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Research Article

The Frequency of Droughts in the Rasht Valley (Tajikistan) Under Climate Change

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Abstract

The geographical location of Central Asia, including the Republic of Tajikistan, makes the region highly vulnerable to various climate-related natural disasters, such as floods, droughts and mudslides, which significantly affect sustainable development and people's living conditions, including their access to adequate food and drinking water. Droughts, especially in their extreme forms, accelerate the development of desertification, the main cause of which is excessive anthropogenic pressure, which increases under conditions of prolonged and intense drought. In this context, the issue of developing and improving modern systems for monitoring and forecasting droughts, as well as preparing for and mitigating their consequences, becomes extremely important. The problems of droughts occurrence in two districts of Tajikistan (Rasht, Lakhsh) with developed agricultural industry depending on meteorological conditions with wide application of standardized drought indices are considered. It was found that the occurrence of drought in a specific area does not have certain regularity, but is determined by a combination of meteorological parameters. The dynamics of the Standardised precipitation index and the Standardised precipitation and evapotranspiration index in Rasht district for the period 1950-2023 is characterised by a constant trend. The results of studies of meteorological conditions of Lakhsh district for the period 1961- 2021 to identify the possibility of drought occurrence are presented. The trend of the drought indices shows an increase in humidity over the period 1961-2021. Despite the positive trend in humidity over the period considered, extreme and severe droughts of varying duration have been observed.

Keywords

Drought, Rasht, Lakhsh, Precipitation, Temperature, SPI, SPEI

1. Introduction

Drought, as one of the manifestations of emergencies, is a serious problem for Central Asia. According to experts, more than 70 per cent of the region's territory is considered vulnerable to natural disasters. Droughts are less frequent than floods, but they affect more people. Over the past decade, droughts have affected 60 per cent of the population exposed

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to extreme weather events. Droughts are expected to become more frequent in Tajikistan, Turkmenistan and Uzbekistan due to projected higher temperatures and longer periods of extreme heat and evaporation in areas with less rainfall. Over the past ten years, more than 2,500 people have died as a result of natural disasters and some 5.5 million people, or 10 per cent of Central Asia's population, have been affected by the adverse effects of nature. The coming decade will be characterised by cycles of natural disasters, alternating years of drought and floods, as was the case in 2000-2001 and 2002-2003 [1].

Over the past two decades, Tajikistan has experienced a significant increase in the number of disasters caused by natural hazards. The National Disaster Risk Reduction Strategy of the Republic of Tajikistan for 2019-2030 (approved by Resolution of the Government of the Republic of Tajikistan No. 602 of 29 December 2018) notes that the total damage from disasters caused by natural hazards that occurred between 1997 and 2018 exceeded USD 589 million. The largest financial losses (in all economic sectors combined) were caused by mudslides, averaging about USD 15 million per year. Droughts are the second largest source of financial losses (USD 5.4 million) [2].

Data to analyze future climate change in Tajikistan are limited, but the current warming trend will continue. Temperatures in the Pamir and Hindu Kush mountains may rise faster than in the plains and arid areas. According to the climate model, the average annual temperature across the country will increase by 0.2-0.4℃ by 2030 compared to the 1960-1990 period. The largest temperature increase is projected to occur in winter, reaching 2℃. By the end of the century, the southern regions of Tajikistan, as well as the mountains of central Tajikistan and western Pamir, are expected to experience the largest temperature increase of about 5℃ compared to the 1961-1990 baseline period. Information on the influence of the mountainous regions of Tajikistan on climate is difficult to incorporate into a general climate model. As a result, there is no consensus among projections, which show different trends for future precipitation. However, precipitation instability and increased intensity are expected to continue. In addition, summer and winter will become wetter and spring and autumn drier [3].

Data for the period 1940-2012 show that temperatures have increased in most parts of the country, including lowland (up to 1000 m above sea level), mountain (1000-2500 m a. s. l) and highland (above 2500 m a. s. l) regions, but the degree of warming varies according to geographical location and climatic factors. In the plains of Tajikistan, the average annual temperature has increased by 0.1-0.2℃ per decade, with the largest increase being 0.5-0.8℃ [4].

The current stage of climatic changes, characterised by the manifestation and intensification of extreme natural phenomena and significant changes in the components of the ecosystem, requires the organization of systematic monitoring of meteorological conditions in the regions that dominate the supply of agricultural products to Tajikistan, and the adoption of urgent measures to adapt the industry to climatic cataclysms.

The organization of activities on systematic monitoring of meteorological conditions of the geographical latitudes of the country allows to accumulate long-term rich material and to create a database, which allows to develop scientifically based scenarios and models for prediction of drought occurrence.

The purpose of the present work is to assess the factors of drought occurrence on the basis of systematization and processing of meteorological data of the Rasht valley of Tajikistan and to reveal the regularities of drought interrelations with climatic factors of the area.

The results of this study can serve as a basis for expanding the monitoring of drought occurrence throughout the country and can be adapted for use throughout the Central Asian region.

2. Materials and Methods

The districts of Rasht (39°05' N 70°30' E) and Lakhsh (39°15' N 71°30' E) in the Rasht valley were studied. Meteorological data from the meteorological stations “Rasht” (39°05′00″N, 70°30′00″E) and “Lakhsh” (39°17′58.2″N, 71°31′32.52″E), kindly provided by the Hydrometeorological Agency of the Republic of Tajikistan, were used. Data processing was carried out using standard statistical methods with extensive use of “Statistika” and Excel programmers. Pearson's and Student's correlation methods were used to assess the reliability of the processing results and the correlation dependencies of the data.

To determine the dynamics of the average annual change in temperature and precipitation, the monthly averages of each year of the study period were used and then the annual averages were calculated using Excel programmers. The graph of the dynamics of the meteorological parameters for the period under consideration was made using the Excel graphing program.

The Rasht district is located in the upper central part of Tajikistan and is part of its republican subordination region. The wide slopes of the Rasht Valley provide favourable conditions for agricultural activity and livestock farming. Thus, 66 per cent of the total land area is arable, of which 21 per cent is arable and 45 per cent is pasture. The main crops grown in the Rasht district are potatoes, vegetables, fruits, cereals, legumes and wheat [5].

The altitude in the Rasht district ranges from 1000 to 7600 m a.s.l. The majority of the population lives in mountainous areas between 1000 and 2800 m a.s.l. The climate of the Rasht valley depends on its altitude. The altitude creates a valley rich in biodiversity with several agro-ecological zones. Since the beginning of the 20th Century, there has been a steady increase in average temperature of 0.07℃ and a change in precipitation trends. Winter precipitation is steadily increasing, while average spring precipitation has remained stable.

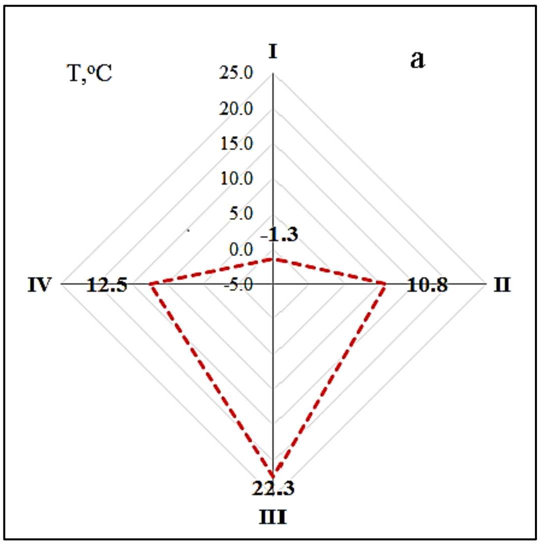
While total spring rainfall has remained constant over the last 100 years, there has been an increase in the amount of heavy rainfall. These heavy rains cause land degradation by destroying topsoil and important nutrient elements, and consequently damage the development of fruit crops during the flowering period. These climatic changes have a strong negative impact on the yield and quality of local crops. The combination of heavy rainfall, late frosts and strong winds has led to more frequent mudslides and floods [6].

The Lakhsh district is the extreme north-eastern edge of the ancient historical province of Karategin, covering both the western and eastern geographical areas of the region. It is a high mountainous area located in the foothills of the Alai and Peter the Great Mountain ranges. The mountain valleys with settlements and farms are located at altitudes of up to 2000 m a. s. l. The district covers an area of 4.58 km^2.

The climate of the district is characterised by aridity and uneven temperatures. The average temperature in January in the plains can range from 0 to -20 ^{o}C, while in the mountains it can drop to -50 ^{o}C. In summer, the average temperature in July is +23 to +28 degrees in the plain part and -12 to +5 degrees in the mountain part of the district. Rainfall is also uneven, depending on the altitude of the terrain and the direction of the slopes. The average annual norm varies from 120 mm to 1500 mm on the eastern slopes of the mountains.

3. Results and Discussion

Seasonal distribution of mean annual temperature and precipitation in Rasht district is shown in Figure 1 values of temperature and precipitation in Rasht district are observed in summer and spring, respectively, with the peculiarity that, unlike other geographical latitudes, the temperature is kept within moderate limits with abundant precipitation in spring. The observed climatic conditions are considered favorable for the cultivation of a wide range of agricultural products.



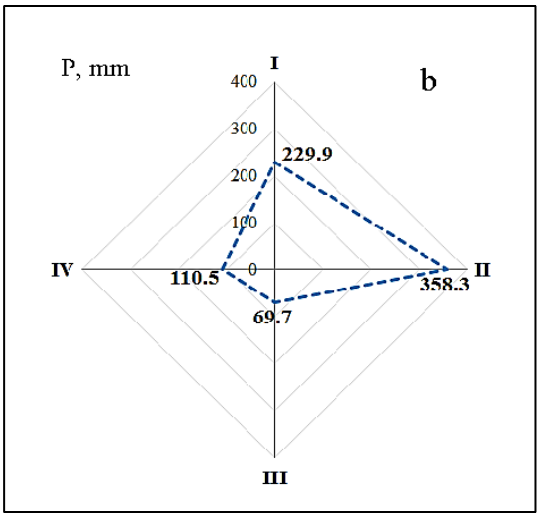


Figure 1. *Seasonal distribution of (a) temperature and (b) precipitation in Rasht district.*

The change in temperature and precipitation for a period of more than 50 years in the Rasht district, as can be seen in Figure 2, is characterised by an almost constant trend, which is probably related to the location of the valley, surrounded by high mountain areas of the Karategin, Zeravshan and Alai ridges that belong to the Alai mountain system, and to the south on the left bank - the Peter the First ridge that is part of the Pamir-Darvaz mountain system.

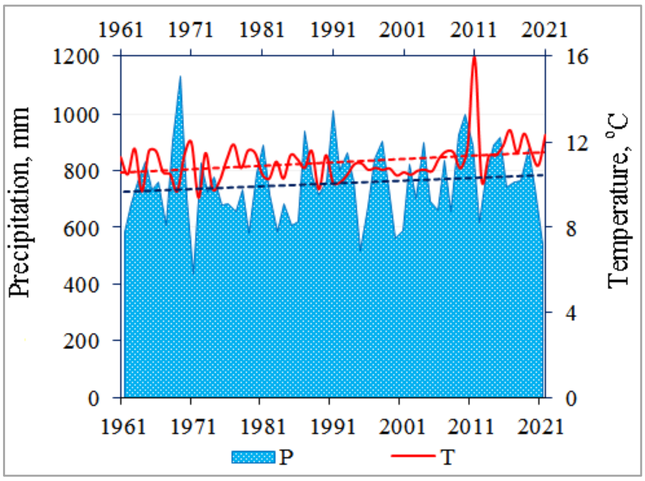


Figure 2. *Dynamics of temperature and precipitation in Rasht district for the period 1961- 2021.*

Figure 3 shows the results of SPI and SPEI calculations for the Rasht district based on meteorological data from the Rasht meteorological station, which show an almost constant value of the trend of the indices for the period 1950-2023. From Figure 3 it can be concluded that the dynamics of the Standardised precipitation index and the Standardized precipitation and evapotranspiration index in Rasht district for the period 1950 - 2023 is characterised by a constant trend. In other words, it can be assumed that with the observed trend of meteorological conditions for the period 1950-2020, the probability of drought in Rasht district is negligible.

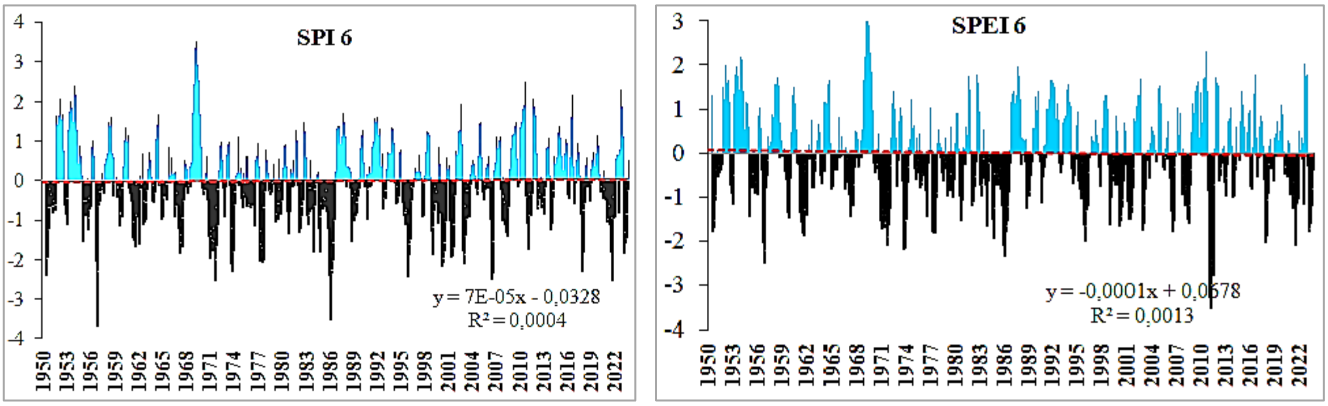


Figure 3. *Dynamics of SPI6 and SPEI 6 for Rasht district for the period 1950 – 2023.*

The duration of droughts in each of the decades of the considered period in the Rasht region, shown in Figure 4, shows that the occurrence of droughts in a certain selected geographical area does not have a certain regularity, but is determined by a certain combination of meteorological parameters of this area, the most important of which is the amount of precipitation and temperature.

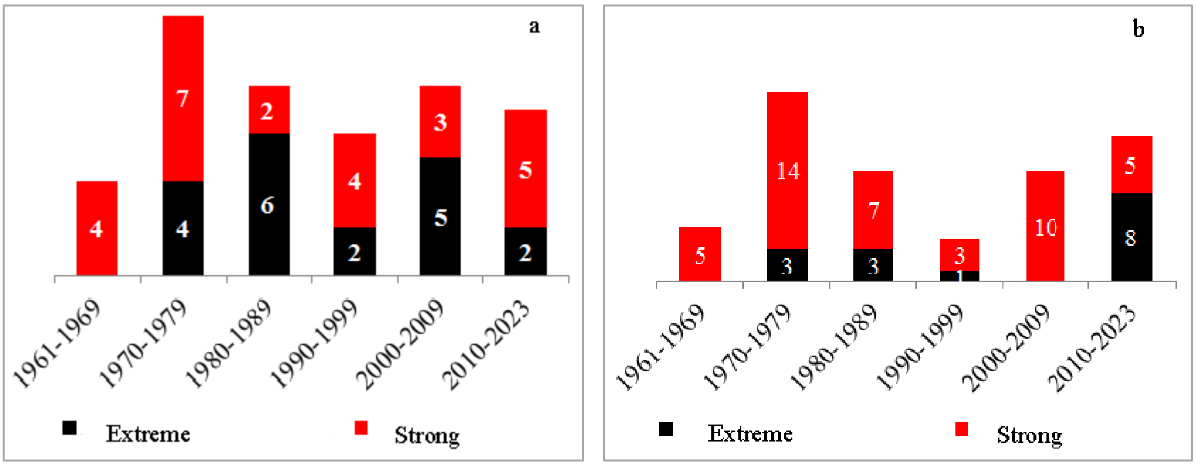


Figure 4. *Duration of extreme and severe droughts in months in each decade of the period 1950-2023 in Rasht district.*

The comparison of SPEI with SPI is important to identify the role of potential evapotranspiration (PET) in the occurrence of a significant difference between the indices.

As the difference between SPEI and SPI is normally distributed, the standard deviation Δ (SPEI-SPI) is used to quantify the variability of SPEI and SPI index values. When plotted over time, the standard deviation shows that the models are again clustered according to their radiation term, with the differences between SPEI and SPI remaining constant over the year [7].

The inclusion of potential evapotranspiration (PET) leads to a noticeable difference in the index values, confirming that SPEI is a significantly different drought index from SPI. The largest differences between SPEI and SPI are observed in summer, when PET accounts for most of the climatic water balance. SPEI is most sensitive to the radiation term of PET, and therefore SPEI is recommended as an alternative to SPI for quantifying anomalies in the accumulated climatic water balance that includes potential evapotranspiration.

Figure 5 shows the difference between the Standardised Precipitation and Evapotranspiration Index (SPEI) and the Standardised Precipitation Index (SPI).

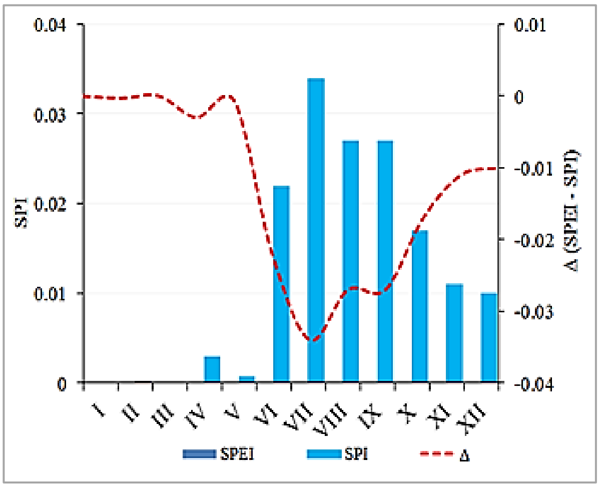


Figure 5. Long-term monthly of SPI, SPEI and their differences in Rasht district.

Figure 5 shows that the difference between SPEI and SPI is minimal in the winter and spring periods, and maximum in the summer period. SPEI is an important and useful tool for comparing meteorological droughts, as it takes into account the temperature regime as a factor leading to evapotranspiration in addition to precipitation. The inclusion of PET makes a noticeable difference in the index values, confirming that SPEI is a significantly different drought index to SPI. The largest differences between SPEI and SPI are observed in summer, when PET accounts for most of the climatic water balance.

In order to establish the relationship between the standardized drought indices and the meteorological conditions of Rasht district, the long-term monthly averages of precipitation and temperature were compared with the climatic norms of the area shown in Figure 6a, 6b.

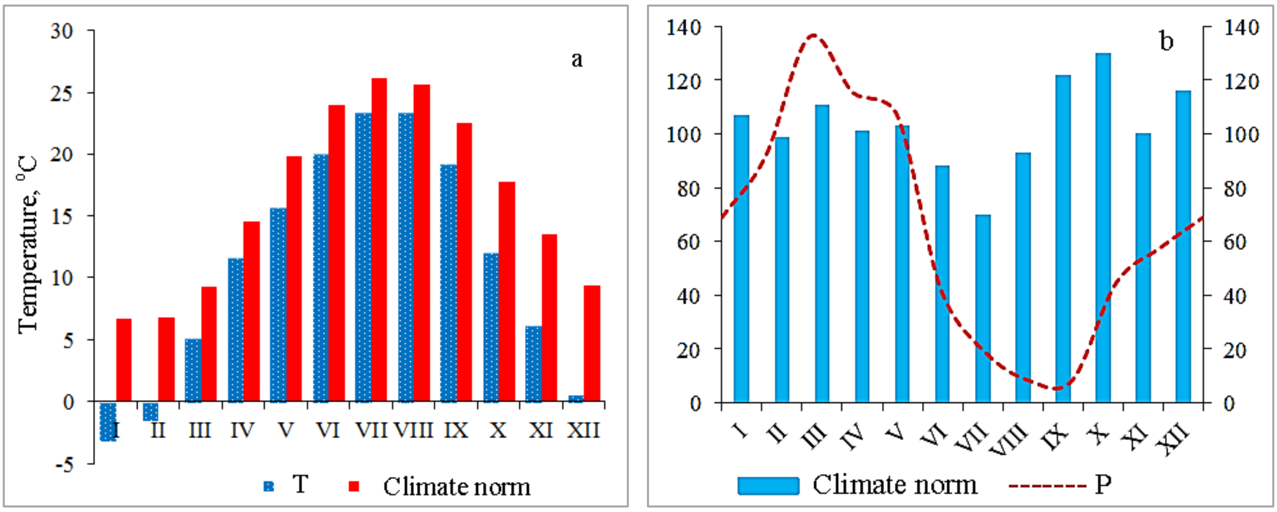


Figure 6. Long-term monthly of temperature (a) and precipitation (b) in Rasht district to relation to climatic norms of temperature and precipitation.

As can be seen from Figure 6a, the average monthly temperature of the southern Tajik lowlands is significantly above the average monthly climatic norms in all seasons. This is naturally reflected in the values of the drought indices and negative values of SPI and SPEI dominate almost throughout the year. A similar picture is observed in the dynamics of changes in the monthly mean values of atmospheric precipitation (Figure 6b).

It should be noted that the effects of climate change on drought behavior are not only explained by the increase in global temperature, but also by changes in precipitation trends. The variance of precipitation may increase without significantly changing the overall magnitude [2, 4], thereby increasing the frequency of intense wet periods with a skewed distribution [8, 9].

This precipitation behavior leads to prolonged intra-month droughts, catalyzing drought impacts on agriculture and social dynamics that may not be captured by traditional indices such as the Standardised Precipitation Evaporation Index (SPEI). As a result, wet month droughts are mischaracterized [10]. This mischaracterization of drought can have implications for drought preparedness, particularly in regions where agriculture is dependent on seasonal rainfall. For example, despite monsoon flooding in South Asia, the agricultural sector suffers from drought due to the highly uneven distribution of extremely wet periods [11].

Change in temperature and precipitation in Lakhsh district for the period 1961-2021 is characterised by a weak trend of increasing associated, as well as in Rasht district by its location surrounded by high mountain ranges of Karategin, Zeravshan and Alai mountain systems (Figure 7).

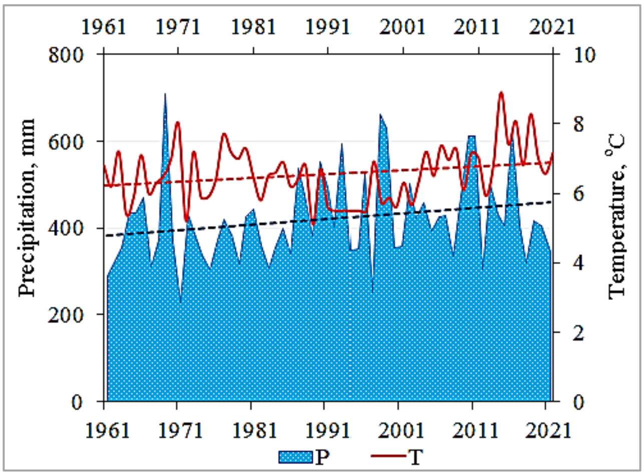


Figure 7. *Temperature and precipitation dynamics in Lakhsh district for the period 1961- 2021.*

The season with maximum precipitation in Lakhsh district covers the months from April to June and the minimum from October to December. The geographical location and orography of the district favours precipitation in the summer season (Figure 8a, 8b).

Figure 8 shows that the maximum average annual temperature in Lakhsh district corresponds to the summer season, although it is not high and is not typical for most areas of the Republic of Tajikistan.

The climatic conditions of Lakhsh district shown in Figure 8 are favorable for the production of many agricultural products.

In a number of recently published works, based on the results of greenhouse gas (GHG) emission scenarios, the average annual temperature in the Rasht Valley is prognoses to increase by 1.1 ℃ to 6.1 ℃ by 2080. Under the high emissions scenario of RTC8.5, the average temperature increase obtained using several models is estimated to be about 1.7 ℃ in 2030, 2.9 ℃ in 2050 and 5.3 ℃ in 2080 [8].

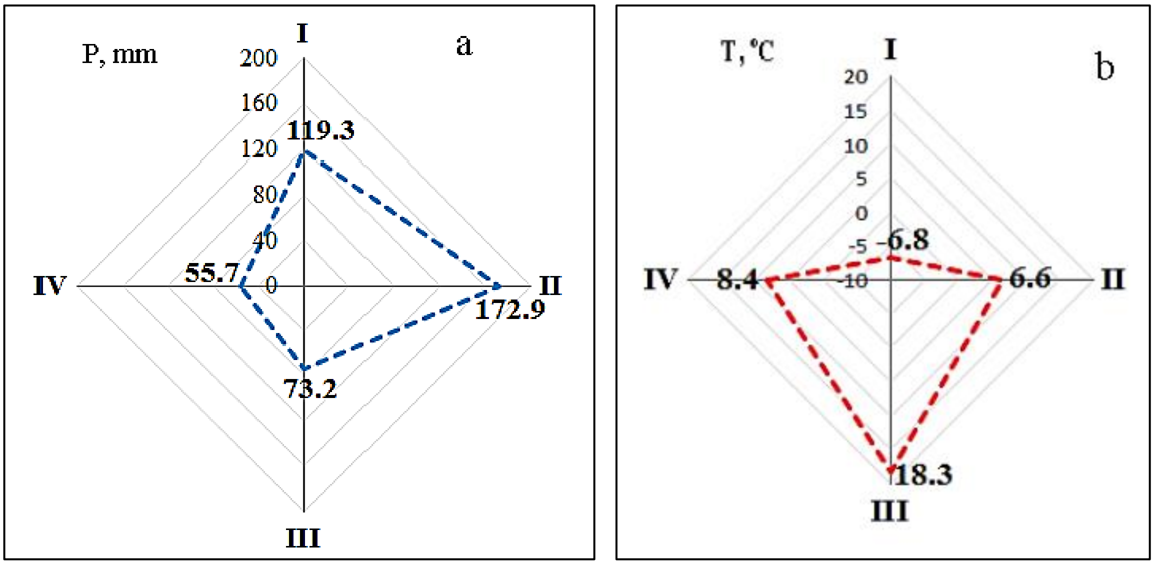


Figure 8. *Seasonal distribution of (a) precipitation and (b) temperature in Lakhsh district.*

Given current prognoses, monitoring drought is an important and necessary step in developing mechanisms for drought mitigation and adaptation.

A whole class of indices has been developed to determine the magnitude of drought events [9, 10]. Among them, the Standardised Precipitation Index (SPI) and the Standardised Precipitation and Evapotranspiration Index (SPEI) are widely used. The SPEI is a multi-scale index that is more appropriate and expressive than other indices in characterizing drought, climate variability and global warming [11-13].

The Figure 9 shows the results of SPI and SPEI calculations of Lakhsh district based on the meteorological data of Lakhsh meteorological station. Also Figure 9 shows that the dynamics of the Standardised Precipitation Index and the Standardised Precipitation and Evapotranspiration Index in Lakhsh district for the period 1961-2021 is characterised by an increasing trend. In other words, it can be assumed that with the observed trend of meteorological conditions for the period 1961-2021, the probability of drought in Lakhsh district is low.

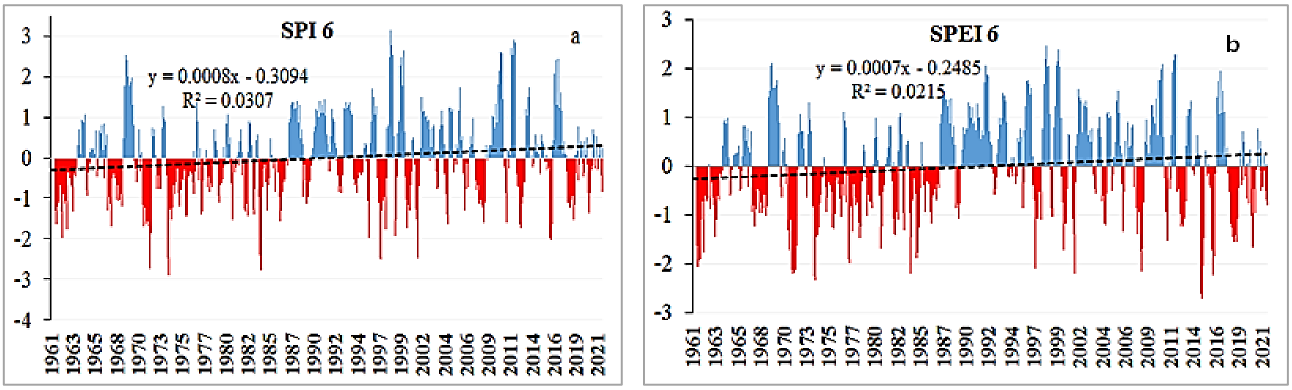


Figure 9. Dynamics of SPI6 and SPEI 6 in Lakhsh district for the period 1961-2021.

However, it should be noted that regardless of the moisture sufficiency and the increasing trend of precipitation, extreme and severe droughts have been observed in Lakhsh district (Figure 10).

The Figure 10 presents data on the number of extreme and severe droughts in Lakhsh district for each 10-year of the period 1961-2021.

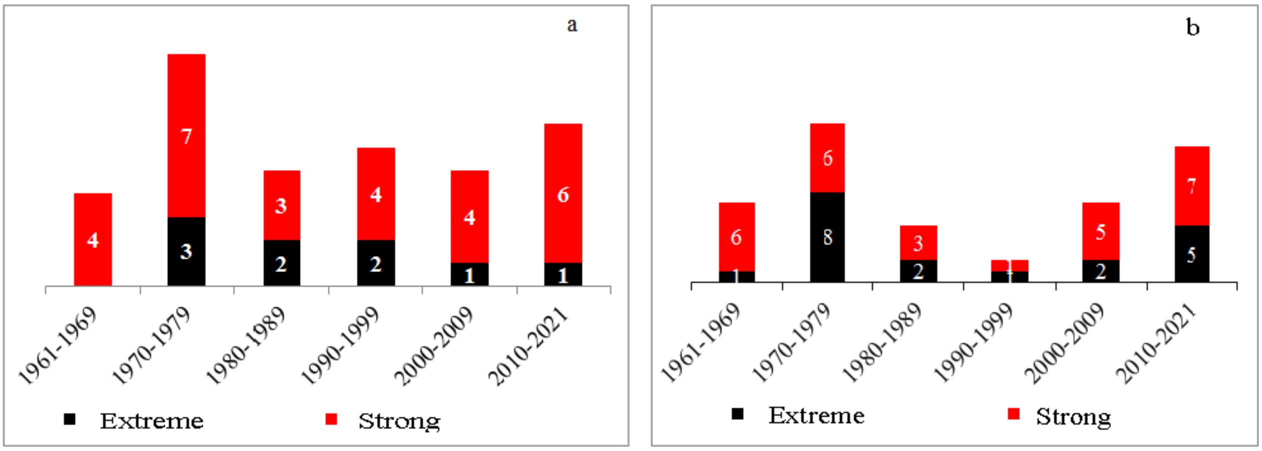


Figure 10. Number of extreme and severe droughts in each decade of the period 1961-2021 in Lakhsh district according to SPI6 (a) and SPEI 6 (b).

4. Conclusion

Thus, as a result of studying the seasonal distribution of mean annual temperature and precipitation in Rasht district, it was found that their maximum values are observed in summer and spring, respectively, and unlike other geographical latitudes, the temperature is kept within moderate values with abundant precipitation in spring. It was found that the occurrence of drought in a specific area does not have certain regularity, but is determined by a combination of meteorological parameters. The dynamics of the Standardised precipitation index and the Standardised precipitation and evapotranspiration index in Rasht district for the period 1950-2023 is characterised by a constant trend. The results of studies of meteorological conditions of Lakhsh district for the period 1961-2021 to identify the possibility of drought occurrence are presented. Climatic data of the meteorological station "Lakhsh" were used. It was found that the trend of temperature and precipitation for the considered period is characterised by a slight increase. The seasonal distribution of precipitation Lakhsh district shows that the maximum of precipitation in Lakhsh district falls mainly from April to June. In turn, the hottest period in Lakhsh district is the summer months. The maximum temperature in most cases does not exceed 20 ℃. It is assumed that the altitude of the district in relation to the sea level and the location of the district surrounded by ridges of mountain systems create a favorable climatic condition, due to which Lakhsh district dominates in the production of agricultural products. The trend of the drought indices shows an increase in humidity over the period 1961-2021. Despite the positive trend in humidity over the period considered, extreme and severe droughts of varying duration have been observed.

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Abbreviations

GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
a.s.l.	Above Sea Level
SPI	Standardized Precipitation Index
SPEI	Standardized Precipitation and Evatranspiration Index
PET	Potential Evapotranspiration

Author Contributions

Inom Normatov: Conceptualization, Formal Analysis, Methodology, Supervision, Writing – original draft, Writing – review & editing

Abulkosim Muminov: Data curation, Investigation, Methodology, Software, Visualization

Alisher Rahimzoda: Data curation, Formal Analysis, Methodology, Software, Validation, Visualization

Gurdofarid Saburova: Conceptualization, Formal Analysis, Investigation, Methodology, Resources, Writing – review & editing

Abdusamad Hojiev: Data curation, Formal Analysis, Investigation, Software, Validation, Visualization

Conflicts of Interest

The authors declare no conflicts of interest.

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Biography

Inom Normatov is a Corresponding Member of the National Academy of Sciences of Tajikistan, Professor, Head of the Department of Meteorology and Climatology at the Tajik National University. He defended his doctoral thesis in 1993. From 2002 to 2009 he was the Director of the Institute of Water Problems, Hydropower and Ecology of the National Academy of Sciences of Tajikistan.

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Alisher Rahimzoda is a leading researcher at the Institute of Mathematics of the National Academy of Sciences of Tajikistan, doctor of physical- mathematical science. He defended his Ph.D. thesis at the Institute of Mathematics of the National Academy of Sciences of Tajikistan in 2017.

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Abdusamad Hojiev is a PhD student at the Department of Meteorology and Climatology, Tajik National University. He is conducting research on the topic of his thesis: "Monitoring the occurrence of drought on the territory of Tajikistan depending on meteorological conditions". Author of three publications.

Research Field

Inom Normatov: Meteorology, Climatology, Agrometeorology, Hydrochemistry, Glaciology

Abulkosim Muminov: Drought, Emergency, Agrometeorology, Climatology

Alisher Rahimzoda: Mathematical Modeling, Correlation, Hydrology, Meteorology, Hydrological Prognosis

Gurdofarid Saburova: Meteorology, Climatology, Ecology, Hydroecology, Hydrobiology

Abdusamad Hojiev: Drought, Agrometeorology, Meteorology