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ARTICLE

Relationship and Variability of Atmospheric Precipitation Characteristics in the North-West of Ukraine

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ABSTRACT

The paper deals with the issues of differentiation of atmospheric precipitation into gradations according to their characteristics and established meteorological practices. The division of atmospheric precipitation into gradations allows one to have an idea of the possible consequences of their fallout on life in the area. The dependence of the average intensity of precipitation on their duration for the entire series of observations is not described by a power-law dependence with a sufficient degree of reliability, and when differentiating into gradations according to the amount of precipitation (< 2.5 mm, 2.5-10 mm, ≥ 10 mm), the dependences are obtained with a high degree of correlation. The scatter of points can be explained by the presence of intermediate categories of precipitation, which does not take into account the accepted division of the data. Thus, for large values of the amount of precipitation, the existence of a separate curve is possible, since the existing classifications of precipitation imply the division of heavy showers into separate gradations. Differentiation of rains by their duration shows a stronger stratification of the field of points for shorter rains (up to 60 minutes). This stratification of the field of points is successfully differentiated into shorter segments of 20, 30 minutes. Associated with the greater heterogeneity of shorter precipitation, it can be both rains of low intensity and heavy downpours of short duration. The probability of the position of the maximum intensity of precipitation during rain has more significant differences for precipitation less than 2.5 mm (the curves are more curved). For rains with a precipitation amount of 2.5 mm or more, the probability curves approach straight lines, which is associated with greater heterogeneity of precipitation less than 2.5 mm.

Keywords: Precipitation; Gradation; Intensity; Duration; Shower

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1. Introduction

Atmospheric precipitation is an integral part of the cycle of substances in nature. They carry out the moistening of the territory, dissolution and transportation of substances on the surface of the earth and in the soil layer, which contributes to the interaction of all elements in natural and territorial complexes, which, in turn, ensures the development of vegetation, the existence of animals and humans as well.

Various manifestations of atmospheric precipitation (dew, hail, drizzle, rains, showers, etc.) are important for ecosystems. Humidification of the territory is provided not only by showers, but also by smaller rains, especially in areas where their percentage of the total precipitation is the largest.

Actually, low-intensity rains provide replenishment of groundwater reserves and support low-water runoff in rivers, have a beneficial effect on the development of vegetation cover and, as a result, reduce the heating of the soil surface and evaporation. Downpours are responsible for floods and soil erosion, which often leads to large material costs, however, in the current physical and geographical conditions, they also provide channel formation and ecological cleaning of river channels.

The question arises of dividing atmospheric fallout (precipitation) into gradations that allow one to have an idea of their possible influences on natural and economic processes and human life in a given area.

Precipitation is divided by origin and by the nature of precipitation, they are divided into types, views, and classes. There are types of precipitation: cyclonic, convective and orographic. Types of precipitation: drizzle, rain, ice, freezing rain, snow, snow pellets, ice pellets, and hail [1,2].

As criteria for dividing atmospheric precipitation into gradations, such consequences of rainfall as the beginning of runoff formation, erosion of the soil surface, the formation of mudflows, etc. are also used.

There is no generally accepted division of genetically different types of sediments according to morphometric features [3,4]. The most common morphological definitions relate to shower and non-storm precipitation and are conditional. The reason for this may be the physical and geographical features of the area under study [5]. Showers are typical for arid regions and, in particular, for the forest-steppe and steppe zones of the European territory of the USSR [2] and are characterized by great diversity and local distribution, covering at the same time, as a rule, small areas of the order of tens, less often hundreds of square kilometers.

The first researcher of showers in Russia, E.Yu. Berg, considered showers as the most intense areas of rain with an average intensity of more than 0.5 mm/min with a duration of 5 minutes, etc. [2,5,6].

A.I. Voeikov proposed to consider rain with an intensity of at least 0.5 mm/min as a downpour [7]. In other countries, the shower is determined by different intensity figures [7]: Switzerland (Riggenbach)—0.34, America (Fassig)—1.28 mm/min, England (Simon)—0.76 mm/min, Germany (Gellmann)—1.01 mm/min.

As mentioned, there are differences in the definition of showers among states—for example, in Canada it is considered light rain at 0.2 mm/h and heavy rain at 7.6 mm/h [8].

Currently, rains with an intensity of up to 2.5 mm/h (0.04 mm/min) are often considered light rain, rains with a precipitation intensity of 2.5-7.5 mm/h (0.04-0.125 mm/min). Heavy rains are considered with an intensity of more than 7.5 mm/h (more than 0.125 mm/min).

Drizzle is considered light drizzle < 0.1 mm/h, moderate drizzle 0.1-0.5 mm/h, heavy drizzle 0.5 mm/min [9]. The rain is classified as light rain < 2.5 mm/h, moderate rain 2.5 to 10.0 mm/h, and heavy rain over 10.0 m/h. Rainfall over 50 mm/h is considered heavy.

In Spain [4], the National Meteorological Institute has defined the following average hourly intensity (I) thresholds: light rainfall $I \leq 2$ mm/h, moderate rainfall $2 < I \leq 15$ mm/h, heavy rainfall $15 < I \leq 30$ mm/h, very heavy rainfall $30 < I \leq 60$ mm/h, heavy rain $I > 60$ mm/h. However, these thresholds vary considerably from one country to another, which means that it would be difficult to obtain a universal classification based on different thresholds [4].

Rains with a precipitation amount of up to 10 mm are considered light, 11-30 mm—moderate, 31-50—heavy, and more than 51 mm—very heavy [10].

In the territory of Ukraine, the intensity of precipitation increases from north to south [11]. The highest maximum intensity for a 5-minute interval in the southern steppe zone (including the steppe part of the Crimea) and Transcarpathia reach 30-40 mm/min, in the northern part of Ukraine—20-30 mm/min. The highest maximum precipitation intensity for a 10-minute interval is much lower than for a 5-minute interval, and reaches 2.5-3 mm/min in the southern steppe, the steppe part of the Crimea and Transcarpathia, and 1.0-2 in the northern part of the territory 2 mm/min.

Studies of the seasonal dynamics of large-scale and convective precipitation in the territory covering the East European Plain and the Black Sea region revealed an excess (2 times) of the number of showers over precipitation [12].

Our study of rains with more than 10 mm of precipitation in the Northwest of Ukraine showed that at the present stage of climate change in the Northwest of Ukraine, there is a general tendency to increase the amount of precipitation per year. This trend is not the same across the territory and depends on the height and latitude of the area. The amount of precipitation varies both in space and time, but the distribution of the characteristics of the rains themselves (intensity, duration, and others) continues to be similar throughout the researched territory [13,14].

The creation of automated precipitation tracking systems (radar complexes, etc.) in recent years requires the same autonomous system for their differentiation and recognition [10]. Deepening and refining our understanding of the structure and relationships in rainfall will make it possible to make the right decisions in their forecasting. Making decisions based on the results of observations and forecasts also requires specification in terms of precipitation gradations in order to prevent damage to the economy of the region and the population.

The task of this work was to identify the features of grouping the range of changes in rain characteristics with different parameters. To trace the relationship and change in the characteristics of rains (their number, intensity, duration) of different gradations over time in the Northwest of Ukraine.

2. Materials and methods of research

The analysis used materials from observations of all rains that could be recorded at meteorological stations in Kyiv and Kamenka-Bugskaya. The locations of the stations on the territory of Ukraine were presented earlier [14] (**Figure 1**).

The completeness and coverage of the range of precipitation measured at meteorological stations are presented in **Tables 1-2**. The order and trend of changes in the characteristics of rain for the two weather stations, in general, coincide.

Table 1. Characteristics of the series of observations of atmospheric precipitation at meteorological stations Kyiv and Kamenka-Bugskaya.

Characteristics	**Weather stations**	
	Kyiv	Kamenka-Bugskaya
Precipitation observation period, total (number of years of observation)	1856-2020 (162)	1894-1905, 1932-1934, 1946-2020 (89)
Period of observations with pluviographs, total (number of years of observations)	1913, 1924-1929, 1950-1980, 1993-2020 (59)	1963-1985-1988-2018 (56)
Average long-term precipitation per year, mm	599	645
Range of changes in the amount of precipitation per year, mm	331-925	311-959

Table 2. Characteristics of rainfall observation series for meteorological stations Kyiv and Kamenka-Bugskaya.

Weather station	Characteristics	Precipitation, mm			
		less than 2.5 mm (by 1970)	2.5-10 mm	10 mm or more	All
Kyiv	number of recorded rains	738	1112	407	2257
	Precipitation range for rain, mm	0.1-2.4	2.5-9.9	10-76.7	0.1-76.7
	Range of average intensity of precipitation for rain, mm/min	0.00085-0.58	0.002-1.2	0.01-0.60	0.00085-1.2
	Range of maximum intensity of precipitation for rain, mm/min	0.00097-0.8	0.002-3.15	0.013-7.1	0.00097-0.71
	Precipitation duration range for rain, min	1-567	6-1837	21-2218	1-2218
Kamenka-Bugskaya	number of recorded rains	85	1355	521	1961
	Precipitation range for rain, mm	0.4-2.4	2.5-10	10-98.5	0.4-98.5
	Range of average intensity of precipitation for rain, mm/min	0.01-0.22	0.01-1.02	0.01-1.58	0.01-1.58
	Range of maximum intensity of precipitation for rain, mm/min	0.02-0.53	0.01-3.0	0.03-2.62	0.01-3.0
	Precipitation duration range for rain, min	3-423	5-1272	11-2505	3-2505

On the network of the hydrometeorological service of Ukraine, observations of heavy rains have been introduced since 1934-1935 [15], however, observations of the course of atmospheric precipitation, including rainfall, with the help of pluviographs at individual weather stations were also carried out earlier (from the end of the 19th to the beginning of the 20th century). Since 1961, dew has been excluded from the number of observed phenomena, only its presence is noted without describing the time of the beginning and end of the phenomenon and its intensity, which was noted according to the instructions for meteorological stations in 1928-1935 [16]. Instructions to weather stations in 1954 and 1958 [17,18] emphasize that heavy rain determines the nature of rainfall, and not the amount of precipitation, which may be insignificant. Heavy rain has a significant intensity of precipitation in a short time. The amount of precipitation here may be less than that of rains with low intensity but long duration.

Rain observations with the help of a pluviograph at the studied meteorological stations were carried out with interruptions in observations for almost 100 years at the Kyiv meteorological station and 56 years at the Kamenka-Bugskaya meteorological station. Rain records were made using a Gelman pluviograph with a receiving area of 500 cm^2. During this time, the approach to the analysis of recorder tapes (pluviographs) and the selection of pluviograph records for analysis changed. Unfortunately, materials deciphering the tapes of the pluviograph until 1952 according to the Kyiv weather station have not been preserved.

So, until 1935 [19], heavy rains were selected for analysis and publication according to the E. Berg norms (**Table 3**) [6], where showers were understood as rains during which, for a given time, the rain intensity did not fall below values presented in **Table 3**. Later [4], the processing of tapes was carried out according to the method presented in the Manual for Hydrometeorological Stations and Posts [18], in the collection [15] materials were published on rains, the amount of precipitation for which was 10 mm or more. Priority in the publication of data on observations of the course of rains using pluviographs with a rainfall of 10 mm or more has been preserved to this day [20].

Table 3. The norms of E.Yu. Berg (1905) in the definition of the concept of shower [6].

Shower duration, min	The amount of precipitation for the specified time, mm	Shower intensity, mm/min
5	2.5	0.50
10	3.8	0.38
15	5.0	0.33
20	6.0	0.30
25	7.0	0.28
30	8.0	0.27
35	9.0	0.26
40	9.6	0.24
45	10.25	0.23
50	11.00	0.22
10	12.00	0.20
120	18.00	0.15
240	27.00	0.11
720	45.00	0.06
1440	60.00	0.04

Until the 1970s, data on decoding tapes of pluviographs with all recorded liquid atmospheric precipitation were placed in TM-14; later, only materials with precipitation of 2.5 mm or more began to be placed there. Since 1984, the data of observations with the help of pluviographs for rains with a precipitation amount of 2.5 mm or more have been placed in the TMS-1 summary meteorological tables. In addition, at most meteorological stations, rainfall is recorded with the help of pluviographs from May to September (this also applies to the Kamenka-Bugskaya meteorological station).

However, for individual weather stations, including the Kyiv weather station, in recent years, rain observations with the help of pluviographs were carried out from 2009 to 2013 from April to November, and since 2014 they have been carried out almost monthly (if weather conditions permit). That is, the series of observations of precipitation are not homogeneous according to several criteria—the time of observation and the boundary conditions of selection (2.5 mm or more).

However, if we also take into account the periods when the pluviographs were not able to record the falling precipitation (the intensity and amount of precipitation exceeded the limits of the speed of the device or the breakdown of the device mechanisms, etc.), then there will be even more heterogeneous breaks in the rows. However, in general, the series under consideration can be considered assets of random variables characterizing the corresponding periods.

In the study of the presented materials, a graphical-analytical method, descriptive statistics, elements of probability theory and regression analysis were used.

3. Results

Many researchers [2,5,7,21,22] confirm the existence of a close relationship between the duration of showers and their average intensity. The highest mean intensities occur during short showers. The longer the duration of the shower, the lower its average and maximum intensity. Most researchers believe that these dependencies are characterized by a power function [6].

Studies show that the dependence of the amount of precipitation on their duration is positive, but the field of points is strongly dispersed from year to year. The grouping of years according to the amount of atmospheric precipitation per year brings the communication lines somewhat closer, but the dispersion of points remains.

The existing practice of processing rain observation data using pluviographs [15], used in the USSR and Ukraine, including (as mentioned above), makes it possible to distinguish between the available series of rain observations into three gradations: 1) less than 2.5 mm, 2) 2.5-10.0 mm, 3) more than and equal to 10 mm, and analyze the presence of differences between these gradations.

Thus, the dependence of the average intensity of precipitation on their duration for the entire series is not described by a power-law dependence with a sufficient degree of reliability, and when differentiated into these gradations, the dependences are obtained with a high degree of correlation (**Figures 1 and 3**).

The scatter of points can be explained by the presence of intermediate categories, which does not take into account the accepted division of the data. Thus, for large amounts of precipitation, the existence of a separate curve is possible, since the existing classifications of precipitation imply the division of heavy showers into separate gradations (heavy, mountainous, Texas, etc.) [23]. **Figure 2** clearly confirms this.

Rains of varying intensity and duration affect the water balance of the study area and the economic indicators of the region's development stability in different ways. The probability of precipitation with different intensity and duration is shown in **Figures 4-6**. According to the classifications of precipitation discussed above, the probability of occurrence of rains of different "power" of impact on natural and economic systems is different (**Table 4**).

The experience of meteorological and climatic studies [3] shows that a fairly reliable and clear criterion for separating precipitation, reflecting both genetic and morphometric features, is their duration. All rains according to this criterion [3] are divided into rains lasting < 1 h, from 1 to 3 h and more than 3 h. So, on a meteorological station Kyiv Kamenka-Bugskaya (**Figures 7 and 9**) the differentiation of rains on their duration shows stronger stratification of a field of points for less long rains (till 60 minutes). This stratification of the field of points successfully differentiates into shorter time intervals (**Figure 8**) of 20, 30 minutes.

The general field of points is strongly scattered. However, when data are differentiated by precipitation duration, this chaos of points becomes more ordered. The deepening of differentiation by the duration of precipitation of shorter rains increases the tightness of the grouping of points near the trend lines. Different colors show the dependence of the intensity of precipitation on their amount for different durations.

According to a number of authors [3], the course

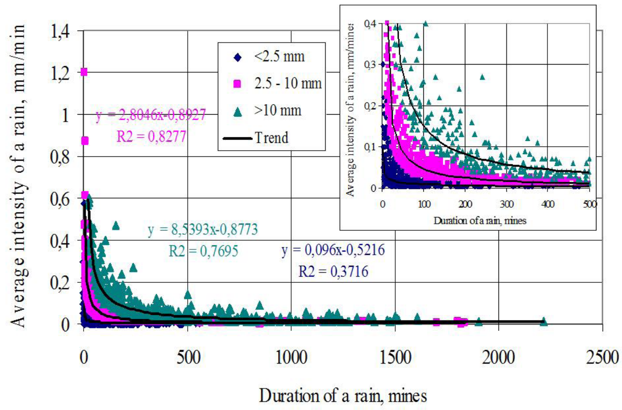

Figure 1. The dependence of the average intensity of precipitation on their duration at the Kyiv weather station, differentiated by the amount of precipitation per rain.

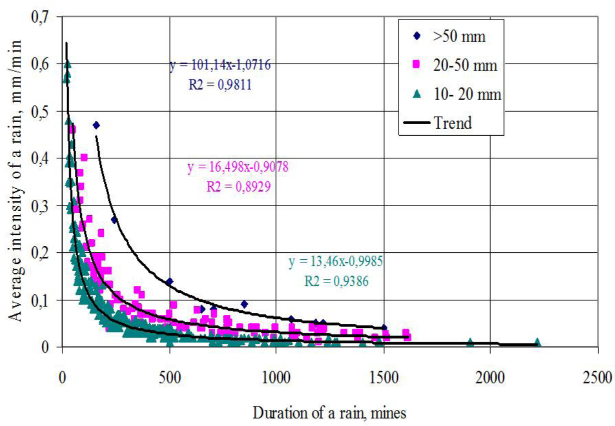

Figure 2. Dependence of the average intensity of precipitation over 10 mm on their duration according to the Kyiv meteorological station, differentiated by the amount of precipitation per rain.

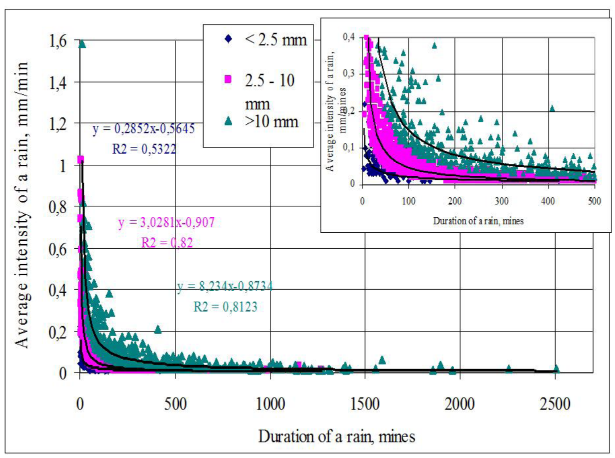

Figure 3. Dependence of the average intensity of precipitation on their duration at the Kamenka-Bugskaya meteorological station, differentiated by the amount of precipitation per rain.

Table 4. Probability of occurrence of rains of different intensities, %.

Characteristic	**Gradations**	**Weather station**															
		Kyiv				Kamenka-Bugskaya				Kyiv				Kamenka-Bugskaya			
		Average intensity of precipitation, mm/min								Precipitation duration, min							
		0.01	0.04	0.125	0.5	0.01	0.04	0.125	0.5	10	20	60	180	10	20	60	180
The amount of precipitation for rain, mm	< 2.5 mm	52	20	3	-	91	51	4	-	80	65	35	10	93	75	30	2.3
	2.5-10 mm	79	37	11	-	85	50	13	0.5	99.6	97	80	45	99	96	77.7	39
	> 10 mm	95	56	22	1	98	73	26	2.7	-	-	95	72	99.8	98.6	92	62.6
	Whole range	73	35	10	0.5	89	57	16	1	95	88	68	39	99.5	95.9	79.6	44
Precipitation duration for rain, min	< 60 min	92	57	22	1	99.9	96	52	5.5								
	60-180 min	92	52	8	-	99.9	71	13.5	-								
	> 180 min	93	21	1	-	99.9	26	1.7	-								
	Whole range, min	93	42	10	1	99.9	56.5	16.2	1								

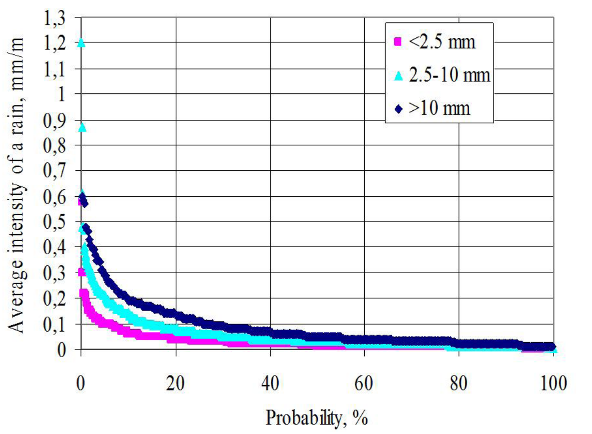

Figure 4. Availability of average intensity of precipitation at the meteorological station Kyiv is differentiated by the amount of precipitation per rain.

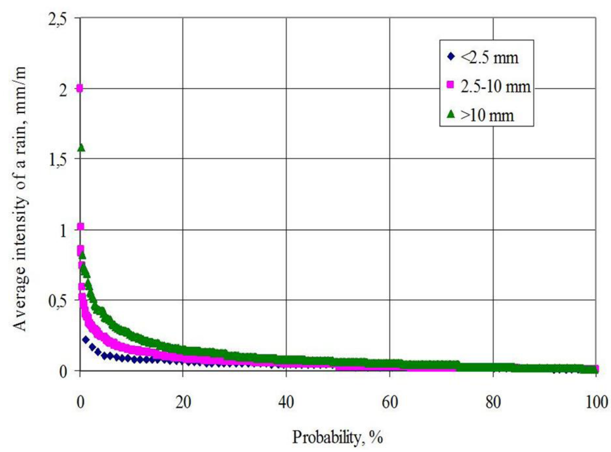

Figure 5. Availability of average precipitation intensity at the weather station Kamenka-Bugskaya is differentiated by the amount of precipitation per rain.

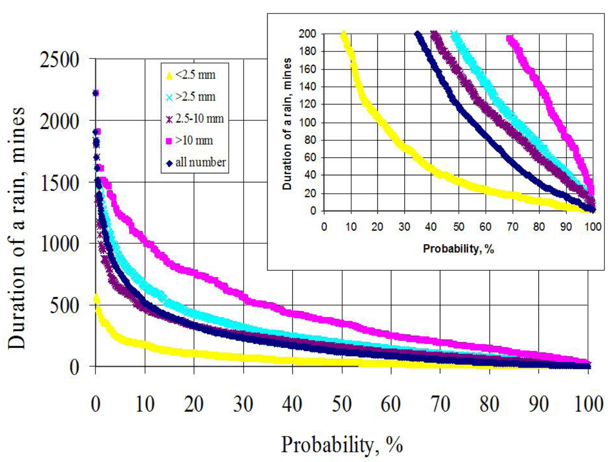

Figure 6. Availability of precipitation duration according to Kyiv weather station differentiated by the amount of precipitation per rain.

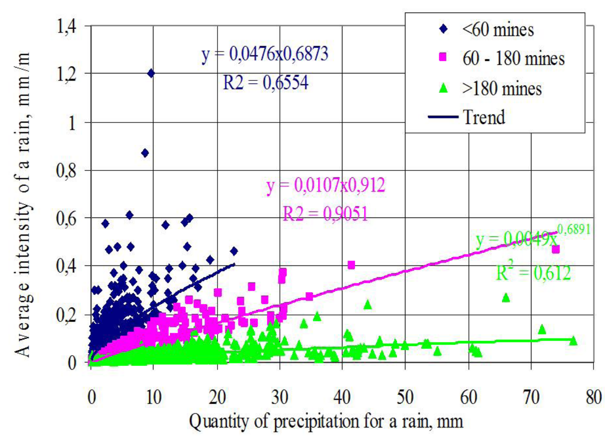

Figure 7. Dependence of the intensity of precipitation on their amount, differentiated by the duration of rain at the meteorological station Kyiv.

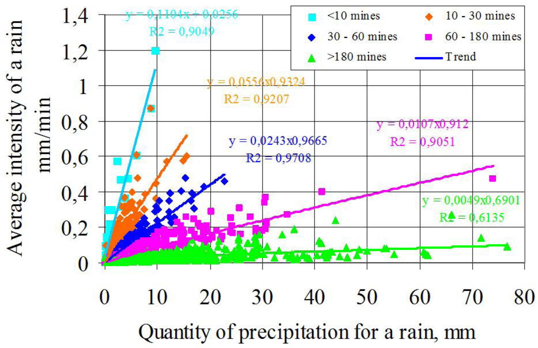

Figure 8. Dependence of the intensity of precipitation on their amount, differentiated in more detail by the duration of the rain, Kyiv meteorological station.

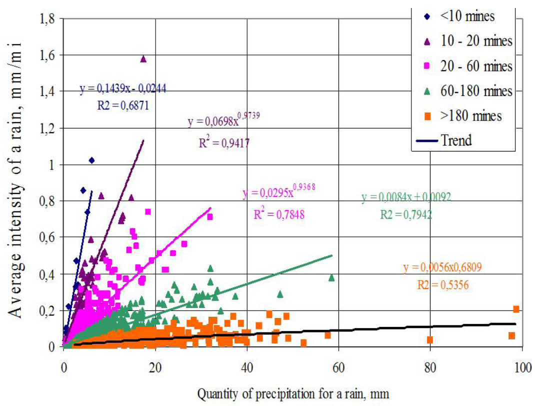

Figure 9. Dependence of the intensity of precipitation on their amount, differentiated in more detail by the duration of rain, meteorological station Kamenka-Bugskaya.

of rain does not depend on either the amount of precipitation or its duration. The change in the intensity of precipitation presumably depends on the synoptic conditions of their formation, as well as on the power of the process and baric gradients. At the front line, in the presence of a large temperature contrast, the most intense precipitation falls, and with the distance from the frontal section, their intensity weakens [3]. Our studies of the rain [24] show that the position of the intensity maximum during rain depends on the amount of precipitation, its duration and average intensity, air and soil surface temperature, air humidity, and wind speed.

Studies by N.V. Gladun et al. [25] show a large weight of precipitation of low intensity in the structure of shower precipitation. The duration of precipitation with an intensity of 0.01-0.10 mm/min is 51% of the duration of the rest of the precipitation, and the area occupied by them is 44% of the area of precipitation of greater intensity.

According to the course of rain intensity Z.P. Bogomazova and Z.P. Petrova [26] identified 6 types of rains.

The probability of the position of the maximum intensity of precipitation during rain for rains with different amounts of precipitation has more significant differences for precipitation less than 2.5 mm (the curves are more curved), for rains of 2.5 mm and more, the probability curves are closer to straight lines (**Figure 10**). Apparently, this is due to the fact that precipitation less than 2.5 mm is more heterogeneous in origin, it can be dew and drizzle, etc.

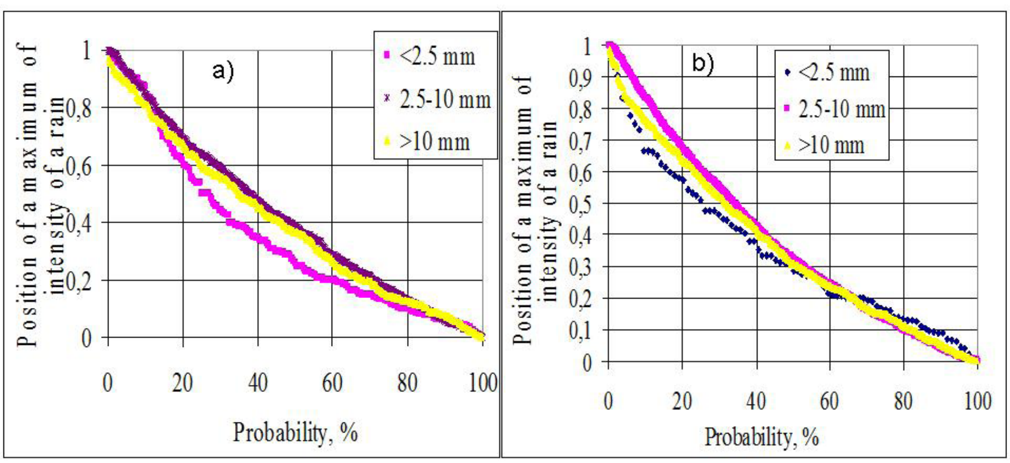

Figure 10. Availability of the position of the maximum intensity of precipitation at meteorological stations Kyiv (a) and Kamenka-Bugskaya (b) differentiated by the amount of precipitation per rain.

When differentiating the probability curves for the position of the maximum intensity of precipitation during rain by the duration of the rain, it is noted that rains of longer duration (more than 180 min) line up more in a straight line than rains of shorter duration (**Figure 11**). Moreover, rains lasting less than 60 minutes show a greater curvature of the probability curve, which is most likely due to the greater heterogeneity of the nature of precipitation in this category, there may be short rains with low precipitation and intense showers.

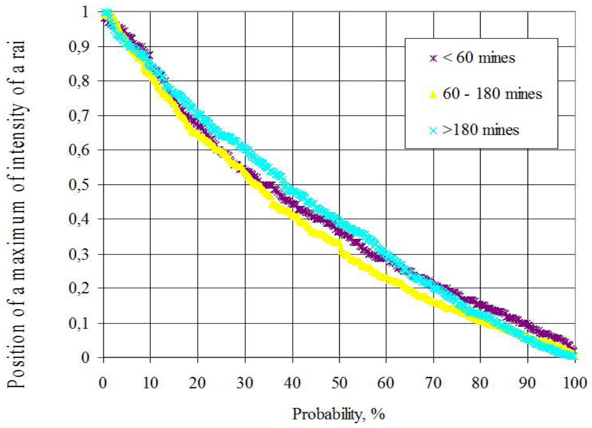

Figure 11. Availability of the position of the maximum intensity of precipitation at the meteorological station Kyiv is differentiated by the duration of precipitation per rain.

4. Discussion and conclusions

The dependence of the average intensity of precipitation on their duration for the entire range of series of observations is not described by a power law with a sufficient degree of reliability, and when differentiated into gradations according to the amount of precipitation (< 2.5 mm, 2.5-10 mm, ≥ 10 mm), the dependences are obtained with a high degree of correlation (**Figures 1 and 3**).

The scatter of points can be explained by the presence of intermediate categories, which does not take into account the accepted division of the data. Thus, for large values of the amount of precipitation, the existence of a separate curve is possible, since the existing classifications of precipitation imply the division of heavy showers into separate gradations (heavy, mountainous, texases, etc. [23]).

Differentiation of rains by their duration shows a stronger stratification of the field of points for shorter rains (up to 60 minutes). This stratification of the field of points is successfully differentiated into shorter segments of 20, 30 minutes. Associated with greater heterogeneity of shorter duration precipitation, it can be both rains of low intensity and heavy downpours of short duration. The deepening of differentiation by the duration of precipitation of shorter rains increases the tightness of the grouping of points near the trend lines.

The probability of the position of the maximum intensity of precipitation during rain for rains with different amounts of precipitation has more significant differences for precipitation less than 2.5 mm (the curves are more curved), for rains of 2.5 mm and more, the probability curves are closer to straight lines, which is associated with a greater rainfall heterogeneity less than 2.5 mm.

The conducted studies show the possibility of creating a classification of atmospheric precipitation based on the quantitative principle. Why is it necessary to increase the spatial coverage of the territory and introduce into consideration the characteristics of the state of the weather at the time of precipitation (air temperature, atmospheric pressure, wind speed, etc.).

Conflict of Interest

The author has no conflict of interest.

Data Availability Statement

Work is executed on materials of supervision to the state hydrometeorological service for the long-term period. The part of materials is published in Meteorological monthly journals and Materials of supervision [15,19,20]. They are accessible in the central libraries of the countries of the former USSR and Ukraine including. The part is accessible in the state archive of the hydrometeorological service of Ukraine (these are materials with 1995 for 2020 and supervision over rains with the quantity of precipitations less than 10 mm).

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