

CHARACTERISTICS OF SPATIOTEMPORAL DISTRIBUTION OF ATMOSPHERIC PRECIPITATION IN THE KURA-ARAS LOWLAND REGION

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Abstract

This study analyzes spatiotemporal variability patterns of atmospheric precipitation in the Kura intermountain lowland region, utilizing observational data from 15 hydrometeorological stations (1961–2023) and employing modern mathematical-statistical, physical, and cartographic methods to examine both extreme precipitation events (1961–2023) and contemporary distribution patterns (monthly, seasonal, annual, and spatial for 1991–2023).

In the Kura lowland region (1991–2023), mean annual precipitation averaged 285 mm, with 46% occurring in warm and 54% in cold seasons. Precipitation increases southeast-northwest during warm periods, reversing in cold seasons. Compared to the 1981–2010 climate norm, annual precipitation decreased by 9% (27 mm) during 2011–2023, with 70% of wettest years occurring before 1994. Maximum precipitation events declined by 23% in 2011–2020. Annual recurrence predominantly features 10–40 mm precipitation gradations (< 10, 11–20, 21–30, 31–40 mm). Continued climate trends threaten expanded ecological crises (drought, salinization) in this key agricultural zone. Findings inform land-use planning, mapping, economic assessments, and climate mitigation strategies.

Key words: global warming, atmospheric precipitation, GIS technology, recurrence threshold, difference integral, moving average quantity

Introduction. Climate change on Earth has already been recognized as an ecological crisis. The rapid intensification of its ‘warming’ characteristics over

the past 35 years has become an inevitable reality. Global warming is distinguished by its diverse manifestations across different regions of the Earth [1, 2]. The numerous impacts of climate change are predominantly observed in the mid-latitudes. One of these regions is the South Caucasus, where the Republic of Azerbaijan is located [3, 4]. In recent times, climate change in this region has been observed as an increase in temperature, evaporation rates [5], the recurrence of hazardous [6] and extreme hydrometeorological events, soil salinization, landslide-prone areas [7], and precipitation amounts [8], while a decrease has been noted in snow and glacier areas as well as in the Caspian Sea level [5].

Climate change also affects extreme hydrometeorological events. Analyses conducted in various countries have shown that warming is associated with large-scale significant changes in temperature extremes [9]. In over 70% of the sampled global land area, a significant decrease in the frequency of cold nights and a significant increase in the frequency of warm nights have been observed [10]. Changes in extreme precipitation have, in turn, demonstrated a large-scale and significant increase [11]. It is known that extreme precipitation events correspond to rainfall amounts that are rarely observed in the long-term distribution and fall at statistically high percentiles [12].

Research by TASHILOVA et al. [13] indicates that a warming trend predominates across all climate zones in the South Caucasus region. Since the onset of global warming (from 1976), this trend has further intensified. The long-term trend of precipitation in this region has not been unidirectional. The maximum warming in the region has occurred during the summer season, averaging 0.3 °C per decade.

ELIZBARASHVILI et al. [14] have shown that recently (1950–2022), temperature changes have been more pronounced in mountain and subalpine zones. Precipitation changes in the region vary significantly across landscapes: in humid plains, the maximum occurs in autumn-winter, whereas in arid and semi-arid zones, peaks are observed in spring or late autumn. Statistically significant trends include an increase in cold-season precipitation in humid regions and a decrease in spring precipitation in arid areas.

The scientific explanation of the spatiotemporal distribution of atmospheric precipitation across the country was first presented in the monograph by MADATZADE and SICHLINSKIJ [15]. However, in subsequent periods, the number of such studies has increased. Subsequent decades witnessed expanded research, with notable contributions from N. Sh. Huseynov, R. N. Mahmudov, R. A. Ismayilov, A. Kh. Hajiyeve [2], J. S. Huseynov [8], etc., examining regional precipitation characteristics including monthly, seasonal, and zonal distribution patterns, multi-year dynamics, and threshold-specific precipitation amounts [2, 4, 5, 16]. As the Kura intermountain lowland represents Azerbaijan's largest morphostructural plain, contemporary re-evaluation of its precipitation regime constitutes a vital research priority.

The purpose of this research is to determine the modern characteristics of the spatiotemporal distribution of atmospheric precipitation in the Kura depression region.

Materials and methods. Research is based on atmospheric precipitation observation data from 15 hydrometeorological stations (Jeyranchol, Mingachevir, Yevlakh, Barda, Tartar, Goychay, Zardab, Kurdamir, Beylagan, Imishli, Jafarkhan, Hajigabul, Bilasuvar, Neftchala, Salyan) operating in the Kura depression region under the National Hydrometeorological Service during 1961–2023. The initial data were obtained from periodic statistical publications of state agencies, online resources, and research materials of various scientists. The analyses were processed using monthly, seasonal, and annual total precipitation indices, as well as long-term average values of the same series. Using the identified general indices, the spatiotemporal dependencies of precipitation distribution were investigated. The obtained results were visualized using MS Excel’s graphical tools, histograms, and tables, and mapping capabilities of ArcGIS software. The study examines the general distribution patterns of precipitation during 1991–2023, a period of intensified climate change. To identify recent impacts of climate change, comparative analyses were made with the latest climate normals (1981–2010) defined by the WMO. Various parameters of the hydrometeorological stations are presented in Table 1.

The study used moving averages to more clearly identify long-term precipitation trends in the graphs. This approach smoothes out random fluctuations in

T a b l e 1
Main characteristics of hydrometeorological stations

Station	Elevation, m	Observation period	Climate norm: 1981–2010, Precipitation, mm
Jeyranchol	425	1966–2023	306
Tartar	160	1996–2023	332
Goychay	107	1961–2023	398
Mingachevir	93	1961–2023	349
Bilasuvar	75	1961–2023	323
Barda	69	1984–2023	287
Beylagan	62	1961–1976, 1984–2023	273
Yevlakh	13	1961–2023	297
Kurdamir	2	1961–2023	339
Imişli	–1	1962–1976, 1984–2023	277
Zardab	–5	1961–2022	290
Hajigabul	–7	1961–2023	234
Jafarkhan	–16	1961–2023	282
Salyan	–21	1965–2022	245
Neftchala	–23	1961–2023	277

the data, making it easier to determine the direction of trends during different periods [4].

The parameter is calculated as follows:

$$(1) \quad X_i = \frac{X_1 + X_2 + X_3 + \dots + X_{10}}{10}.$$

Here, X_i represents the 10-year moving average of the annual precipitation amount. $X_1, X_2, \dots$ denote the series values for the considered year and the following nine years. The moving average value in the given cell corresponds to the arithmetic mean of the 10 years including that year.

In the Kura depression region, Mann–Kendall and Sen’s slope analyses were performed on the annual precipitation series for hydrometeorological stations with complete time records covering the period 1961–2023. The Mann–Kendall analysis result ($S = -348$, $Z = -2.06$, $p = 0.0396$) indicates a decreasing trend (statistically significant at the 95% confidence level).

That is, a statistically significant decline in precipitation is observed over the 1961–2023 period. According to the calculations, the Sen’s slope magnitude for this time series is -1.0 mm/year , meaning that the annual precipitation in the Kura depression region has decreased on average by 1 mm per year during 1961–2023.

In many studies, extreme precipitation events are defined as rainfall amounts exceeding 50 mm within 24 h or falling above the 90th percentile [1].

Discussion. The Kura depression’s physiographic position creates distinct spatiotemporal patterns in atmospheric precipitation distribution. These orographic features significantly influence regional precipitation gradients through rain shadow effects and elevation-dependent mechanisms [10].

The southeastern coastal region encompassing the Salyan plain and southeastern Shirvan lowland demonstrates unexpectedly low precipitation quantities despite the Caspian Sea’s abundant moisture reserves. Persistent high evaporation rates throughout the year generate localized atmospheric circulation that transports moisture toward prominent orographic features [17, 18].

Analysis of long-term data indicates that, in the Kura depression region, the average annual precipitation between 1991 and 2023 was approximately 285 mm. Of the region’s long-term precipitation totals, 46% falls during the warm half of the year, while 54% occurs during the cold half [4]. The highest annual precipitation 367 mm is recorded in the northeastern part of the Kura-Araz lowland, specifically in the plains bordering the foothills near the sea (e.g., Goychay). Other areas with relatively high precipitation levels include the plains located closer to the foothills of the Greater and Lesser Caucasus Mountains (such as Tartar, Mingachevir, and Kurdamir). In these zones, warm and humid air masses that pass over the plains move toward the mountainous areas, where they predominantly release heavy precipitation in the middle mountain belt.

The regions located in the central strip of the area, extending from the northwest to the southeast, receive relatively less precipitation. These districts encompass the plains of the region, particularly the Kura-Aras lowland. The distribution of precipitation throughout the various seasons of the year changes progressively from the coastal districts toward the west. In other words, during the warm season, precipitation increases from the southeast to the northwest, while in the cold season, the opposite trend is observed, with precipitation amounts rising from the northwest to the southeast [19].

As one approaches the fore-mountain boundary of the southern slope of the Greater Caucasus Mountains (Goychay), the seasonal distribution of precipitation becomes almost equal. In the Kura depression region, higher precipitation is observed during the spring and autumn seasons, while lower amounts occur in summer and winter.

In this study, the contemporary spatial distribution of precipitation across the surface of the Kura depression region was also determined using GIS technology (Fig. 1). The map uses the WGS 1984 UTM Zone 39N coordinate system.

The map was created by colour-coding the long-term precipitation values of stations positioned by elevation in a DEM file. In areas without hydrometeorological station data, interpolation methods were used. For the IDW method, the

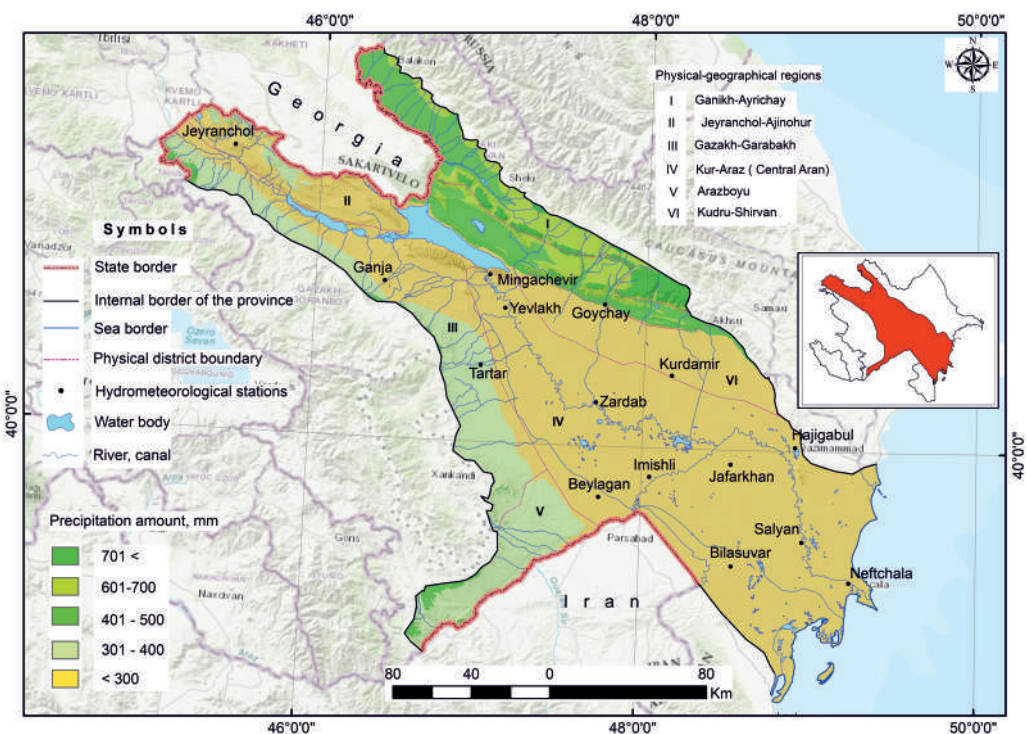


Fig. 1. Average annual precipitation indicators (1991–2023)

following formulas were applied:

$$(2) \quad \hat{P}(x_0) = \sum_{i=0}^n w_i(x_0) P_i, \quad w_i(x_0) = \frac{d(x_0, x_i)^{-p}}{\sum_{k=1}^n d(x_0, x_k)^{-p}}.$$

Here, P_i is the precipitation at the i -th station, $d(x_0, x_i)$ is the distance between x_i and x_0 , p is the power parameter (usually $p = 2$), and $\sum_i w_i = 1$ [20].

There is a significant variability in precipitation distribution within the region. The northern parts of the region, specifically the fore-mountain areas bordering the southern slopes of the Greater Caucasus, experience higher long-term precipitation totals compared to other parts of the region. However, these areas receive less precipitation than the southern fore-mountain zone of the Greater Caucasus. The precipitation values presented on the map were determined based on general gradations derived from the analysis of elevation belts and data from hydrometeorological stations.

The trend of changes in precipitation levels in the region between 2011 and 2023 compared to the climatic norm (1981–2010) is also of particular interest (Fig. 1). Specifically, in the Kura depression natural region, the average monthly precipitation increased by 21% in January and 10% in February compared to the norm. The precipitation amounts relative to the norm reached: 11% in March, 37% in April, 3% in May, 20% in June, 11% in July, 40% in August, 12% in September. In the region, precipitation increased by 2% in October but decreased by 17% in November. By December, precipitation rose again by 14% across the region. The average long-term (2011–2023) precipitation indicators show a 9% (22 mm) decrease compared to the climatic norm (1981–2010) for the region. However, statistical evaluations ($t = -1.33$, $p = 0.195$) indicate that the decrease in precipitation (9%) in the region is not statistically significant ($p > 0.05$).

Although the trend line indicates changes over the entire period, the moving average provides a more accurate reflection of dynamics in individual periods. Focusing on the moving average, we can observe a gradual decrease in precipitation across the province from 1971 to 1979, followed by an increase in 1980 and 1981. From 1982 to 2002, there was a slight decline again, whereas the period from 2003 to 2012 saw a modest increase. Since 2013, despite occasional positive fluctuations, precipitation has generally decreased toward the end of the period (Fig. 2). The highest precipitation occurred in 2003 or earlier.

The difference in trends at these stations is related to their physical-geographical location, as the area is more influenced by southern cyclones, resulting in a positive precipitation trend.

The percentage distribution of the most frequently occurring precipitation thresholds over the long-term period for the entire region is presented in Fig. 3. During the calculations, if the amount of precipitation in the analyzed months meets the given condition, it is assigned a value of ‘1’; otherwise, it is assigned ‘0’.

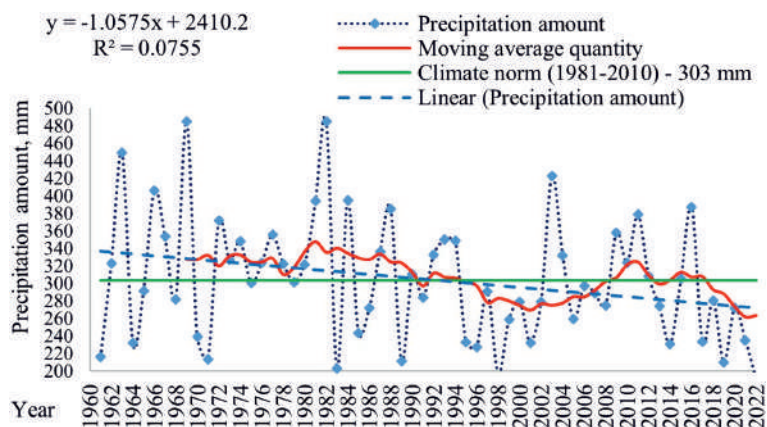


Fig. 2. Long-term dynamics of precipitation amounts in the Kura depression region

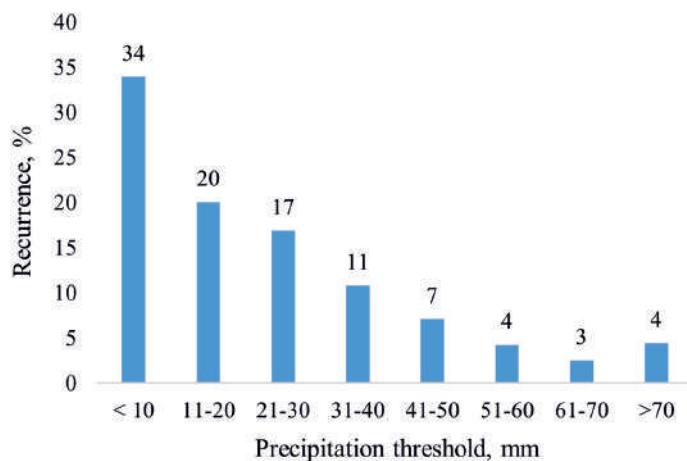


Fig. 3. Monthly recurrence of different precipitation thresholds (%) in the Kura-Aras lowland

Based on this, the selection for the respective month is made. In the subsequent stage, the total number of such events is determined, and finally, the percentage ratio of the events is calculated.

An examination of the graph shows that the monthly precipitation amounts, based on predefined thresholds, vary for the Kura depression region. Specifically, across the entire territory of the region, monthly precipitation most frequently falls below 10 mm (34%), within 11–20 mm (20%), and within 21–30 mm (17%). The least frequent monthly precipitation amounts observed in the region during the year are within 61–70 mm. Higher precipitation totals exceeding 70 mm, which are considered to cause hazardous natural events, account for only 4% of the overall occurrence. The analysis indicates that the intensity of precipitation in the Kura-Aras lowland is very low and covers a short time span. This is associated with the weak development of strong convective processes and cumulonimbus clouds

in the lowland, where precipitation mainly originates from stratiform clouds. In other words, heavy downpours have low intensity (4%).

The analysis reveals that the intensity of precipitation over the Kura-Araz lowland is generally low and confined to short time periods. As a result, heavy downpours (intense rain events) have a relatively low frequency, accounting for only 4% of total precipitation events.

If climate change continues with this trend in the Kura depression region, the decrease in precipitation and humidity in this major agricultural area of the republic will lead to significant ecological crises such as drought and salinization, expanding their spatial extent [2].

Conclusion. Based on the preliminary analysis of atmospheric precipitation data in the Kura intermountain depression region from 1961 to 2023, the following conclusions were drawn:

1. The annual precipitation amount increases from the southeast to the northwest of the region during the warm half-year, while the opposite trend is observed in the cold half-year.
2. The annual precipitation amount in the region decreased by 9% (27 mm) in 2011–2023 compared to the climate norm of 1981–2010.
3. The most frequent annual precipitation amounts fall within the gradations of less than 10 mm, 11–20 mm, 21–30 mm, and 31–40 mm.

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