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A. Massakbayeva[1,2,3], J. Abuduwaili[1,2,3], G. T. Issanova[4,5,6], S. Bissenbayeva[1,2,3], B. Issina[1,2,3]

[1]State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography,
Chinese Academy of Sciences, Urumqi, China,
[2]Chinese Academy of Sciences Research Center for Ecology and Environment of Central Asia, Urumqi, China,
[3]University of Chinese Academy of Sciences, Beijing, China
[4]Al-Farabi Kazakh National University, Faculty of Geography and Environmental Sciences, Almaty, Kazakhstan,
[5]Research Centre for Ecology and Environment of Central Asia (Almaty), Kazakhstan,
[6]Abai Kazakh National Pedagogical University, Institute of Natural Sciences and Geography, Almaty, Kazakhstan.
E-mail: asia_94_10@list.ru, jilil@ms.xjb.ac.cn, gul_nur.777@mal.ru, isina1994@list.ru

TEMPERATURE AND PRECIPITATION TREND IN THE ARAL SEA AND ARAL SEA REGION DURING 1960-2016

Abstract. Climate change in the Aral Sea and Pre-Aral region is a complex combination of global, regional, and local processes of varying spatial and temporal scales. Investigating data on temperature and precipitation in the Aral Sea and Pre-Aral region during 1960-2016, we analyzed trends using the Mann-Kendall criterion (MK). Our results showed that the maximum temperature rises by ($P < 0.001$) and at a speed of 1.5 ° C/decade, and the minimum temperature also rises with each decade at a speed of 6.2 °C. The Mann-Kendall static test showed that the trend of average temperatures increases by ($P < 0.001$) and at a speed of 3.2 °C/decade. Annual precipitation showed a significant upward trend ($P < 0.001$) at a rate of 0.8 mm/decade. The correlation between air temperature and precipitation was $R = 0.265$. It is assumed that the results of this study will contribute to a deeper understanding of climate change in the Aral Sea and Pre-Aral region.

Keywords: Climate Change**,** Aral Sea, Pre-Aral region, Mann-Kendal Test.

Introduction. Climate change is a long-term problem that is likely to cause extreme temperatures, floods, droughts, intense tropical cyclones and rising sea levels.

Climate change has become the greatest danger of the 21st century. Climate change manifests itself in the form of irregularities and disturbances in the climate cycle as a result of an increase in the temperature of the Earth due to global warming. Under global warming, climate change has a significant impact on the environment, water resources, industrial production, agricultural activities, and people's lives, but it is especially intense in dry regions. Although scientific observations and studies indicate a worldwide increase in average air temperature[1-2], meteorological observations confirm that between two 30-year control periods of 1942-1972 and 1973-2003, surface temperatures in Central Asia increased by 0, 65 °C.

The serious effects of climate change have already begun to manifest, and the latest example of this is that 2016 has overtaken 2015; It was the warmest year in history. According to the analysis of the World Meteorological Organization (WMO) of the United Nations Climate Agency, the average global temperature in 2016 was 1.1 degrees Celsius above the previous period.

The impact of climate change on water resources is particularly noticeable in Central Asia. In this region, the Aral Sea has historically played an important role in mitigating the cold northerly winds in the fall and winter, reducing the air temperature in the summer. Since the drying up of the Aral Sea, the summer was dry and hot, and in the winter it was cold and long.

In the northern desert part of Central Asia, within Uzbekistan and Kazakhstan, the Aral Sea is located, which until 1960 covered an area of 68 ths.km^2 with a volume of 1000 km^3 of water [3-5]. In these dimensions, the Aral Sea ranked second in the world among the inland mainless lakes after the Caspian Sea [6].

Since the early 1960s, increasing anthropogenic impacts, i.e. The intensive development of irrigation construction has contributed, ultimately, to the emergence of the Aral Sea problem [7].

The subsequent intensive process of reducing the horizon of the sea began, which entailed a change in the hydrological, hydrochemical and hydrobiological regimes of both the Aral Sea itself and the change of the situation in its adjacent territory, in the lower reaches of the Amudarya and Syrdarya rivers. Due to the reduction in river flow inflow by the end of this period (1987), the sea level dropped to 40.19 m abs. BS. Due to the structure of its basin, the Aral began to disintegrate into separate residual reservoirs. The process of separation of the Big Sea from the Small in 1988 began, due to high water flow, the bridge between the Big and Small Aral disappeared, and in subsequent years a dried sea bottom appeared again between them [8, 9].

Despite the presence of observational, meteorological stations on the territory of the Aral Sea region, it is not possible to demonstrate the exact limits of the influence of the sea on the surrounding territory. According to many authors, the general picture of the zone of influence of the sea, both in the multiyear period and during its distribution within the year, was based not on the studied and actual experimental data, but on abstract intuitive reasoning. There is no consensus about the zone of distribution of the moisturizing effect of the sea and its influence on climate change over a period of many years [10].

According to the United Nations Environment Program (UNEP), in recent decades there has been an increase in surface air temperature of about 0.6 °C, in mountainous regions - by 1.6 °C. For natural reasons, the melting of glaciers in Central Asia is pollution. dust (per year on the glaciers accumulates up to 20 g/m^2 of dust), which is carried by dust storms from Iran, Afghanistan, China and other desert areas, and in recent years - from the arid region of the Aral Sea.

Climatology suggests that climate change impacts are measured relative to baseline and expressed as changes in temperature and precipitation. To determine the direction of climate change impact on ecosystems, it is necessary to identify the main long-term trends of meteorological characteristics (temperature and precipitation) that are most important for ecosystems, as well as their joint effect. Long-term fluctuations in air temperature are due to fluctuations in evaporation from the earth's surface and, therefore, can lead to an increase or decrease in humidity in the region.

Many scientists, such as [11, 12], have been studying climate change in the Aral Sea and the Pre-Aral region.

The purpose of this study is to analyze the perennial climate change in the Aral Sea and Pre-Aral region.

Study area. The Aral Sea is located within Uzbekistan and Kazakhstan in the northern part of Central Asia (figure 1) (table 1) [13, 14].

The Aral Sea in the west is bounded by steep slopes of the vast Ustyurt Plateau extending to the Caspian Sea, rising 100–200 m above the Aral level. In the south, there is a flat expanse of the modern and ancient Amudarya delta, southward passing into the dune sandy massifs of the Zanghuz Karakum. In the east it borders with Kyzylkumy - a desert plain with a general bias towards the sea. In the north and northwest, the coastline of the water area is bounded by the sand dunes of the Mugodzhar foothills [15, 16].

Since the 1960s, the sea level (and the volume of water in it) began to decline rapidly [17], including as a result of drawing water from the main feeding rivers of the Amudarya and Syrdarya with the purpose of irrigation, in 1989 the sea broke up into two isolated reservoirs - the Northern (Small) and the Southern (Large) Aral Sea [18].

Continentality and aridity are the main features of the local climate fluctuations. In the northern parts of the region the climate is continental. in the south - subtropical. Average annual amplitudes of air temperature reach 33-36 °C [19].

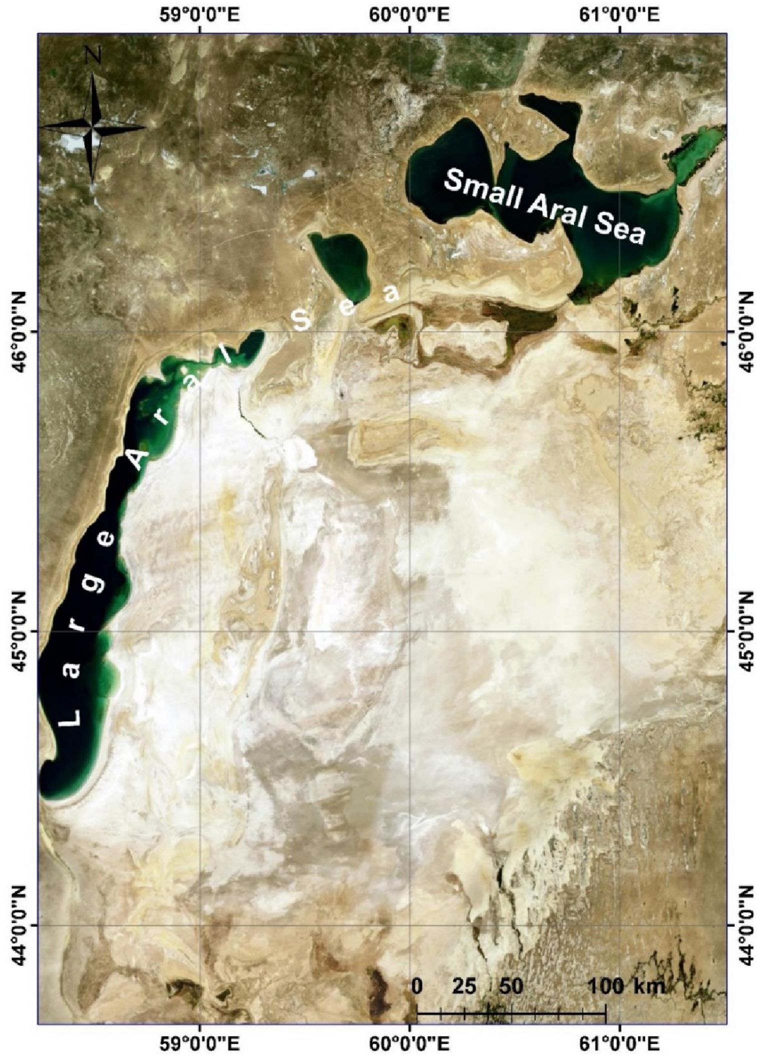

Figure1 – Map of the Aral Sea region

Table 1 – Morphological characteristics of the Aral Sea

	Water surface area, ths.km^2	Water level, m	Water volume, km^3
Large Aral	4,23	26,5	11,6
Small Aral	3,43	43	23,3

Hot long summer, the average July air temperature is 26-33 °C. In winter, cold air masses penetrate here, reducing the overall temperature level. In the northern deserts, the average January temperature is 10–15 °C, in the south in some places it is above 0 °C. Annual precipitation is 20-120 mm [20].

Data collection and Methodology. Data on air temperature and precipitation in the Aral Sea and Pre-Aral region were taken by Climatic Research Unit [21].

Regression to evaluate hydro-meteorological relationships. In this study, regression was used to evaluate climate change in the characteristics of annual mean temperature and total precipitation time series. The linear regression equation for estimating meteorological-hydrological parameters was developed as [22].

$$y = \beta_1 t + \beta_0 \tag{1}$$

where y is temperature (degree Celsius), precipitation (millimeter) or runoff (10^8 m^3), β_1 and β_0 are regressionslope and intercept, respectively, and t is time (year).

Mann-Kendalltest. The Mann-Kendall rank statistics test is an effective method for testing monotonic trends and abrupt time series changes [23-24]. This paper used the Mann-Kendall monotonic trend test [25-26], the nonparametric test, and the abrupt change test method to analyze change trends and possible transition points for temperature and precipitation in the Aral Sea and Pre-Aral region.

In this method, HO represents distribution of random variables and $H1$ represents possibility of bidirectional changes. The test statistic S is given by

$$S = \sum_{i=1}^{n-1} \sum_{k=i+1}^{n} sgn(x_k - x_i) \tag{2}$$

In which x_k and x_j arethesequentialdatavalues,$n$isthelength of the data set, and

$$sgn(\theta) = \begin{cases} +1, \theta > 0 \\ 0, \ \theta = 0 \\ -1, \theta < 0 \end{cases} \tag{3}$$

In particular, if the sample size is larger than 10, the statistic S is nearly normally distributed, i.e., the statistic

$$Z_c = \begin{cases} \frac{S-1}{\sqrt{var(S)}}, S > 0, \\ \qquad\quad S = 0, \\ \frac{S+1}{\sqrt{Var(S)}}, S < 0; \end{cases} \tag{4}$$

is a standard normal random variable, whose expectation value and variance are

$$E(S) = 0 \tag{5}$$

$$\text{var(S)} = \left[n(n-1)(2n+5) - \sum\nolimits_t t(t-1)(2t+5)\right]/18 \tag{6}$$

in which t denotes the extent of any given tie and Σ denotes the summation over all ties.

Results and Discussion. *Temperature trends.* The Aral Sea and Pre-Aral region occupies the extreme northern position in the zone of continental subtropical climate. This area receives a large amount of solar heat, on average for the year the total radiation here is 5860 MJ/m^2 [27].

The formation of the temperature regime at the stations of the Aral Sea largely depends on the impact of the water basin in a narrow coastal strip, as the air temperature changes from the water body into the depths of the land, being affected by the influence of the continent.

The average annual air temperature in the Aral Sea and Pre-Aral region, as in the multiyear plan, as in some periods, varies in latitude, decreasing from south to north. As the distance from the reservoir into the depths of land increases, the temperature increases. There is a slight fluctuation in air temperature of the Aral Sea for period 1960-2016.

In figure 2 shows the annual maximum, minimum and average temperature fluctuations in different periods using the moving average method for 5 years. The results suggest differences in the inter-decade variations, which may be due to the unique geographical location and climatic conditions of the landscapes being studied.

Since the analysis of moving averages shows that the entire region had relatively changes. As a result of the analyzed data, we can observe that the indicator of maximum temperatures for the first decade of 1960-1969. averaged 14.6 °C per year, and the minimum was 2.9 °C, and the average was 8.7 °C.

For the second decade (1970-1979), the minimum and average air temperature in the Aral Sea region. rises steadily, and the maximum temperature is slightly wary. In the following decade (1980–1989, 1990–1999, and 2000–2009), there is a slight fluctuation in the mean and maximum air temperatures, and the minimum temperature rises steadily over these decades. In the last period (2010-2016), the minimum temperature in the Aral Sea and Pre-Aral region decreases, and the maximum and average temperatures change little.

Over the entire period, we can observe that in the Aral Sea and Pre-Aral region the temperature rises slightly (figure 2).

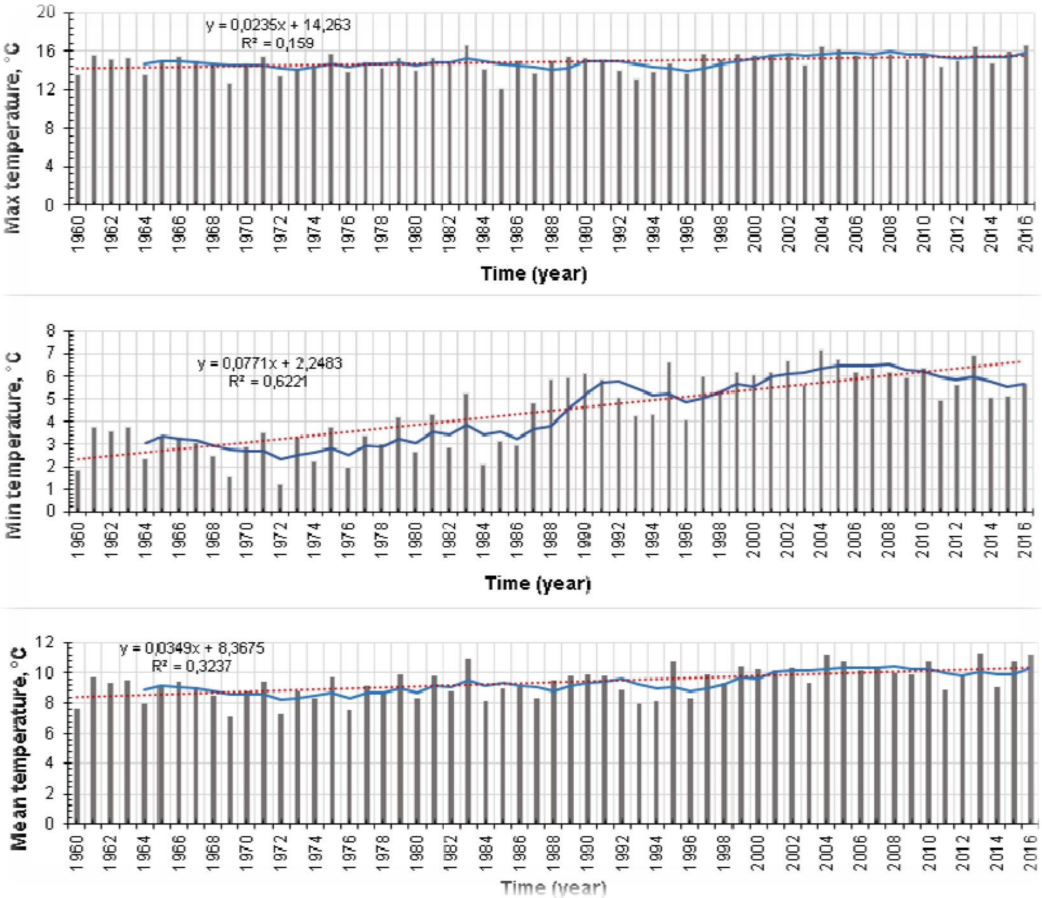

Figure 2 –The trends of the annual max, min and mean temperature in the Aral Sea and Pre-Aral region for the period 1960-2016 (red color implies a linear fit; blue color implies a fit of a 5-year moving average)

Using statistical tests of the Mann-Kendall slope, such fluctuation of indicators showed that during 1960–2016 in the Aral Sea and Pre-Aral region there was a significant tendency to increase the average annual maximum, minimum and average temperatures ($P < 0.001$) at a rate of mean temperature (3.2 °C/decade), min temperature (6.2° C/decade), max temperature (1.5 °C/decade).

Temperature variations in different periods. If we consider the temperature in terms of seasonal indicators, then as can be seen from the data in the winter months, there is a significant increase in temperature (figure 3). The maximum temperature varies little by area. In winter, it averages -3. -4 °C, and in the summer 29-30 ºC (figure 3).

The average minimum temperature gives an approximate temperature profile at night. If you look at the trend of the minimum temperature, you can see that the trend is rising. In winter, it averages -9, -10 ºC, and in the summer 19-21 ºC (figure 3). And the average temperature in the Aral Sea and Pre-Aral region varies little.

The long-term distribution of average air temperature showed only positive reliable trends.

Precipitation trends. The Aral Sea region belongs to a zone slightly moistened with precipitation, where an average of about 90-130 mm of precipitation falls annually, with the maximum amount observed during the cold season.

If we consider the precipitation divided by a decade. In the first decade for the period 1960-1969. The average long-term annual layer of precipitation falling on the water area of the region was equal to 125 mm per year (figure 4).

In the subsequent decade (1970–1979), the average rainfall was slightly lower – 103.4 mm on average per year. In the third (1980–1989) decade, the average long-term annual precipitation layer averaged 150 mm per year. In the fourth (1990–1999) and fifth decade (2000–2009) precipitation

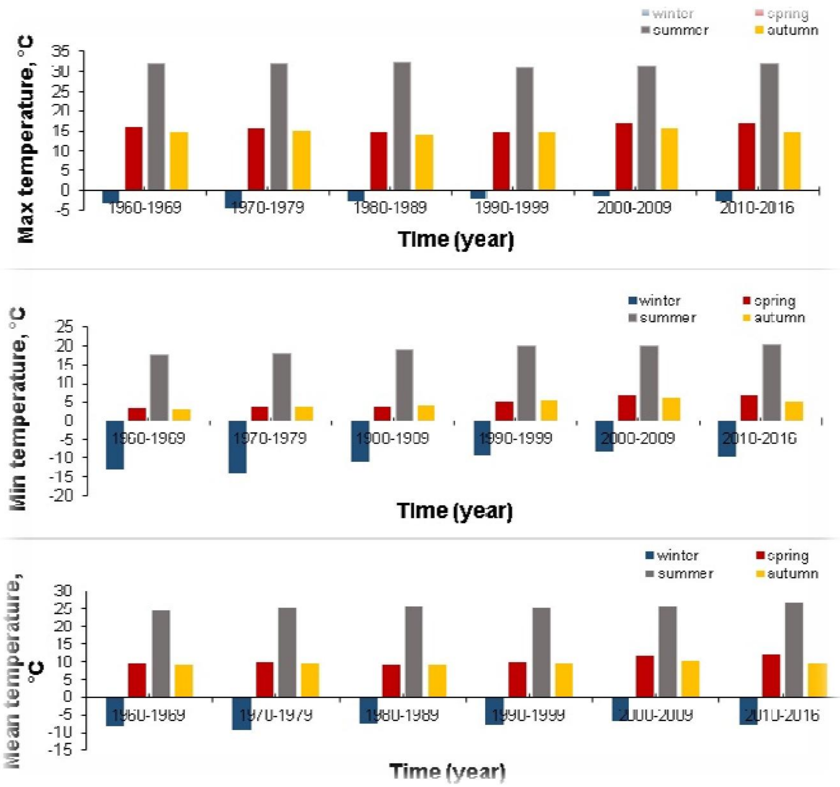

Figure 3 – Seasonal maximum, minimum and average air temperatures in the Aral Sea and Pre-Aral region

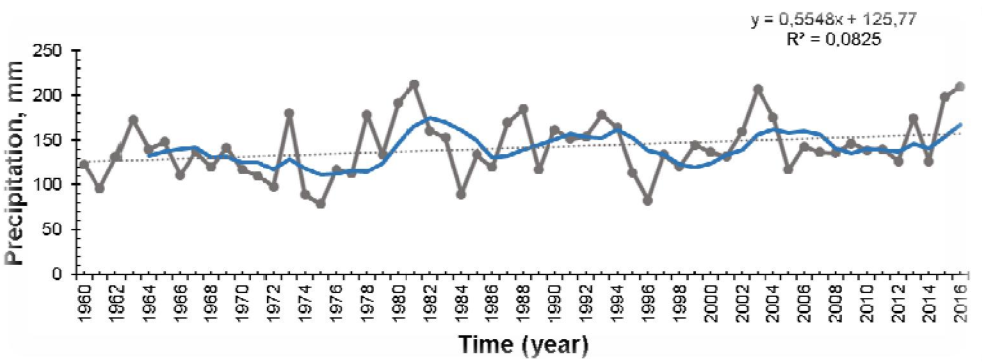

Figure 4 – The trends of the annual precipitation in the Aral Sea and Pre-Aral region for the period 1960-2016 (red color implies a linear fit; blue color implies a fit of a 5-year moving average)

difference in the Aral Sea region was 9 mm. In the last period (2010-2016), precipitation averaged 154 mm per year.

In general, for the years 1960-2016. the average long-term annual precipitation in the sea region averaged 133 mm. Over the entire period, the maximum amount of precipitation was observed in 1981 (235 mm), and the minimum in 1984 (75 mm) (figure 4).

Comparison of precipitation in different 10 years showed that the most significant differences exist between periods.

The correlation between temperature and precipitation in the Aral Sea and Pre-Aral region was R = 0.26 (figure 5).

The Mann-Kendal static test showed that 1960-2016 precipitation in the Aral Sea and Pre-Aral region is increasing ($P < 0.001$) and at a speed of 0.8 mm/decade.

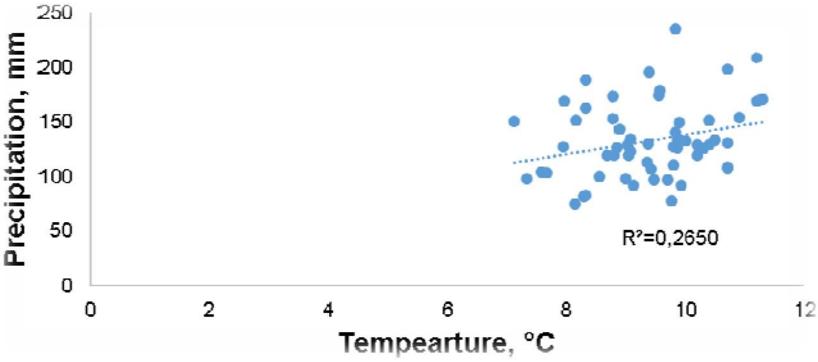

Figure5 –Correlation between temperature and precipitation

Precipitation variations in different periods. In the long-term aspect of the distribution of seasonal rainfall, significant reliable trends have been recorded.

In the second decade (1970-1979), precipitation in the Aral Sea and Pre-Aral region increased sharply during the winter months, in which it averaged 45.6 mm. The reason for this is in these decades, the air temperature was also maximum, and the remaining decades in the winter months the precipitation gradually increases.

Thus, the analyzed data in the Aral Sea and Pre-Aral region revealed significant reliable trends for different periods of the long-term distribution of total precipitation (annual and seasonal), all positive (no negative trends). This significant increase in annual rainfall is due to the cold half of the year and partly due to the warm half of the year, which is due to their main seasonal increase in winter and an increase in half in size in autumn and spring.

Here, the maximum increase in precipitation is undoubtedly observed in the cold half of the year and in the winter season, which increases their share per year (figure 6).

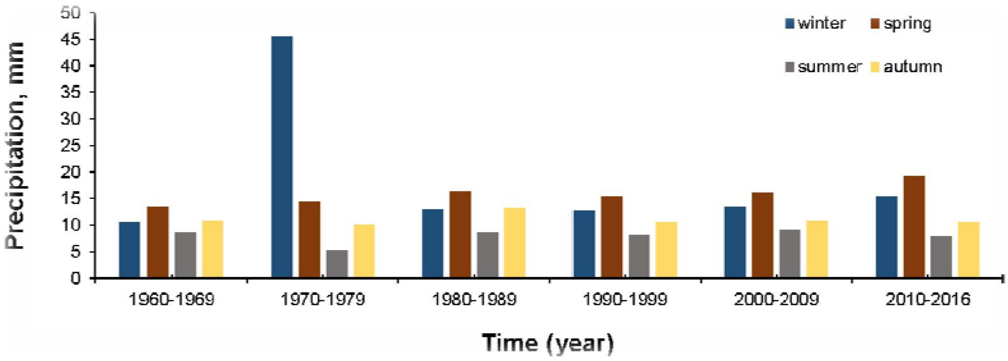

Figure 6 – Seasonal Precipitation in the Aral Sea and Pre-Aral region

Potential causes of climate change in the Aral Sea and Pre-Aral region. It is known that from 1963-1965. The process of lowering the sea level began, it corresponds to the period of creating specialized rice farms in the lower reaches of the Amudarya River. At the same time, an artificial water surface in the lower reaches of the Amudarya River with an area of about 100 thousand hectares was created in the irrigation contour, which led to significant local climate mitigation. In the irrigation zone, in general, irrigated land areas increased, which led to a widespread increase in air humidity. Of course, in the zone of active influence of the sea within a radius of 70-100 km from the water's edge, a noticeable change in climate occurs it becomes sharply continental, but in the irrigated land zone as a result of the development of large tracts of desert land, there is some climate mitigation, which is of a local nature [10].

On the one hand, the reduction of the Aral Sea area leads to an increase in temperature in this region, and on the other, the expansion of irrigated land areas leads to a decrease in air temperature.

Climate, land use and hydrology are interconnected in complex ways. Any change in one of these systems causes a change in the other. For example, changes in the hydrological and vegetation cover in the basin caused changes in temperature patterns and a decrease in precipitation, when local boundary conditions dominate the large-scale circulation. On the other hand, global and regional climate change influences hydrological processes with respect to mean conditions and variability, as well as land use options. Water use is affected by climate change, and, more importantly, by changes in population, life, economics and technology; in particular, the demand for food that is being irrigated is the largest water sector globally. Significant changes in water use or the hydrological cycle (affecting water supply and water supply) require adaptation in water management [12].

Climate changes in the Aral Sea basin are a complex combination of global, regional and local processes of variable spatial and temporal scales. They are due to multiple interrelated factors, such as changes in the atmospheric circulation associated with global warming, regional hydrological changes caused by multi-glacial melting and massive passaging, land use, and hydrological, biogeochemical and meso-and microclimatic changes in the Aral Sea and its rapid expansion of the open dry bottom [12].

Recent climatic trends and variability in Central Asia tend to be characterized by an increase in surface air temperature, which is more pronounced in winter than in summer. The series of meteorological data available in the Aral Sea basin from the end of the nineteenth century show a steady increase in annual and winter temperatures in this region. Climate data studies [28-30]point to a steady warming trend of 1-2 °C per century throughout the region.

Degradation of the Aral Sea has led to significant changes in surface albedo, soil temperature and humidity, evapotranspiration, cloudiness, precipitation, wind speed and direction, atmospheric transparency and many other mesoclimatic parameters in the immediate vicinity of the sea [31-33].

Climate records from around the sea show dramatic changes in temperature and precipitation since the 1960s. The average, maximum and minimum temperatures near the Aral Sea changed by 8 °C, increasing both seasonal and daily amplitudes, as the lake effect decreased [31].

Conclusion. In this paper, we studied climate change trends in the Aral Sea and Pre-Aral region over the past 57 years, and the results have contributed to deepening our understanding of climate change in the region. The results will facilitate and inform future planning and management of climate change programs in the Aral Sea and Pre-Aral region, especially against the backdrop of global warming.

During 1960–2016, maximum temperatures experienced a marked increase at a rate of 1.5 mm/decade (($P < 0.001$), and minimum temperatures (($P < 0.001$) at a speed of 6.2 mm/decade and average temperature (($P < 0.001$), at a rate of 3.2 mm/decade. This figure corresponds to the rate of temperature increase in Central Asia. In general, temperatures showed weak variability.

During the same 57-year period, annual precipitation observed a significant upward trend ($P < 0.001$) at a rate of 0.8 mm/decade. The correlation between precipitation and air temperature was $R = 0.26$.

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Ә. Масақбаева[1,2,3], Д. Абудувайли[1,2,3], Г. Т. Исанова[4,5,6], С. Бисенбаева[1,2,3], Б. Исина[1,2,3]

[1]Шөл және оазистер экологиясы мемлекеттік зертханасы, Шыңжаң экология және география институты, Қытай ғылым академиясы, Үрімші, ҚХР,
[2]Орталық Азия экология және қоршаған орта ғылыми-зерттеу орталығы, Үрімші, ҚХР,
[3]Қытай ғылым академиясы университеті, Пекин, Қытай,
[4]әл-Фараби атындағы Қазақ ұлттық университеті, География және табиғатты пайдалану факультеті, Алматы, Қазақстан,
[5]Орталық Азия экология және қоршаған орта ғылыми-зерттеу орталығы, Алматы, Қазақстан,
[6] Абай атындағы Қазақ ұлттық педагогикалық университеті, Жаратылыстану институты, Алматы, Қазақстан

1960-2016 ЖЖ. АРАЛ ТЕҢІЗІ МЕН АРАЛ АЙМАҒЫНДАҒЫ ТЕМПЕРАТУРА МЕН ЖАУЫН-ШАШЫННЫҢ ҮРДІСІ

Аннотация. Арал теңізі және Арал аймағындағы климаттың өзгеруі жаһандық, аймақтық және жергілікті кеңістіктік және уақытша ауқымды процестердің күрделі үйлесуі болып табылады. 1960-2016 жж. Бұл мақалада Арал теңізімен Арал аймағындағы температура мен жауын-шашын туралы мәліметтер зерттеліп, Mann-Kendall критерийі (МК) арқылы үрдістер талданды. Зерттеу нәтижелері бойынша максималды температура (P<0.001) және 1,5 °C/онжылдықта көтеріліп, минималды температура да әрбір онжылдықта 6,2 °C жылдамдықпен көтерілгенін көрсетті. Манн-Кендал статикалық сынағы көрсеткендей, орташа температура үрдісі (P<0.001) және 3.2 °C/онжылдықта жылдамдығымен артты. Жылдық жауын-шашын 0,8 мм/ он жылдық жылдамдықпен айтарлықтай көтерілу үрдісін көрсетті (P <0.001). Ауа температурасы мен жауын-шашынның ара-қатынасы R = 0,265 тең. Зерттеу нәтижелері Арал теңізі мен Арал аймағындағы климаттың өзгеруін тереңірек түсінуге мүмкіндік береді.

Түйінді сөздер: климаттың өзгеруі, Арал теңізі, Арал аймағы, Манн-Кендаль сынағы.

Ә. Масақбаева[1,2,3], Д. Абудувайли[1,2,3], Г. Т. Исанова[4,5,6], С. Бисенбаева[1,2,3], Б. Исина[1,2,3]

[1]Государственная Ключевая Лаборатория Экология пустынь и Оазисов, Синьцзянский институт экологии и географии АН КНР, Урумчи, Китай,
[2]Научно-исследовательский центр экологии и окружающей среды Центральной Азии, Урумчи, Китай,
[3]Университет Академии наук Китая, Пекин, Китай,
[4]Казахский национальный университет им. аль-Фараби, факультет географии и природопользования, Алматы, Казахстан,
[5]Научно-исследовательский центр экологии и окружающей среды Центральной Азии, Алматы, Казахстан,
[6]Казахский национальный педагогический университет им. Абая, Институт естествознания, Алматы, Казахстан

ТЕНДЕНЦИЯ ТЕМПЕРАТУРЫ И ОСАДКОВ АРАЛЬСКОГО МОРЯ И ПРИАРАЛЬЯ ЗА ПЕРИОД 1960–2016 ГГ.

Аннотация. Климатические изменения в регионе Аральского моря и Приаралья представляет собой сложную комбинацию глобальных, региональных и локальных процессов различного пространственного и временного масштаба. Исследуя данные о температуре и осадках Аральского моря и Приаралья за период 1960–2016 гг., были проанализированы тренды, используя критерий Манна-Кендалла (МК). Результаты исследования показали, что максимальная температура повышается на (P<0,001) и со скоростью 1,5 °C/десятилетие, а минимальная температура также повышается с каждым десятилетием со скоростью 6,2 °C. Статический тест Манна-Кендалла показал, что тенденция средних температур увеличивается на (P<0,001) и со скоростью 3,2 °C/десятилетие. Годовое количество осадков показало значительную тенденцию к росту (P <0,001) со скоростью 0,8 мм/десятилетие. Корреляция между температурой воздуха и осадками составила R = 0,265. Результаты этого исследования будут способствовать углублению понимания климатических изменений в регионе Аральского моря и Приаралья.

Ключевые слова:изменение климата, Аральское море, Приаралье, тест Манна-Кендала

Information about authors:

Massakbayeva Assiya, Master in Natural Sciences (Physical Geography), CAS, the Research Center for Ecology and Environment of Central Asia, Xinjiang, Urumqi; asia_94_10@list.ru; https://orcid.org/0000-0002-9926-6073

Abuduwaili Jilili is a Doctor in Geography, Professor, Deputy Director at the Xinjiang Institute of Ecologyand Geography, Chinese Academy of Sciences, an Executive Director at the Research Center for Ecology and Environment of Central Asia (Almaty), and a foreign academician of the Academy of Agriculture of Kazakhstan; jilil@ms.xjb.ac.cn; https://orcid.org/0000-0001-8483-1554

Issanova Gulnura is a PhD in Natural Sciences (Physical Geography), scientific secretary at the Research Center for Ecology and Environment of Central Asia (Almaty) and PostDoc at the al-Farabi Kazakh National University; gul_nur.777@mail.ru; https://orcid.org/0000-0002-4496-0463

Bissenbayeva Sanim, PhD student at the Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences; djusali@mail.ru; https://orcid.org/0000-0002-3770-3143

Issina Botagoz, Master in Natural Sciences (Physical Geography), CAS, the Research Center for Ecology and Environment of Central Asia, Xinjiang, Urumqi; isina1994@list.ru; https://orcid.org/0000-0003-4525-340X

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