,Altitudinal distribution of monthly norms of precipitation on the northern slope of the Kyrgyz range (Kyrgyzstan)

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1. Introduction

Our main task was to identify territorial distribution of precipitation on the northern slope of the Kyrgyz range (NSKR) (within Kyrgyzstan), where over 30 rivers, widely used for irrigating in Chui valley are formed.

Precipitation is the main source of river feeding. River regime predominantly depends on the place of catchment and time (season) of precipitation fall. That is why it is important to know spatial distribution of precipitation for hydrology.

At the same time it should be marked that precipitation is one of the most variable parameter. Distribution of precipitation has a complicated nature and is characterized by great riot (diversity). This is especially applicable to mountain regions where the influence of orography reveals. The meteorological stations network where observation of precipitation takes place is insufficient for getting the entire picture of precipitation distribution. In this consequence the necessity of revelation dependences which allow finding out the distribution of precipitation by indirect methods appears. In other words it is needed to identify dependences in precipitation distribution on the factors that form it.

It is known that factors determining precipitation distribution include site altitude, slope orientation and moisture-laden air flows accessibility. In the first approach it can be assumed that in general such factors as slope orientation and moisture-laden air flows accessibility within the NSKR are homogenous. Therefore, during the study of precipitation distribution on the NSKR the factor of site altitude was prioritised.

2. Orography of the study area

The Kyrgyz range (figure 1) is stretching along the northern periphery of the Tien Shan mountain system. Tien Shan is a heavy elevation in Central Asia predominantly with latitude and sub-latitude oriented ranges located between 40-45° north latitude and 67-95° east longitude. The mountain country of Tien Shan is in the centre of the continent being surrounded by deserts and far from oceans as moisture sources.

The Kyrgyz range is included into the system of ranges forming the northern Tien Shan range branch. The Kyrgyz range links to Kungei Ala-Too in the east. Kungei Ala-Too has a slightly partitioned ridge with the average height of about 4 km. In the central part of Kungei Ala-Too it is joined to the north Zailiysky Ala-Tau with the average height up to 4 km. Its continuation in the west-north-west is Jety-Jol range gradually lowering in the same direction with low spurs in the north called after Kindyk-Tas mountains and Chu-Ili mountain. Thus, the mentioned ranges bring together (gather) eastward to the arch between Kungei Ala-Too and Zailiysky Ala-Tau. Chui valley is located between the ranges being narrow in the east widening to the west and open in the north-west. So, the Kyrgyz range is fully open in the north-west being covered in the north-east by relatively low mountains (but much lower than the Kyrgyz range). In the south of the Kyrgyz range there is a number of ranges of the same height (the average height is 4-4.5 km) of Inner Tien Shan and Pamiro-Alay.

The interaction between circulating conditions and orographic characteristics form a peculiar regime of precipitation in this region. As NSKR is open to north and north-west airflows it becomes a favourable factor for penetration of moisture carried by west and north-west inflows. In relation to southern cyclones which are characterised by high moisture contents, NSKR is in a less favourable position than to west and north-west cold inflows.

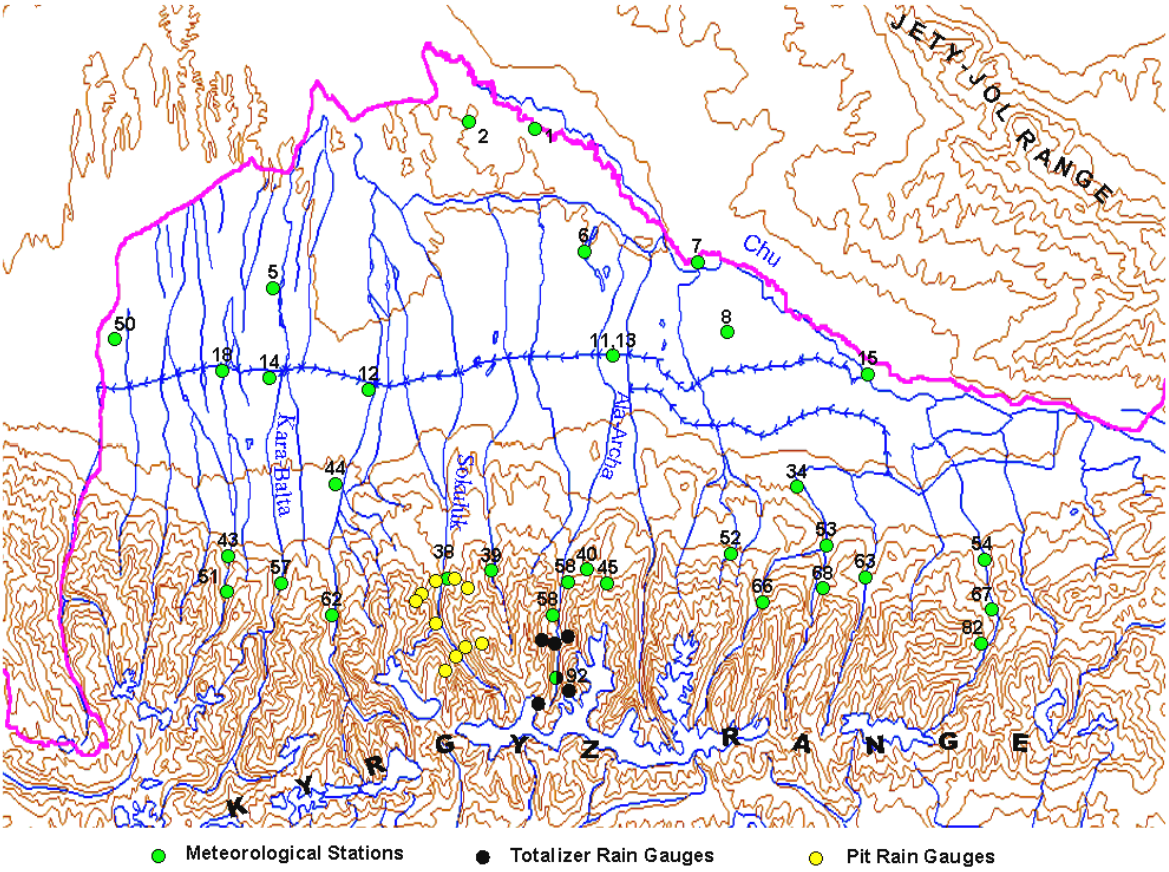

Figure 1. Distribution of precipitation gauging points on the NSKR.

3. Available data and data quality

For the implementation of the stated task the following data were used: data of 33 meteotological stations (MS) of the regular national network located on the NSKR; data of special observations by totalizer precipitation gauges; and data of our survey in the Sokuluk river basin, which is briefly discussed in Table 1.

Table 1

Brief characteristics of observation points the data of which was used in the study

Observation point	Period	Discontinuity of observation	Altitude range	Equipment	Number	Location
Meteorological stations and hydroposts of Kyrgyzhydromet	1891-1965	2 times a day	560…2945 m	Tretiakov's Precipitation gauges	33	Nothern slope of the Kyrgyz range
Surface rain gauges NCCR programmes	Jun-Sept 2004 May-Sept 2005	1 time for 5 days	1402 … 2700 m	Pit rain gauges	12	Sokuluk river basin
Totalizer precipitation gauges of Kyrgyzhydromet	1976/77-1985/86	1 time a month	2190…3610 m	Precipitation gauges M-70	6	Ala-Archa river basin

The data provided by the national network of MS (Annex 1), in our opinion, are more comprehensive and reliable as measurements are taken regularly which ensures synchronism of observations within the entire network, there is a regular control and inspection of equipment. Data from the Climate Manual of the USSR (1969) were used for the study. Data series of the Manual were brought to one period; ingemogeneousity in data serires caused by the replacement of the rain-gauge with Nifer protection for Tretiakov's presipitation gauge was removed. Data were used from this Manual because the later editions provide data generated by fewer MS.

The majority of MS, that provided data included in the Manual, are located various altitudes up to 1,800m covering the the valley and foothill area, and only MS "Ala-Archa" is located at 2,945 m. This is obviously not sufficient to cover the upper mountain area by MS observations and to generate relevant data on it. In mountain regions not covered by observations of the regular network, the Kyrgyzhydromet installed totalizer precipitation gauges being observed several times a year, besides, the period of measurements was not always the same. Only in the Ala-Archa river basin observations were conducted monthly. Therefore the data received from six totalizer precipitation gauges, installed in the basin, were used in the study (observations of snow cover and precipitation in the mountains 1976/77-1985/86).

Based on our preliminary analysis of annual sums of precipitation from the data of MS of NSKR the period from 1977 to 1986 was selected. During that period one full moistening cycle was observed. Just for this period averages of monthly sums of precipitation of totalizer precipitation gauges were calculated (Annex 2) to have some comperable data for monthly norms of precipitation provided by MS.

During the warm periods of 2004 and 2005 in one of the river-basins of selectsd region – in the Sokuluk river basin – with the support of Swiss programme NCCR North-South special observations were conducted to identify the territorial distribution of precipitation in the basin. Precipitation were measured at the discontinuity of 5 days using 12 pit rain gauges (Figure 1). Each measured value was corrected for the moisture on the surface of the measuring bottle by +0.2 mm assumed for liquid precipitation. Then the final values were summed up by months (Annex 3).

4. Methods of the analysis

In order to define the distribution of precipitation in the selected site, we used the well-known regularity manifested in the mountains: amount of precipitation altitude increase with the altitude (Dikih A.N., Mikhailova V.I., 1976, Ponomarenko P.N., 1976)

First of all, an attempt was made to present dependences of monthly norms of precipitation y on altitude x as a linear regression model:

$$\tilde{y}_i = b_0 + b_1 x_i \pm \sigma_M, \quad (1)$$

where σ_M – a random error of the model

The angular coefficient b_1 [mm/m] in the produced regression equations shows the altitude change rate of precipitation. For the sake of convenience it is accepted to use pluviometric gradient $\gamma=100 \cdot b_1$ [mm/100m] instead of b_1. The sign of γ indicates direction of dependences: sign "+" means that regression is a linear responsive proportion, and the amount of precipitation increases with altitude, and the sign "–" indicates a reverse dependence when the amount of precipitation decreases with altitude.

Furthermore, for the produced regression equations r^2 and F- ratio, were calculated which allow to judge about the quality of regression (Podrezov, 2003).

r^2 – determination coefficients, indicates which part of the entire dispersion (point spread) in the sample can be explained (i.e. defined or determined) by regression. Then the remaining part of dispersion corresponds to random factors which are not considered in regression. It is generally accepted that there is a very close relation (dependence) between the values if r^2>0.36...0.49. (However, such dependence also exists and can be used even when r^2<0.36, if it can be explained by physical reasons) (Podrezov, 2003).

F-ratio of Fisher, is often use to check the regression value representing as the ratio:

$$F = \Sigma_y / \Sigma_2, \tag{2}$$

where $\sum_y = \Sigma(y_i - \bar{y})^2 = \Sigma_1 + \Sigma_2$ is full squared sum, $\sum_1 = \Sigma_1(\tilde{y}_i - \bar{y})^2$ is squared regression sum, $\sum_2 = \Sigma_2(y_i - \tilde{y}_i)^2$ is remaining squared sum.

Setting the level of confidential probability p or the level of significance $q=(1-p)$, we define $F_{(critical)}=F_{(n-1);(n-2);\ q}$. Considering the fact that data of 33 weather stations was used (n = 33), at the level of confidential probability p = 0.95 (q = 0.05) F_{critical} will be F_{critical} = 1.82. If F empirical calculated by ratio (2) is more than F_{critical} = 1.82, then regression at the level of 0.95 is significant statistically and vice verse.

Such parameters of linear dependence like b_0, b_1, σ_M, r^2, Σ_1 and Σ_2 were calculated by using Excel-2000.

5. Results

Table 2 provides parameter values of F-ratio, determination coefficients r^2 and pluviomentric gradients for all months of the year calculated based on the data of weather stations.

Table 2

Pluviomentric gradients, determination coefficients and Fisher parameters calculated for average monthly precipitation based on data of 33 WS of the northern slope of the Kyrgyz range.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
F	2,16	1,14	1,01	1,17	3,06	9,15	18,14	8,94	7,29	1,12	1,03	2,83
r^2	0,54	0,13	0,01	0,14	0,67	0,89	0,94	0,89	0,86	0,11	0,03	0,65
γ мм/100м	-0,81	-0,36	-0,22	1,40	3,78	3,88	3,60	2,64	1,57	0,44	-0,23	-0,91

It can be seen from the Table 2 that for 5 months (February-April and October-November) $F_{\text{эempirical}} < F_{\text{critical}}$. It means that there is no linear dependence of precipitation norms for these months. As for the other months, the calculated linear regressions revealing dependence of monthly precipitation rates on altitude should be regarded as significant at the level of confidence probability $p = 0.95$.

Determination coefficient r^2 defining the quality of regression, shows that linear regression equations clearly depict dependence of precipitation on altitude from May to September (r^2 = 0.67…0.94). Values of r^2 for December and January are slightly less (r^2 =0.54…0.65). At the same time, like F-ratio, r^2 indicates the absence of linear dependence of precipitation on altitude in February-April and October-November, which, however, does not deny non-linear dependence of precipitation on altitude in these months.

The range of values that can be covered by the pluviomentric gradient γ is fairly wide. The sign of γ indicates that from May to September the average monthly precipitation rates increase with altitude. The module of gradient γ indicates that increase or decrease of precipitation depending on altitude occurs at various intensiveness which can be seen in Figure 2. Thus, the largest gradients of precipitation correspond to the period from May to August (γ = 2.64…3.88) with their maximum value in June.

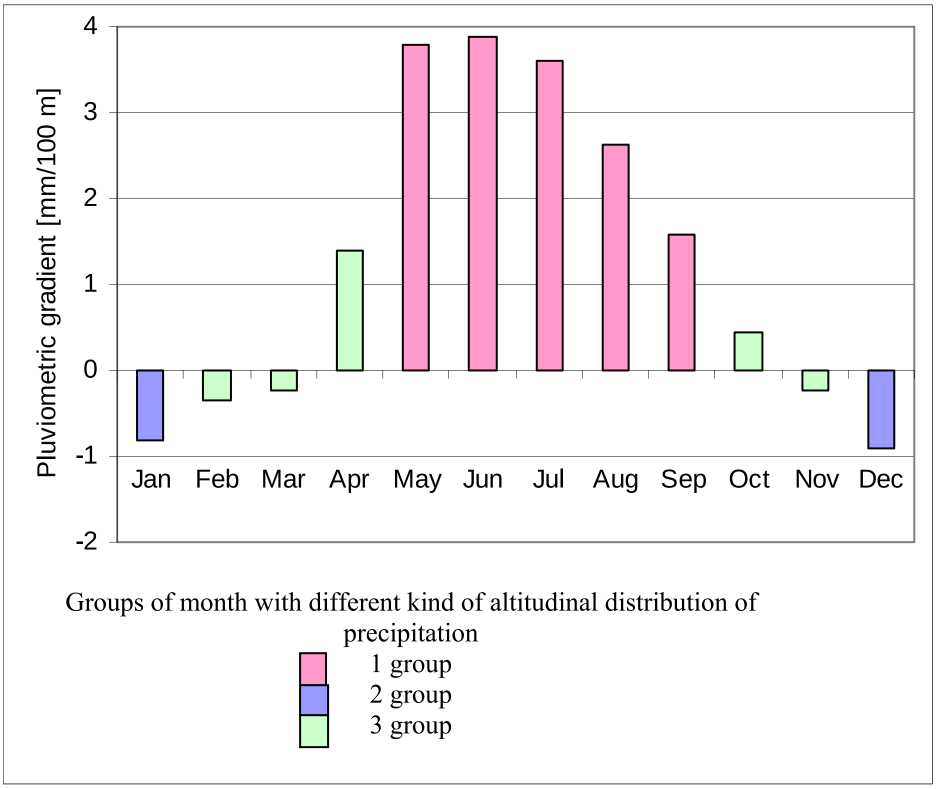

Figure 2. Pluviometric gradients by months (according to Table 2)

Thus, during the year we can distinguish 3 groups of months with different types of altitude distribution of precipitation:

1 group includes the months of warm period (May-September) being characterised by monthly precipitation norms increase with altitude;

2 group include the months of cold period (December-January) being characterised by monthly precipitation norms decrease with altitude;

3 group includes two transitional periods (February-April and October-November) being characterised by absence of a significant linear change in monthly precipitation norms with altitude.

Figure 3 demonstrates the charts of altitudenal distribution of precipitation for months representing the above three identified groups. In addition to data of weather stations, Figure 3 includes data of average precipitation sum for 10 years (1977-86) obtained by totalazer gauges. This data allows checking whether the distribution calculated by using data of WS is valid for the upper area.

For the months of the first group (except May) and the second group, data of totalazer gauges confirms the validity of altitudenal dependences calculated by using data of weather stations. As for May, the calculated altitude dependence may provide excessive values of precipitation for the area over 1,700-18,000 m.

For the months of the transitional periods altitudenal distribution of precipitation is identified by the non-linear law. Thus, before 1,100-1,300 m precipitation increases with altitude, but over this level, precipitation either decreases or changes very little (Figure 3, April).

The data of survey made during the warm period of 2004 and 2005 (Figure 3, July) allows to judge about the distribution of precipitation for the years with different moisture. It can be seen that for some years monthly precipitation can significantly differ from the standard. However, altitudenal precipitation increase occurs practically for each separate year although their gradients are different.

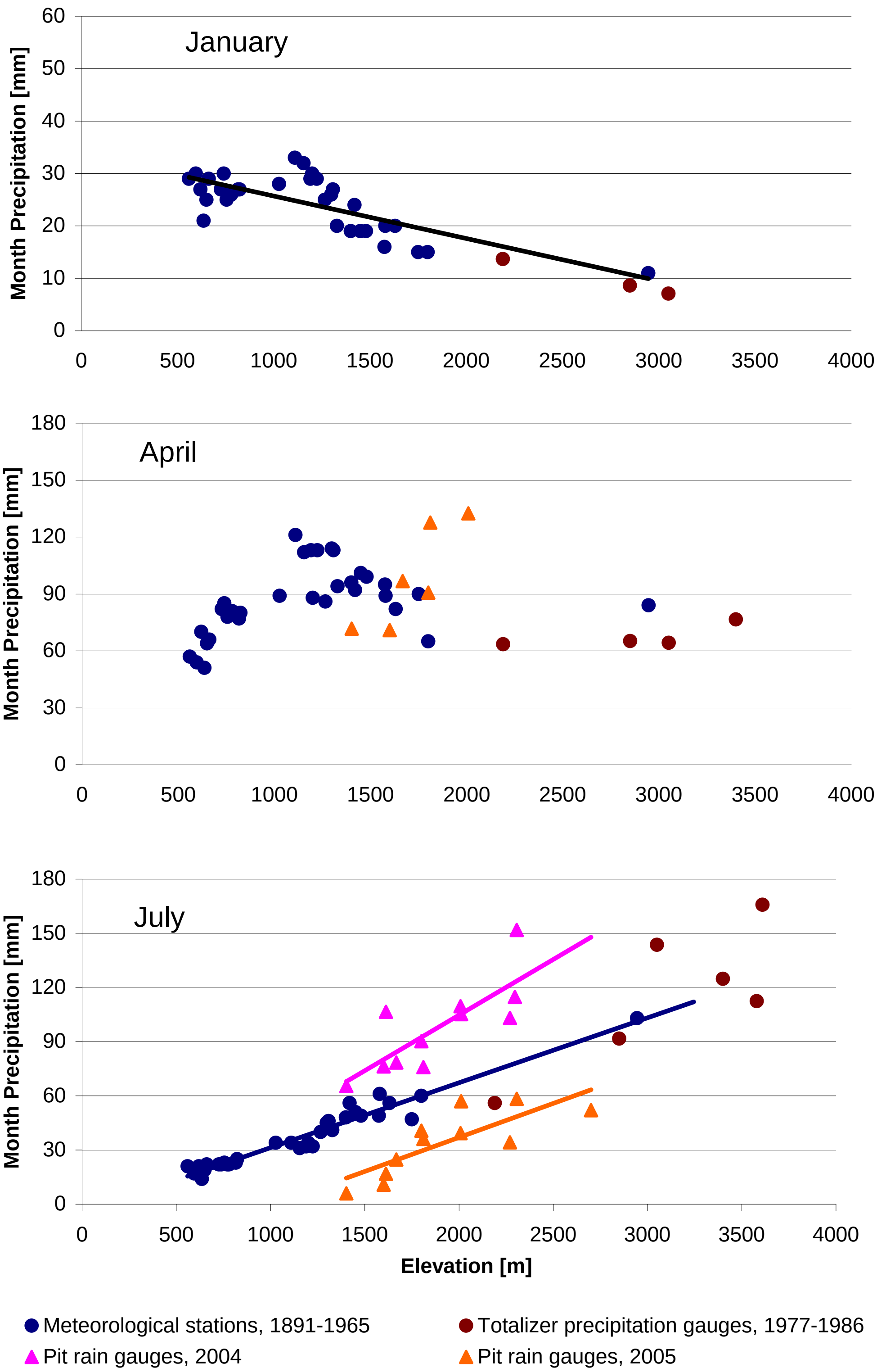

Figure 3. Altitude distribution of precipitation in January, April and July

6. **Discussion**

7.1. Discussion of outputs

Precipitation formation is determined by moisture contents of air mass and conditions required to cause upward air movements (Zhakov S.I., 1982). When moisture contents of air mass run on mountain abstacle it is occur upward air movements which explains the regular altitude increase of precipitation. However, such regularity does not occur in all year seasons, as during the year conditions for precipitate formation are changing (extent of atmospheric stability, moisture contents etc.)

Thus, in the spring-autumn period with a low level of condensation and unstable condition of air mass, intensification of the atmospheric front occurs already when air mass runs into foothills causing precipitation fall. (Grigoriev A.A., 1964). This statement conforms to our conclusions that during the transitional periods on the northern slope of the Kyrgyz range, increase in precipitation occurs up to a certain altitude (1,100…1,300 m) and there is no linear altitudenal dependence of precipitation.

From May to September foothills do not any more make a significant impact due to a high level of condensation and altitudenal dependence of precipitation is more unique: increase of altitude results in increase of precipitation.

In winter months the level of condensation does not go up very often higher than 1,000…1,100 m (Grigoriev A.A., 1964) and atmosphere is relatively stable. This explains the winter decrease of precipitation above 1000…1200 m.

Many scientists were involved in studying the issue of precipitate territorial distribution in Tien Shan using various methods and approaches. The works of Grigoriev A.A. (1964), Dikih A.N. and Mikhailova V.I. (1976) are concentrated not only on altitude, but also the impact of relief (closeness of the site, forms of relief). Although the altitude impact in their works is still a dominant factor, however altitude dependences are calculated separately for various types of relief and closeness.

The northern slope of the Kyrgyz range is fairly considerable in its length and it would be logically assumed that in its various sections there are regions that are different in their altitudenal dependences of monthly precipitation sum. In our study we could not make such classification for the northern slope of the Kyrgyz range. Charts of Figure 3 show that in general, points form a unified area and it is not possible to distinguish separate groups among them by territories they belong to.

At the same time, along all its length the northern slope of the Kyrgyz range is partitioned by deep meridian-oriented river canyons, which, in their turn, have side canyons and so on. Therefore, a more detailed review of the northern slope of the Kyrgyz range reveals it fairly compound structure and various orographic units (windward sides, leeward sides, canyon bottoms) are different in terms of their accessibility for moisture carrying flows and consequently have a diversity of precipitate distribution. It is very complicated to describe the full picture of how all small features of relief impact on precipitate distribution due to their large diversity and poor coverage by measuring points.

Thus, it can be concluded that the calculated altitude dependences of precipitation are applicable for the entire northern slope of the Kyrgyz range although these dependences can be different for separate small forms of relief, but in general this should not distort the general picture of precipitate distribution.

Another approach to the analysis of territorial distribution of precipitation is discussed in the work of Gekter M.I. et al. (1972) where its authors substantiate the possibility to use dependences of cumulative precipitation on remoteness from the axis of mountain ridges.

7.2. Application of the results

The altitudenal dependences calculated during the study can be applied to map the distribution of monthly precipitation norms along the northern slope of the Kyrgyz range for the months of the first and the second groups. As for the months of the transitional period and May it is recommended to use curvilinear dependence or by splitting altitude areas into elevation intervals, where linear laws can be applicable (Figure 4).

Pluviomentric gradients can be applied to produce maps for individual years, however, actual data of representative weather stations should be used to take into account the moisture intensity of a specific month.

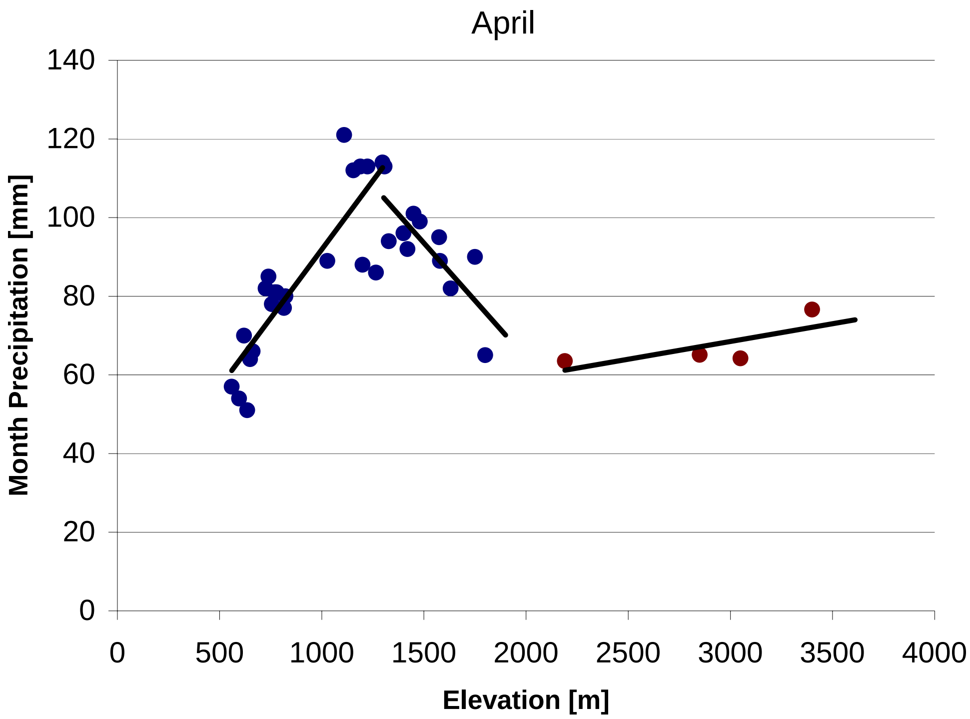

Figure 4. Linear dependences of precipitation in April for various altitude areas.

Creation of the precipitation field for each separate precipitate case will be accompanied by a large error therefore it is not recommended to use gradients for this purpose as precipitation is characterised by a significant space heterogeneity which is smoothed when averaging. Thus, according to Iliasov A.T. (1969): "the concept about vertical gradient to precipitation which could be at least stable during relatively short intervals of time apparently is not applicable, although from the long-term point of view and in relation to certain areas it would probably have a value. On the one hand, local conditions of these or those mountain slope sections play a big role in altitude precipitate distribution, on the other hand it is specific conditions of each year or year seasons." Dependences calculated for precipitation rates are characterised by closer correlative relations than altitude dependences of separate years and months.

7. Conclusions

1) The study results confirm the regularity of altitude precipitate change. However, the nature of altitudenal dependences changes during the year: from December to January there is decrease of precipitation with altitude (-0.81...-0.91 mm/100 m), from May to September it increases (1.57...3.88 mm/100 m). During the months of the transitional period (February-April and October-November) there is no linear dependence of precipitation on altitude.

2) Increase in precipitation amount for the transitional months can probably be explained by the impact of two factors: the level of condensation in this period is rather low while atmosphere is unstable.

3) It is natural that compared to dependences calculated for monthly precipitate norm of individual years altitude dependences are characterises by a considerable spread with gradients being significantly different but keeping their values.

4) The calculated altitude dependences can be applied for mapping the precipitate distribution on the northern slope of the Kyrgyz range.

5) Precipitate distribution in the west, central and east areas of the research site of the northern slope of the Kyrgyz range are similar therefore the calculated altitude dependences are applicable for the entire northern slope of the Kyrgyz range.

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