled over sites and seasons, was found to be significant. The mean infiltration rate for 10 minutes was 11.64 cm/hr and for 30 minutes 10.49 cm/hr.

Interactions among seasons and sites, season and time intervals, sites and time intervals, and among seasons and sites and time intervals were not significant.

Spatial Variability

To examine relationships between the measured infiltration rates at various grid points, autocorrelograms and semivariograms were constructed for the 10- and 30-min measured infiltration rates from both and ungrazed pastures during the summer, fall, and spring. The interpretation of the autocorrelograms (Figure 5 is a typical example) based upon Webster and Cuanalo (1975) and Webster's (1978) concept suggests no linear correlation with the 2-m spacing. Autocorrelograms drop rapidly from 1.0 at 0 lag, then fluctuate near zero. This indicates no significant trend exists in the measured infiltration rates. Examination of the isotropic empirical semivariograms (Figure 6 is a typical example) shows that the semivariance values, for the 10- and 30-min observed infiltration rates during the summer, fall, and spring from both grazed and ungrazed sites, center about the sill value. This also indicates that the infiltration rates are randomly distributed, which means that the covariance between the measured values is zero for all distances *h*. This is the case of a pure nugget effect described by Rendu (1978), a case where infiltration values are uncorrelated. The results obtained from both autocorrelograms and semivariograms reveals the absence of continuity between plots.

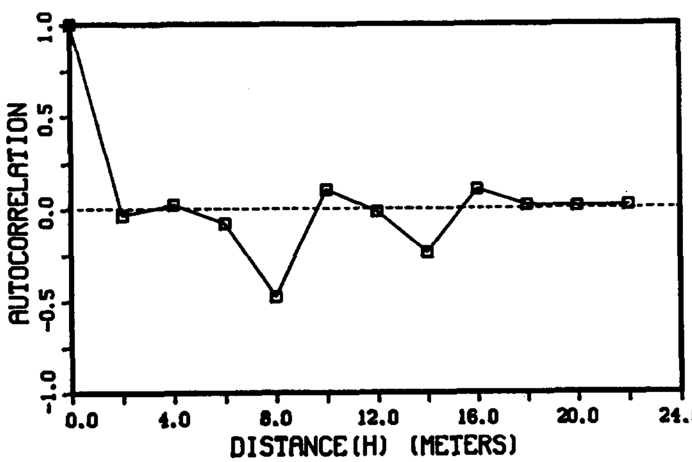

Fig. 5. *Autocorrelogram for the 10 min measured infiltration rates within the ungrazed pasture during the summer. Ungrazed period in excess of 20 years.*

Conclusions

Measured infiltration rates at 10 and 30 min during all seasons and under grazed versus ungrazed conditions were all found to approximate a two-parameter lognormal distribution. Springer and Gifford (1980) found that infiltration rates on a plowed sagebrush site in Idaho could be adequately represented by either a normal or lognormal distribution. However, smaller sample numbers were used in the Idaho study than in the current study; a rainfall simulator was also used versus a ring infiltrometer in this study. Assuming that instrument type makes no difference, the larger sample sizes indicate that lognormal distributions should be assumed when analyzing infiltration data.

Autocorrelograms and semivariograms showed a complete lack of variance structure among the infiltration rates, indicating that measured data were randomly distributed within the 2-m grid

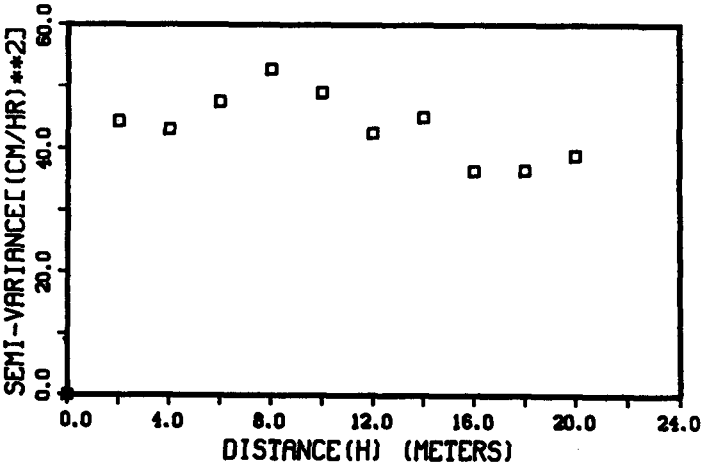

Fig. 6. *Semivariogram for the 10 min measured infiltration rates within the ungrazed pasture during the summer. Ungrazed period in excess of 20 years.*

spacing. These results, which relate to the zone of influence of individual measures, contrast with distances of 5.3 m and 50 m found by Wagenet (1981) and Vieira et al. (1981), respectively, on agricultural soils. The complex nature of rangeland soils undoubtably accounts for the difference.

Significant seasonal trends in infiltration rates indicate the need for a better understanding of the winter recovery process. Such information is currently lacking.

The reduction in infiltration rates on the moderately grazed area was perhaps more than might have been expected based on the model presented by Gifford and Hawkins (1979). However, evaluations with a sprinkling device should be conducted before any conclusions are made regarding increased runoff potentials.

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