JOURNAL OF
ENVIRONMENTAL HYDROLOGY

The Electronic Journal of the International Association for Environmental Hydrology
On the World Wide Web at http://www.hydroweb.com

VOLUME 6 1998

ESTIMATING AREAL AVERAGE RAINFALL FOR AN UNGAGED MOUNTAINOUS BASIN IN THE AMUR BASIN

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A rainfall interpolation method is proposed to estimate areal mean precipitation of a mountainous 212 km^2 basin. The objective was to use two permanent rain gages located more than 50 km away. Rainfall data were obtained from temporary rain gages in a 14-point network installed for four years in the basin. The empirical relationships between the temporary and permanent rain gages were used to predict rainfall totals at four most representative points of the basin. The analysis of the influence of altitude on short-term rainfall allows the part of the basin represented by each rain gage to be defined. The data were used to calculate average basin rainfall. To assess the performance of the rainfall interpolation method, fifty average basin rainfall totals were predicted with a root mean square error of 8.45 mm and a correlation coefficient of 0.94. The direction of improving the method based on basin coverage by the rainfall field is considered.

INTRODUCTION

Areal mean precipitation is important as input to lumped water and energy balance models. Spatial rainfall heterogeneity has a significant impact on runoff simulation for even simple basins (Niemczynowicz, 1984; Ogden and Julien, 1993). In the mountains of the Amur Basin, the systematic (permanent) rain gage network is located mainly in the river valleys. Within this geographical region, the measurements at various gaging stations have been found to differ significantly, depending upon the type of storm and the local topography. Consequently, the average precipitation on a given area can not be estimated by simple arithmetical averaging or even assigning Thiessen weights to the measurements at the various gages. The influence of the local topography, slope and exposure of relief on precipitation must be considered (Kozhevnikova et al., 1984; Fedorovski, 1985). For estimating areal average precipitation using a rain gage for short-term events, along with relief one should consider the size and movement of the rainfall field (Georgakakos and Bras, 1984; Jinno et al., 1993; French and Krajewski, 1994; Bourrel et al., 1994; Goodrich and Woolhiser, 1994). However, because there has been little work done to develop methods of rainfall interpolation in mountains in the short term, it is not clear how one should use available network data to estimate areal mean short term rainfall events.

The main objective of this paper is to develop a rainfall interpolation scheme using available systematic rain gage data and observations obtained during a field experiment where a dense network of temporary raingages was installed in the Left Silinka (L.S.) basin. These observations were a part of a field experiment for the 1977-1980 Water and Energy Balance Representative Basins Program by the Hydrology Laboratory of the Shabarovsk Complex Science Institution.

STUDY REGION AND DATA COLLECTION

The region of interest for this analysis is the area between V. Gorina and Komsomolsk including the northeastern part of the Mao-Chan mountain range and the L.S. basin. The L.S. is a tributary of the Silinka river flowing into the main channel of the Amur river near the town of Komsomolsk-on-Amur above Solnetchny that drains an area of 212 km^2 (Figure 1). Topographically, the basin is located on the southeastern macroslope of the Mao-Chan mountain range. Basin elevation varies from around 350-400 m near the river gage to over 1300-1400 m in the western part of the basin. The mean elevation of the basin is about 780 m.

Mean annual precipitation is approximately 1120 mm (Fedorovski, 1985). About 200-250 mm of the annual precipitation falls from September to May as snow. There are only two nearby rain gages: Komsomolsk and V. Gorina operated by the Hydrometeorogological Service Far East. The Komsomolsk meteorological station is located on the Amur plain about 55 km southeast of the Mao-Chan mountain range. The V. Gorina meteorological station is located in the Gorin river valley about 50 km northwest of the site. For these stations daily data and rainfall records of storms greater than 10 mm are available.

To obtain additional rainfall data, temporary observations were carried out on the L.S. basin from 1977 to 1980 during the warm period of the year (from June to November). Overall, twenty recording rain gages were used. After processing the rainfall data, the most reliable and long period records were selected for analysis. Table 1 shows some characteristics of the observation points, and Figure 1 shows their distribution over the L.S. basin. Approximately 64 percent of the observation points are located above the mean elevation of the basin. Points P6, P8, P12 and P13 are situated near the main divide. The other points are located on the local divides (gages P1-P3, P10) and hillslopes

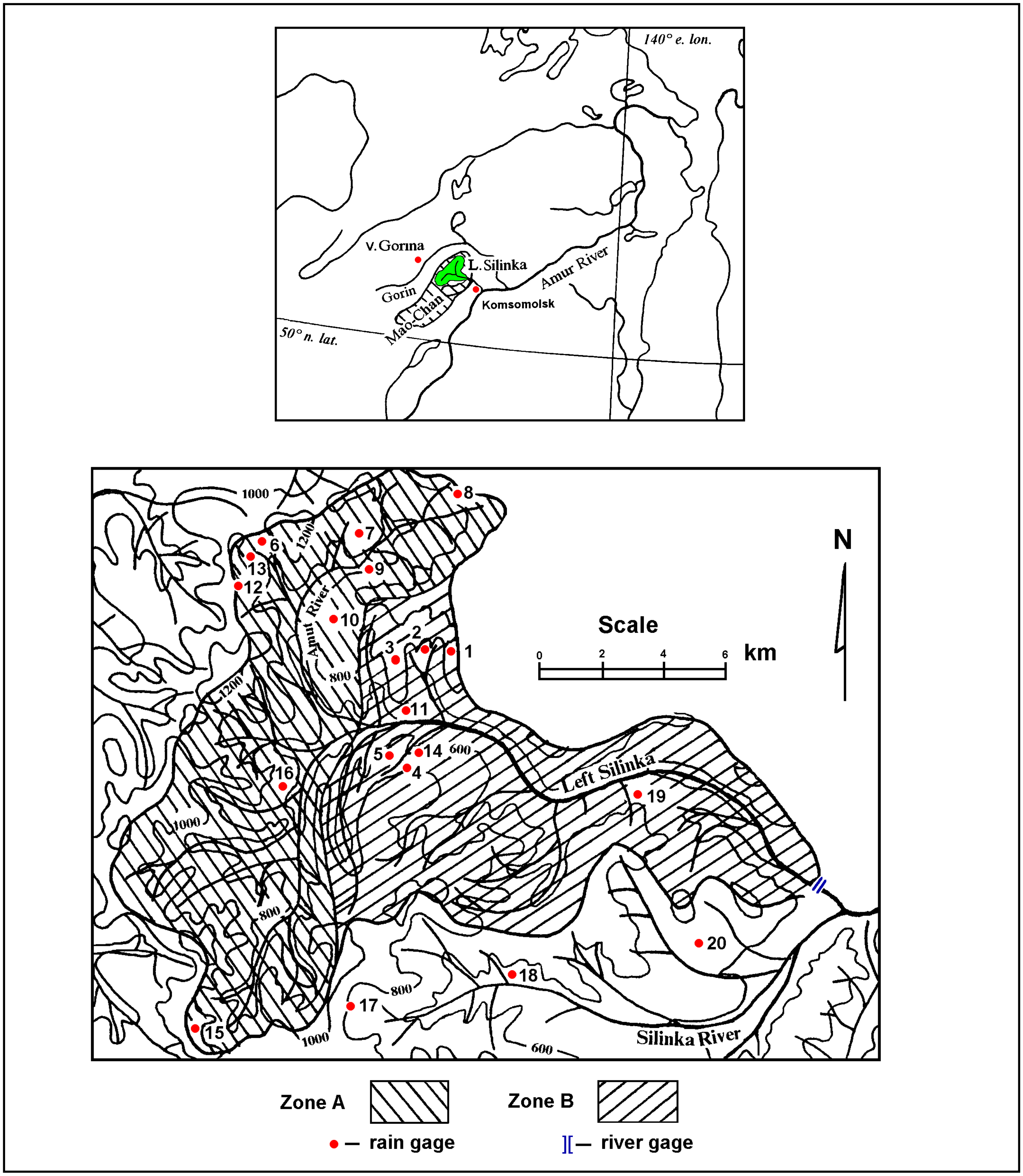

Figure 1. Maps showing the location of the study region and the relief and observation network of the Left Silinka basin.

(gages P4, P5, P7, P14), and only two points (P9 and P11) in valleys of the streams . The gages are installed on the very steep (up to 50 degrees) hillslopes mainly with a south exposure (Table 1).

METHOD DEVELOPMENT

The study approach is based on a simple empirical relationship between rainfall data at temporary and systematic rain gages. This appears to be the only way to solve the rainfall estimation problem

Table 1. Summary of Rainfall Observations (1977-1979)

	Komso-molsk	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	V. Gorina
h, Altitude (m)	20	825	785	800	730	710	960	908	1150	765	945	506	1150	1065	590	315
Slope (deg.)	0	35	50	21	25	21	25	10	15	15	12	0	14	23	30	0
Exposure	-	SW	SE	SE	NW	NE	SW	SE	SW	NW	SW	-	SE	SE	NW	-
P, mm	18.9	23.8	27.1	26.6	25.2	24.2	49.2	46.4	48.4	37.5	28.6	25.8	47.9	46.5	21.8	30.3
σ, mm	12.8	-	25.1	-	26.1	-	-	49.9	46.1	36.3	-	25.1	-	-	22.9	20.3

Note. Standard deviation (σ) is not calculated for points with number of observation less than 20.

if additional data (meteorological radar and satellite observations) are not available or too expensive.

Rainfall Period

The period (interval) of averaging for rainfall data is related to the time existence (TE) and the size of the rainfall field. Three levels of organization (Atmosphere handbook, 1991; Peters-Lidard and Wood, 1994) characterize rain fields. The smallest is the rain cell, which has the TE of 30-40 min. and a size of 5-10^2 km^2. Clusters of rain cells represent a small mesoscale area (SMSA) with a TE of 1-12 hours and an area of 10^2-10^3 km^2. The large mesoscale area (LMSA) or rainband typically represents a synoptic scale front where the TE ranges from 4 to 20 hours. The LMSA size is approximately of 10^4-10^5 km^2 and greater (Alibegova, 1991).

Regional meteorological studies have shown that large cyclones (with radii of 500 km and larger) and slow moving atmospheric fronts which come to this region from the west and southwest carry the main part of precipitation systems. These precipitation systems ordinarily include from 2 to 4 LSMAs and travel over the specific rain gage during periods from some hours up to some days. We will call this period the "Rainfall Period" or RP. The mean distance of rainfall fields associated with the RP travel is expected to be 180-360 km (Atmosphere handbook, 1991). This supports the reasonable assumption that during the RP the main part of moving rainfall fields covers Komsomolsk and V. Gorina, including the L.S. basin. During this study, we choose to define the RP as rainfall events separated from other rainfall events by a time of 2-4 hours. For this purpose, the data of continuous rainfall recorders were used.

The rainfall totals (P) during specific time intervals (minutes, hours, and even days) characterize different rain fields. The correlation of these data for outlying stations will not be genetically stipulated (Alibegova, 1991). Only flood producing rainfall recorded on different gages during the RP can be considered as having a genetically conditioned correlation. Following from this the development of a simple interpolation scheme based on the correlation of rainfall totals during the RP between rain gages is proposed.

Rainfall - Rainfall Relationship

The rainfall data for 60 RPs greater than 5 mm were obtained from the temporary gage network. Only data for 23 RPs recorded by the majority of gages and 30 RPs for P11 were used for the method development. The other data were applied to test the method performance. The rainfall totals vary in time and space over a wide range. For the Komsomolsk station having an altitude (h) of 20 m, rainfall totals (P_K) range from 1-5 mm to 40-45 mm. In the mountains, for instance, values of P_{P7} (h=908 m) for the same RP range from 10-15 up to 190-210 mm. The mean values of rainfall totals ($\overline{P}$) for 23 RPs and standard deviation (σ) are presented in Table 1.

Figure 2 presents relationships between P for the temporary and systematic rain gages and the 1:1 line . In this work, 30 RPs were used for establishing the relation between the Komsomolsk gage and

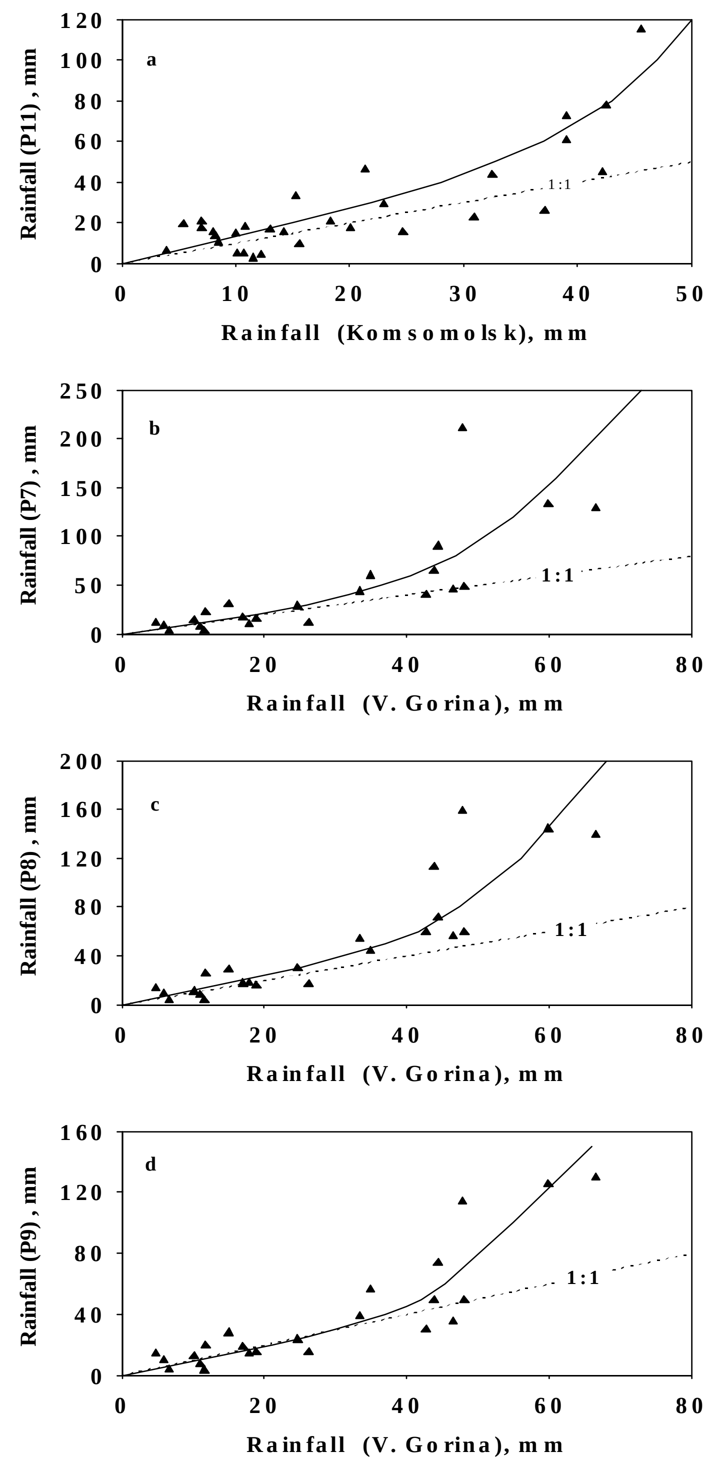

Figure 2. Relationships between rainfall totals for temporary (P7-P9, P11) and systematic (Komsomolsk, V. Gorina) rain gages.

the base temporary point P11 (Figure 2a) and 23 RPs for V. Gorina and P7, P8, P9 (Figures 2b-2d). Despite the fact that the temporary rain gages are located more than 55 km away from the systematic stations, these relationships can be considered as reliable for rainfall prediction.

The greatest divergence of points from the 1:1 regression line is for the relationship between Komsomolsk and P11 (see Figure 2a). The other relationships are closer. For example, almost 60 percent of the points of the relationship between V. Gorina and P8 deviate from the regression line not more than ±10 percent. There is a dependence of deviation from the regression line on rainfall amount. For total rainfall depths of 25-30 mm, average deviation is 25-30 percent The individual storms of 40-60 mm depth have an average deviation about 10-15 percent. The accuracy of the relationship increases (less than 5-10 percent) for events with magnitudes of 60-70 mm. The poorest prediction is for small amounts of precipitation (5-10 mm). The difference between the observed and predicted depth reaches 150-200 percent. Frequently, precipitation of 5-10 or 10-30 mm is caused by nonfrontal processes (an internal air mass transformation) or by small rainfall fields (SMSAs), respectively (Orlova, 1979). In these cases, rainfall fields can cover only part of the study region. Precipitation of 30 mm and more, as a rule, is associated with the large rainfall fields (LSMAs). These fields provide more coverage of the study region and the relation to rainfall of outlying stations is closer.

Average Basin Rainfall

Estimating areal average rainfall is the main objective of this investigation. This requires the definition of the part of the L. S. basin represented by each temporary rain gage (i. e. assigning certain weighting factors). Storm rainfall estimated by a rain gage network is under the influence of different factors, including local topography (Fontaine, 1991; Seed and Austin, 1990; Bourrel et al., 1994).

Figure 3 presents the variation of the mean values of rainfall totals with elevation of the Mao-Chan mountain range. At the beginning and the end of the "x" axis in Figure 3 the position of the Komsomolsk and V. Gorina stations is also shown. In the study region, there are three areas where storm rainfall is affected differently by local topography.

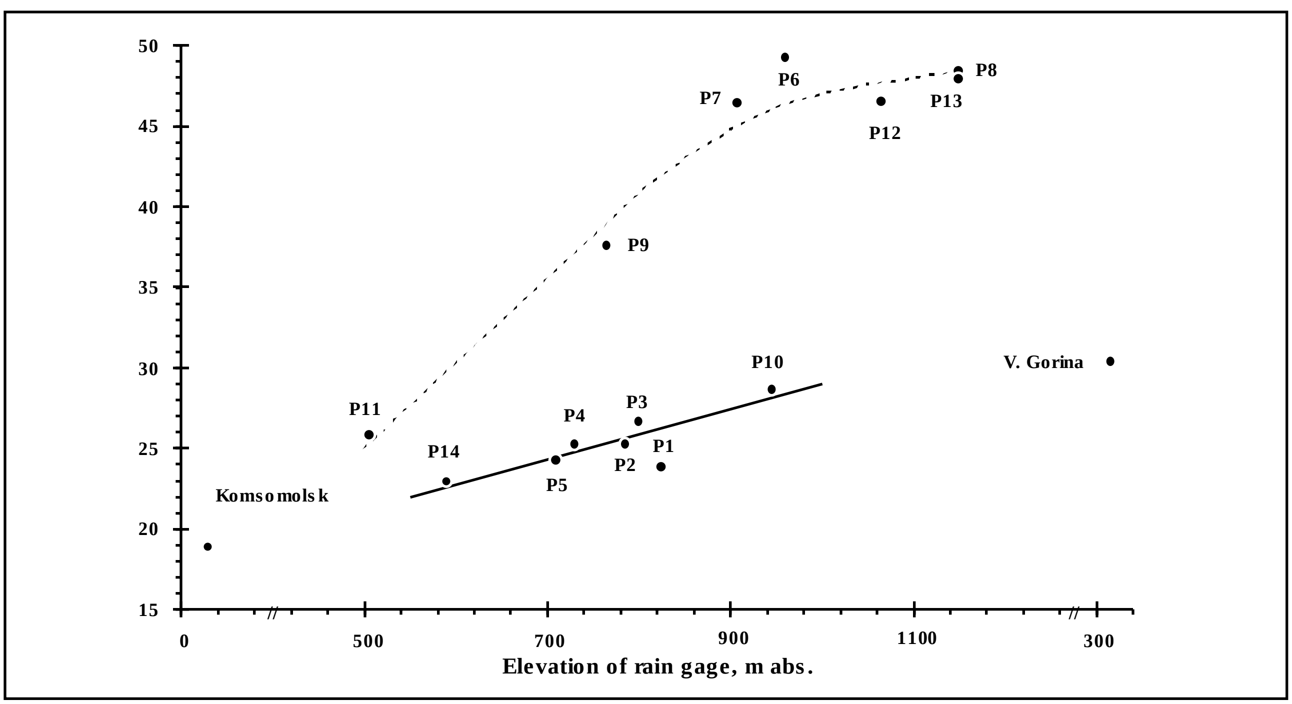

Figure 3. The variation of rainfall totals with elevation of some gages in L.S. basin.

The first area is the Gorin basin which joins to the northwestern macroslope of the Mao-Chan ridge (Figure 1). In this area, cyclonic air masses moving from the west and northwest are given additional lift which increases the updraft velocity of air parcels and makes condensation processes more active (orographic precipitation). The second area covers the part of southeastern macroslope, which immediately follows the main ridge of Mao-Chan. Here no additional air mass lift due to relief occurs and rainfall increments decrease. This area covers the upper basin of the L.S. river and in Figure 1 is shown as Zone A. The third area occupies the low part of the southeastern macroslope. Here, air masses arrive with poor liquid water content. Negative increments of elevation decrease updraft velocity of air parcels and condensation processes are less active than in the first and second areas. This area covers the middle and downstream part of the L.S. basin and is shown in Figure 1 as Zone B.

The value of $\overline{P}$ for the V. Gorina gage, which is located in the first area, is 30.3 mm and this value corresponds to an elevation of approximately 600 m for the second area (Zone A). This is caused by orographic precipitation and it is the largest rainfall increment with altitude in the region (see Figure 3, point V. Gorina with h=315 m). The value of $\overline{P}$ for the points P9 and P2 which have approximately the same elevation (765 and 785 m respectively) differ by 10.4 mm. This difference is also caused by the orographic effect (Figure 3). The smallest increase of rainfall with altitude of the relief is in the third area.

In this case, to assign certain weighting factors to the measurements at the various points one should consider not only the distance between gages (like the classical Thiessen method) but also their altitude. In Zone A, for elevations less than 625 m, gage P11 represents the average rainfall. The elevation ranges 625 to 825 m and 826 to 1000 m are characterized by gages P9 and P7 respectively. In the western part of the basin, near the main divide (for elevations more than 1000 m), gage P8 represents the average rainfall.

In Zone B, the main part of the basin is at an elevation less than 900 m. This area can be characterized by gage P11 (see Figure 3). For elevations greater than 900 m, the most suitable gage is P9. Areas of elevation zones associated with gages are shown in Table 2. Based on percentage of elevation zones, weight coefficients for rain gages k_{P7}, k_{P8}, k_{P9}, and k_{P11} were found to be 0.205, 0.124, 0.200, and 0.471, respectively. Thus, average basin rainfall (P_{av}) was calculated as $P_{av} = k_{P7} P_{P7} + k_{P8} P_{P8} + k_{P9} P_{P9} + k_{P11} P_{P11}$, where P_{P7} , P_{P8} , P_{P9} , P_{P11} are the rainfall totals recorded by gages during RPs.

METHOD PERFORMANCE

The relationships established and the approach used for rainfall spatial averaging formed the rainfall interpolation scheme. To assess the performance of the method, we used rainfall totals obtained from the Komsomolsk and V. Gorina stations during the period 1977-1979 as dependent data sets and six totals for RP of 1980 as the independent data set.

Table 2. Areas of Elevation Zones of the L. S. Watershed

	Zone A				Zone B	
Elevation, m.	<625	626-825	826-1000	>1001	<900	>901
Area, km^2	5.2	30.1	43.5	26.2	94.6	12.4
Area, percent	2.5	14.2	20.5	12.4	44.6	5.8

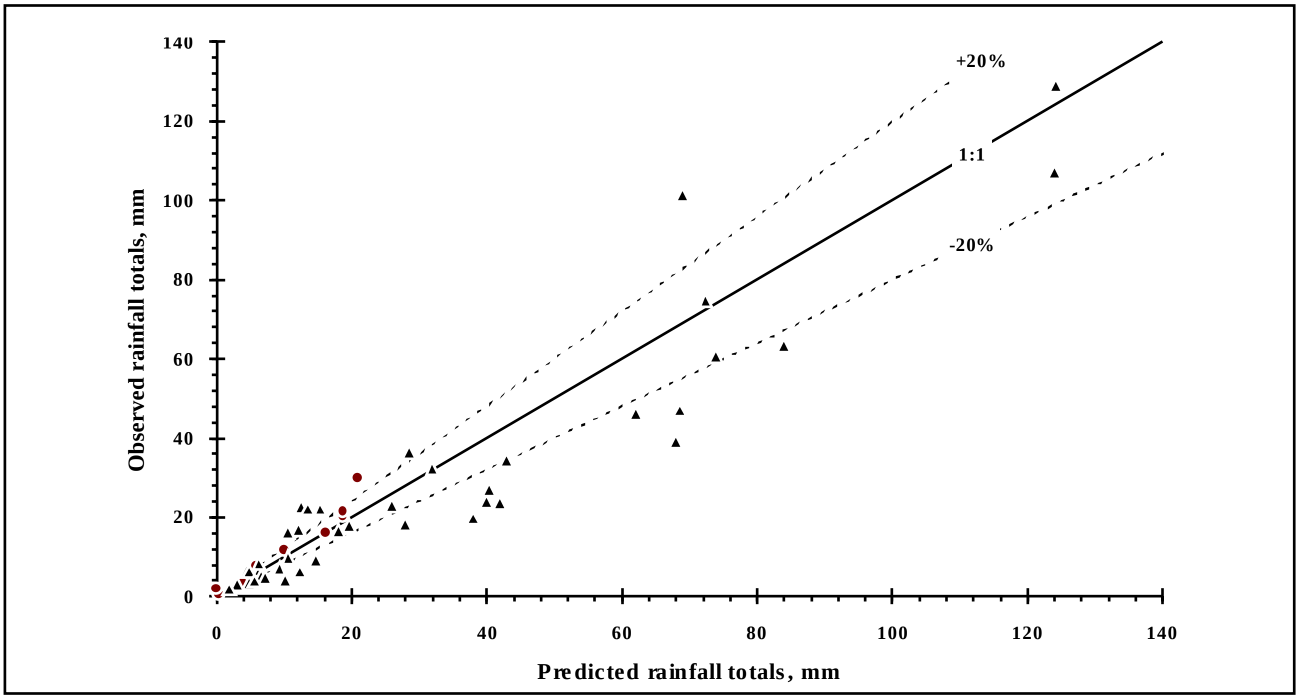

Figure 4. Predicted versus observed average basin rainfall.

Figure 4 presents the calculated and observed values of the P_{av} plotted against the 1:1 line and bracketed with lines showing ±20 percent error. The scheme can reproduce average basin rainfall very well. The root mean square error (RMSE) for the period 1977-1980 was 8.45 mm with a correlation coefficient of 0.94. For points of the independent data set (shown by circles in Figure 4), the calculated results also follow the observed data. Table 3 presents statistical information on method performance for all data. Because of the small size of the independent data set, the statistical parameters are not calculated.

The results shown in Table 3 and Figure 4 state that the method overestimates rainfall in the range of 30-70 mm. The differences between the calculated and observed rainfall occur at times when rainfall fields do not cover the study region completely. If most rain fields cover the eastern part of the region, the value of P_K, as a rule, exceeds $P_{V.G.}$ Otherwise, if most rain fields cover the western

Table 3. Result of the Scheme Performance

Rainfall range, mm	Number observation	Error, %	RMSE, mm
>50	6	18	18.0
26-50	7	36	16.2
16-25	16	35	9.3
6-15	12	30	2.7
0-5	9	32	2.2
Sum	50	-	-
Weighted mean	-	31.4	8.45

part of the region, the value of $P_{V.G.}$ is much greater than P_K (or P_K near zero).

This source of error can be partly corrected by consistent analysis of the proportion of P_K to $P_{V.G.}$ On average, the ratio $\overline{P}_{V.G.}/\overline{P}_K$ is approximately equal to 1.6 (see Table 1). In this situation, when the ratio $P_{V.G.}/P_K$ is less then 1.0, the predicted value of P_{P11} should equal approximately 50 percent of average rainfall for points P7-P9. When this ratio is equal to 8-10 (or P_K=0), the predicted value of P_{P11} should be calculated as 20 percent of average rainfall for points P7-P9. Accordingly, we can reduce the percentage error in P_{av} by up to 15-20 percent

CONCLUSIONS

This work presented a method to estimate areal average flood-producing rainfall for lumped basin modeling. The actual conditions in the mountains of the Amur Basin are estimated using rain gages located at a distance of more than 50 km from the basin. Transferring rainfall data in mountains required considering the influence of local topography. This is the traditional approach for estimating the annual and monthly precipitation in mountains. However, for rainstorms it is rarely applied. The use of the rainfall interpolation method developed here, considering the influence of local topography, was successful in terms of (1) predicting point rainfall in the mountains using rainfall data of outlying rain gages, (2) definition of the part of the basin represented by each gage, and (3) estimating average basin rainfall. Fifty mean rainfall totals were predicted with a RMSE of 8.45 mm and a correlation coefficient of 0.94. The analysis shows that rain field characteristics are the main cause of differences between the predicted and measured rainfall, not rain gage coverage of the study area. This allowed a partial correction to be applied to the method. The consideration of the rain field structure is the most important direction for future improvement of rainfall interpolation in mountains.

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