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RESEARCH ON
ASSESSMENT OF DROUGHT CHALLENGES AND DROUGHT MONITORING MODELS IN CENTRAL ASIAN REGION

CENTER FOR EMERGENCY SITUATIONS AND DISASTER RISK REDUCTION
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ABBREVIATIONS:

DB	Database
VI	Vegetation index
WMO	World Meteorological Organization
GIS	Geographical Information Systems
HTC	Hydrothermal Coefficient of Selyaninov
ERS	Earth Remote Sensing
LWF	Long-term Weather forecast
UNCCD	United Nations Convention to Combat Desertification
CT	controlled territories
MSP	Meteorological Services for the Population
MES RK	Ministry of Education and Science of the Republic of Kazakhstan
MES	Ministry of Emergency Situations
NMHS	National Meteorological and Hydrological Service
NAP	National Action Programs to Combat Desertification
HMP	Hazardous meteorological phenomena
DNP	Dangerous natural phenomena
RSE "Kazhydromet"	Republican state enterprise "Kazhydromet"
DEWS	Drought early warning systems
SRAP/CD	Subregional Program of Action to Combat Desertification
CA	Central Asia
ES	Emergency situation
EE	Extreme event
DRM	Disaster Risk Management
EFI	Extreme Forecast Index
FAR	False alarm ratio
HWDI	Heat Wave Duration Index
NDVI	Normalized difference vegetation index
R	Correlation coefficient
RMSS	Root Mean Square Skill Score assessment of the root mean square quality indicator
ROC	Relative operational characteristics
Si	Pedya's aridity index
SPI	Standardized Precipitation Index
SVSLRF	Standard Verification System for Long-Range Forecast
VCI	Vegetation Condition Index

INTRODUCTION

This study is conducted as a review and recommendations for actions to improve the capacity of countries in Central Asia to effectively use space-based applications for monitoring and early warning of droughts through the Regional Drought Management Mechanism and other related activities in the Central Asian region. The study was prepared by independent experts to stimulate in-depth discussions and offer policy recommendations and directions for actions in this region.

From a geographical point of view, Central Asia is an extremely vast region with no direct access to the ocean and located in the center of the Eurasian continent. (Fig. 1[1]).

Figure 1 Physical map of Central Asia

The main climatic and geographical features of the Central Asian countries are given in table 1.

Due to the geographical location, the region is prone to **various climate-related natural disasters such as floods, droughts and mudflows, which significantly affect people's living conditions, including their access to proper food and potable water.**

About 75% of the territory can be rated insufficiently protected from natural disasters. An increasingly unfavorable climate change characterized by rising temperatures and increasing evaporation restricts economic activity including agriculture, and puts pressure on limited natural resources[2].

Drought is also a common occurrence for Central Asian countries. According to statistics[3], the main economic risk of natural disasters in the Central Asian region is earthquakes, then in descending order, is the

[1] GRID-Arendal, 2019, http://www.grida.no/resources/11141)

2 Mobilization of financial resources for the implementation of the SDGs on topics of water, energy and climate. Survey study. Asian Development Bank, 2019

[3] 3 Central Asia and Caucasus Disaster Risk Management Initiative (CACDRMI): Risk Assessment for Central Asia and Caucasus Desk Study Review (CAC DRMI): Risk Assessment for Central Asia and Caucasus Desk Study Review/ The World Bank, UNISDR, CAREC, GFDRR. 2009. 172 p.

risk of floods, landslides and droughts, but the largest number of victims - up to 70% of their total number[4] - in the region is caused by droughts.

***Table 1** The main climatic and geographical features of Central Asian countries (as in 2017)*

Characteristic	Kazakhstan	Kyrgyzstan	Tajikistan	Turkmenistan	Uzbekistan
Territory area, thousand km^2	2 724,9	187,5	142, 6	491,2	448,9
The share of flat territory, %	58 desert and semi-desert	15	7	80 desert and semi-desert	78,8
Mountain share, %	10	85	93	10	21,2
The share of agricultural land in the total territory, (%)	23 agriculture 70 livestock farming	52	53,6	69.4 of agricultural destination, 27.6 of the reserve land	46.1 of agricultural destination, 20.1 of the reserve land
Maximum and minimum elevations	7010 м; -132 м	7439 м 488 м	7495 м, 300 м	3139 м –81 м	4643 м -12,8 м
January average temperature	- 3ºC (south), -18°C (north)	-2,2°C (south), -29,1°C (mountains)	+ 2ºC in the valleys -27ºC in the mountains	+ 4°C (south), -5°C (north-east)	+3ºC (south), -10ºC (Ustyurt plateau)
July average temperature	south +29°C, north +19°C	+26,8°C(south), +4,1°C (mountains)	+ 30ºC in the valleys + 4ºC in the mountains	+ 34°C (south), + 28°C (north-east)	+37ºC south, +33°C north
Maximum and minimum absolute temperatures	+49ºC (Kyzylkum desert) -57ºC (north)	+43,6°C (Chuy valley) -53,6°C (Aksai)	+ 47ºC (Nizhny Pyanj) -63ºC (Lake Bulunkul)	+ 50°C Repeetek -32.8°C Kushka	+50ºC (south), -40ºC (Ustyurt plateau)
Change in the average annual rainfall over the territory, (mm)	less than 100 in the deserts, up to 500 in the steppes, up to 1600 in the mountains	less than 150 in the deserts, 400-600 in the valleys, up to 1600 in the mountains	from 70 in the eastern Pamirs to 1800 in the mountains	less than 100 in the deserts, up to 150 in the plains, 350 in the mountains	less than 100 in the deserts, up to 900 in the mountains
Share of agriculture in GDP (%)	7	38	21	18	24

Droughts, especially in their extreme occurrence, have an accelerating effect on the development of desertification, the main cause of which is excessive anthropogenic stresses, aggravated by prolonged and intense droughts[5]. In this regard, the issue of developing and improving modern systems for monitoring and predicting droughts in advance, as well as ensuring their readiness and mitigating their consequences, becomes extremely important.

In accordance with the terms of reference, **the goal of the research is to assess drought problems and existing drought monitoring models in the Central Asian region.**

Special emphasis is placed on the analysis of the drought parameterization methods used, and the possibilities of creating drought early warning systems based on hydrodynamic modeling and remote sensing. At the end of the research work, conclusions and recommendations for Central Asian countries on possible mechanisms for mitigating the effects of droughts are given.

To achieve this goal, the following tasks have been solved:
- Conducting a review of current, most significant studies on the problem of droughts, including in the regional aspect;
- Assessment of the relevance of the drought problem in the Central Asian region;

[4] Central Asia and Caucasus Disaster Risk Management Initiative (CACDRMI): Risk Assessment for Central Asia and Caucasus Desk Study Review (CAC DRMI): Risk Assessment for Central Asia and Caucasus Desk Study Review/ The World Bank, UNISDR, CAREC, GFDRR. 2009. 172 p.
[5] Gringof I. G. Droughts and desertification - environmental problems of our time // Transactions of ARRIAM. -2000. - Vol. 33. - P.14-40.

- Analysis of the possibilities of information support for parameterization and modeling of droughts;
- Comparative (relative) analysis of existing parameterization methods (drought monitoring models) in the region, indicating the advantages and possible areas of application;
- Analysis of currently used adaptation mechanisms to reduce vulnerability to drought in the Central Asian region;
- Assessing the feasibility of establishing a drought early warning system in the Central Asian region for management purposes.

Survey research methodology.

This review study was based on a comprehensive analysis of representative material characterizing the current state of knowledge of the drought problem in the Central Asian region, assessing the significance of facts, theoretical generalization, analysis, logical conclusions and practical recommendations. The methodology for this review study includes:

- collection of information on the state of study of the issue, literature review, comparison of information on the research topic from accessible and open sources;
- systematization of versatile approaches and methods to solving the problems of research and forecasting droughts tested in the world community;
- a comparative analysis of the state of assessment of drought problems, primary baseline information and drought monitoring models in the world and in Central Asia;
- a review of recent studies in the field of mitigating risks and drought damage, indicating trends in the development of this knowledge in relation to the countries of the Central Asian region.

It is important to note, that at the time of writing the report of analytical work on identifying the potential for solving problems with droughts in the Central Asian region, there are practically no open sources. Therefore, the conclusions and recommendations in this study are based on the authors' own expertise with links and extrapolation to generally accepted existing monitoring assessments and consequences of drought in world practice and in the studied region.

1. ASSESSMENT OF DROUGHT CHALLENGES IN CENTRAL ASIA REGION

1.1.Definition and classification of droughts

As mentioned above, the Central Asian region is vulnerable to drought due to its geographical location.

Despite the magnitude and duration, drought is a regional phenomenon and even within the territory of one country its intensity and impact in each region are different, since each region has special climatic characteristics: amount, seasonal nature and form of precipitation, air temperature, wind and soil moisture regimes and other components of the hydrological cycle.

There is no single universally accepted definition of drought in the Central Asian region. Therefore, various terminology is used in official documents of the countries.

Definition of drought in accordance with the UN Convention[6]:

"Drought" *a natural phenomenon that occurs when the amount of precipitation is much lower than the normal recorded levels, which causes a serious disruption of the hydrological balance, adversely affecting land productivity.*

"Mitigating the effects of drought" *means activities related to the prediction of drought and intended to reduce the vulnerability of society and natural systems to drought as it relates to combating desertification.*

The humidification conditions of any territory, in fact, are the ratio between the amount of precipitation and evaporation (or air temperature, since evaporation is a function of temperature). With excessive moisture, precipitation exceeds evaporation, and part of the precipitation is removed through underground and surface

[6] United Nations Convention to Combat Desertification in Those Countries Experiencing Serious Drought and / or Desertification, Especially in Africa "(Concluded In G. Paris 17.06.1994)

runoff. With insufficient moisture, precipitation is less than the possibility of evaporation. Volatile humidification is the alternation of droughts with relatively wet periods. Excessive and insufficient soil moisture adversely affects the growth and development of plants. With insufficient moisture, the plants do not fully use the heat and nutrition resources, which ultimately affects the state of the vegetation cover.

Definition of drought in Kazakhstan: In Kazakhstan, activities during natural and man-made emergencies are regulated by the Law on Civil Protection[7]. There is no direct mention of droughts, mainly emergency situations.

Various definitions of drought are found in other regulatory documents and various scientific and applied research:

- ***«Drought»*** *- maintenance for 20 days or more of relative humidity in the daytime of 30% or less with moisture reserves of 35 mm or less in a meter layer of soil, causing damage to plants»*[8]*;*
- *A significant lack of rainfall for a long time in spring or summer at elevated air temperatures is called* ***drought****;*
- ***"Drought"*** *means a natural phenomenon that occurs when the amount of precipitation is much lower than the normal recorded levels, which causes a serious disturbance in the hydrological balance, adversely affecting the productivity of land resources.*

The definition of drought in Kyrgyzstan: In Kyrgyzstan, the national classification of emergencies and criteria for their assessment was approved by a decree of the Government of the Kyrgyz Republic of November 22, 2018. It determines the organizational and legal norms for assessing emergencies according to their severity and regulates the relations arising in the course of activities of the civil protection governing bodies. According to this classification[9]:

- ***«Atmospheric drought»*** *- is defined as the absence of effective precipitation (more than 5 mm per day) during the vegetation period for 30 consecutive days or more at a maximum air temperature above 30 ºC. On certain days (no more than 25% of the period), the maximum temperature of the following values is allowed.;*
- ***«Soil drought»*** *- is a situation in which for two decades, the reserves of productive moisture in the earth layer (0-20 cm) are 10 mm or less.*

Formal definitions of drought in Tajikistan, Turkmenistan, and Uzbekistan could not be found during the preparation of this study.

Thus, **drought** is a complex phenomenon that can be considered from several points of view. Central to the definition of drought is the concept of moisture deficiency. Difficulties in determining drought observed in all countries of CA are associated with the need to consider the various components of the hydrological cycle, as well as time periods and environments, respectively, when and where moisture deficiency appears. The situation when at the same time there is a long-term lack of moisture in the soil at great depths and its short-term excess in the upper layer reflects the complexity associated with the determination and identification of droughts.

There are different approaches to classifying droughts. Depending on the environment in which signs of moisture deficiency are observed, atmospheric and soil droughts are distinguished, and they also speak of a general **atmospheric soil drought**[10].

In foreign literature, focused on monitoring droughts in regions with a high risk of prolonged droughts and a developed insurance system, a more detailed classification of **droughts** is widely spread, taking into account the types and severity of their consequences[11].

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[7] Law of the Republic of Kazakhstan on Civil Protection. (added changes and additions as of April 11, 2019)

[8] Decree of the Government of the Republic of Kazakhstan dated August 28, 1997 No. 1298 "On the State System for the Prevention and Liquidation of Emergencies"

[9] Decree of the Government of the Kyrgyz Republic "On approval of the Classification of emergencies and criteria for their assessment in the Kyrgyz Republic" dated November 22, 2018 No. 550.

[10] Baidal M. Kh., Neushkin A. I. Macrocirculation factors and forecast of droughts in the main agricultural regions of the USSR // Transactions of VNIGMI. - 1979. - Vol. 59. - P. 6-11.

[11] Bull. American meteorological society. Meteorological drought —Policy statement,. -1997.- vol.78. pp.847-849.

In the Central Asian region, droughts, seen as a evidence of climate variability, are divided into the following categories[12]:

- ***Meteorological drought.***

The main sign of meteorological drought is the lack of precipitation, which is accompanied by a decrease in surface runoff, infiltration and replenishment of groundwater, as well as other phenomena: high temperature, low relative humidity, cloudiness, increased solar radiation, the totality of which leads to increased evaporation and transpiration of moisture by plants. Meteorological drought can develop very quickly and end abruptly.

- ***Agricultural drought.***

Agricultural drought is characterized by a lack of soil moisture, leading to plant stress, a decrease in bio-productivity and yield. The agrometeorological indicators used to monitor agricultural droughts in Central Asian countries take into account the conjugate changes in the physical parameters of the surface air layer and root habitats of the soil, as well as changes in the biomass growth indicators. In terms of time, the onset of agricultural drought may differ significantly from the onset of meteorological, depending on the available moisture reserves. The emergence of this type of drought is facilitated by the influence of additional factors hindering the accumulation of moisture reserves in the soil: in winter, there is a lack of snow, in early spring unfavorable conditions for the absorption of melt water (stormy snowmelt, frozen or structureless soil, the presence of ice crusts). At the time of the onset, agricultural droughts are divided into spring, summer and autumn. Sometimes droughts last several months in a row, spanning two to three seasons. According to the intensity and coverage of the territory, droughts are divided into very strong, strong, medium and weak. The most damage to crops is caused by very strong and severe spring-summer droughts in May and June.

- ***Hydrological drought.***

Hydrological drought is characterized by a decrease in the flow of water into rivers and reservoirs and a decrease in their level, a decrease in groundwater reserves, which leads to difficulties in meeting water needs, as well as a decrease in the area of swamps. The severity of hydrological drought is determined, as a rule, for watersheds or river basins. Hydrological drought usually occurs later than meteorological and agricultural. Since the regions are interconnected by hydrological systems, the area of distribution of hydrological drought may be longer than the area of the meteorological drought that caused it. The identification of the relationship between hydrological droughts and precipitation deficit due to climatic factors is often complicated by the simultaneous impact on the hydrological characteristics of the basin of different factors, such as a change in land use (deforestation), land degradation, and the construction of dams. A change in land use in the upper reaches of the river can change such hydrological characteristics as the rate of infiltration and surface runoff, with the result that downstream river flow variability will increase the likelihood of a hydrological drought. A change in land use is one of the anthropogenic impacts causing an increase in the number of situations with water shortages even in the absence of changes in the frequency of occurrence of the primary phenomenon - meteorological drought.

- ***Droughts with socio-economic consequences.***

This type can include droughts, the intensity and scale of which adversely affect the state of the economy of a country (region) and lead to significant social consequences, sometimes acquiring the character of a humanitarian catastrophe. In this case, droughts were considered solely from the point of view of their influence on the crop. A number of drought catalogs compiled for the territory of CA were based on data on crop yields, and meteorological information was used only as accompanying information.

1.2. Status and possibilities of informational support for studying the problem of droughts in the Central Asian region

The assessment of climatic changes in the conditions of aridity is based on data from specialized observations that have been carried out in CA throughout the territory in different natural zones over several decades. Such observations include both observations of soil moisture, which is a key characteristic in determining the conditions of aridity, and other observations that make it possible to monitor the processes of

[12] Meshcherskaya A. V., Blazhevich V. G., Famine M. P., Belyankina I. G. Aridity monitoring on the territory of the main grain-producing regions of the CIS over the past century // Transactions of ARRIAM. - 2000. - Issue. 33. - P. 41-63.

heat and moisture exchange in the surface layer, in particular, observations of evaporation from the soil surface and the water surface.

Traditionally, the National Hydrometeorological Services are responsible for drought monitoring in the region[13].

Since 1991, the condition of the state hydrometeorological observation network has been controversial. At the beginning of this period, there was a sharp reduction in state funding for hydrometeorological services in Kyrgyzstan, Kazakhstan and Tajikistan. Turkmenistan and Uzbekistan were in a better position, having almost completely preserved their hydrometeorological observation network. Currently, the situation is improving, the observing network is being restored both with the participation of the state and with the help of international organizations.

Despite the fact that the National Hydrometeorological Services generally managed to retain highly qualified personnel involved in processing network data, observation posts and preparing weather and river flow forecasts, the monitoring network did not provide sufficiently accurate data to reliably assess extreme weather conditions and their impact, resulting in the quality of forecasting has deteriorated.

With gaining independence, it was necessary to re-organize cooperation between national hydrometeorological services and solve problems at the national level, as well as develop cooperation with national ministries and international organizations.

The agrometeorological network underwent a particularly sharp reduction in the region, which increased the vulnerability of economic sectors to agricultural drought. In CA, where agriculture is a source of employment for a large part of the population and a significant share of the economy, relatively accurate long-term forecasts play an important role, which are impossible without a systematic database to predict the relationship between crop and weather, as well as scientific studies of the impact of weather on agricultural crops and their final crop.

For example, the project **"Integrated management of natural resources in drought-prone and saline agricultural production landscapes of CA and Turkey (CACILM-2)",** risk management in agriculture in Kyrgyzstan revealed the following problems in the field of drought:

- The modernization of the Kyrgyzhydromet observation network does not sufficiently cover agrometeorological stations;
- Agrometeorological equipment is physically outdated and requires urgent updating;
- The technical condition of the network of agrometeorological observations leads to disruption of the output of agrometeorological products;
- At 20 meteorological stations and 10 agrometeorological posts that are part of the Kyrgyzhydromet Agrometeorological Network, there is an acute shortage of instruments for determining moisture, freezing and thawing of the soil;
- There are no agrometeorological observations and software for predicting soil and atmospheric drought, dry wind, hail, and ice;
- Low level of training of specialists in agrometeorology.

Similar problems can be noted in other countries of CA.

At present, the possibilities of providing information to study the problem of droughts in the Central Asian region have been significantly improved as a result of the fact that the national Hydrometeorological Services received significant foreign assistance.

AMRUSAID, NOAA and the Swiss Agency for Development and Cooperation, the World Meteorological Organization and the World Bank have made significant investments in various measures to modernize meteorological and hydrometeorological observation systems and data exchange in CA. Also, thanks to these measures, the potential of the Hydrometeorological Service employees to use new technologies

[13] Drought. Management and mitigation assessment for Central Asian and Caucasus countries. World Bank Report No. 31998- ECA - 2005.

was increased, so the accuracy of river flow forecasts increased by 20-50% and the accuracy of weather forecasts by 5-20%.

Uzbekistan, Kazakhstan, Kyrgyzstan and Tajikistan have developed Climate Risk Profiles. The whole range of measures taken has significantly improved the quality of monitoring and provided the conditions for the development of drought early warning systems in the Central Asian region.

All Central Asian countries are Parties to the UN Convention to Combat Desertification (UNCCD). In accordance with the provisions of the Convention, they all prepared National Action Programs (NAPs) to combat desertification[14].

Since desertification and drought are transboundary issues, the NAPs therefore call for joint action to combat desertification and drought. Based on this, it was decided to develop a Subregional Action Program to Combat Desertification (SRAP/CD) in the context of the UNCCD.

Subject to the provisions of the Convention, the preparation and implementation of the SRAP/CD is considered an integral part of the national sustainable development policies of the country. The need was recognized that the framework of subregional cooperation should cover not only the NAP, but also other national action plans to improve the socio-economic and environmental situation.

In addition, interconnection with other international conventions and relevant legal agreements, as well as regional and/or global programs related to combating desertification and drought, is required.

Appendix 1 *lists the main international projects on disaster risk management, combating drought and desertification and improving the drought early warning system in Central Asia*[15].

2. METHODS OF PARAMETRIZATION AND DROUGHT MONITORING. COMPARATIVE ANALYSIS OF EXISTING MODELS OF DROUGHT MONITORING IN THE REGION, WITH INDICATION OF ADVANTAGES AND POSSIBLE SCOPES OF APPLICATION

2.1 General Provisions

Causes of drought are at the heart of the proposed methods for parameterizing and modeling drought monitoring and providing guidance on early warnings and assessments. Their development is carried out in the following areas:

- use of a single indicator or index;
- the use of multiple indicators or indices;
- use of complex or hybrid indicators.

Currently, various methods of modeling (parameterization) of droughts are used in world practice. Many of these are summarized in the WMO Handbook of Drought Indicators and Indices[16].

Despite the fact that quite a lot of attention has been paid to the study of droughts in the Central Asian region, up to now there is no single index or indicator that could characterize and apply to all types of droughts,

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[14] National report of the Republic of Uzbekistan on the implementation of the United Nations Convention to Combat Desertification and Drought (UNCCD). Tashkent - 2006.

[15] Third National Communication of the Republic of Tajikistan on the UN Framework Convention on Climate Change. Dushanbe, 2014.- 167 p.
The third national communication of the Republic of Uzbekistan on the UN Framework Convention on Climate Change. Tashkent, 2016.- 246 p.
The third national communication of the Kyrgyz Republic on the UN Framework Convention on Climate Change. - B: LLC “El Elion”, 2016. - 274 p.

[16] A guide to indicators and aridity indices. Integrated Drought Management Program (IDMP). WMO- No. 1173.2016

climatic regimes and sectors exposed to drought. Moreover, the indices used in the region have regional characteristics.

In this report, it is advisable to consider in detail only those indices that are possible or are already used in monitoring droughts in the Central Asian region.

2.2 Methods of parameterization and monitoring of droughts based on ground-based observations

In the traditional definitions of drought and its parameters, meteorological data are used, such as precipitation, soil and air surface temperature, soil and air humidity, etc. For various environmental conditions, various indices have been proposed to monitor drought. One index, universal, optimal for the entire region at the time of writing, does not exist.

Table 2 shows the main indices most widely distributed in the region under consideration.

Table 2 *The main indices most common in the Central Asian region for ground-based drought assessment*

Index Name	Symbol	Calculation	Initial information for calculation	Availability of information for its calculation
Hydrothermal coefficient of Selyaninov [17],	(HTC)[18],	$HTC = \frac{\sum r}{0{,}1\sum t}$	∑r - the sum of precipitation (mm) ∑t - the sum of the sum of the active daily average air temperatures	Available
Coefficient of humidification by Ivanov[19]	K	$K = \frac{\overline{R}}{\overline{E}_0}$,	R - the sum of total precipitation for the year, mm $\overline{E}_0$ - volatility per year, mm	Partially available
Pedya's Index (atmospheric soil drought)	Si	$S_i(\tau) = \frac{\Delta T}{\sigma_T} - \frac{\Delta R}{\sigma_R} - \frac{\Delta E}{\sigma_E}$	□T, □R, □Y - anomalies of air temperature, precipitation and humidity in the active soil layer (up to 1 m)	Partially available
Pedya's Index (atmospheric drought)	Si	$S_i(\tau) = \frac{\Delta T}{\sigma_T} - \frac{\Delta R}{\sigma_R}$.		Available
Pedya's Index (soil drought)	Si	$S_i(\tau) = \frac{\Delta E}{\sigma_E}$		Partially available
Standardized Precipitation Index[20 21].	SPI	SPI = F^{-1}G(R)	Precipitation	Available
Standardized Precipitation Evapotranspiration index.[22]	SPEI	Di= Ri-PETi	(R)-Monthly precipitation and PET potential evapotranspiration	
Palmer Drought Severity Index.[23 2425]	PDSI		Precipitation, temperature, moisture available	Partially available

[17] Chirkov Yu.I. Agrometeorology. - L: Gidrometeoizdat, 1979. - 320 p.
[18] Chirkov Yu.I. Agrometeorology. - L: Gidrometeoizdat, 1979. - 320 p.
[19] Bioclimatic potential of Russia: theory and practice / A.V. Gordeev, A.D. Kleshenko et al. - M.: Partnership of scientific publications of KMK, 2006. - 512 p
[20] Łabędzki, L; Bąk, B. Meteorological and agricultural drought indices used in drought monitoring in Poland: a review. *Meteorol Hydrol Water Manag* 2014, 2 (2), 3-14.
[21] User Guide for the Standardized Precipitation Index. Issue No. 1090. Geneva: WMO, 2012.
[22] Vicente-Serrano, SM; Beguería, S; López-Moreno, JI A multiscalar drought index sensitive to global warming: the standardized precipitation evapotranspiration index. *J Clim* 2010, 23 (7), 1696-1718.
[23] Sivakumar, M; Motha, R; Wilhite, D; Wood, D. *Agricultural Drought Indices: Proceedings of an Expert Meeting* . World Meteorological Organization: Geneva, Switzerland, 2010.
[24] Field A. H. Agricultural meteorology. St. Petersburg: Gidrometeoizdat, 1992.- 424 p.
[25] Gringof I.G., Pasechnyuk A.D. Agrometeorology and agro- meteorological observations. St. Petersburg: Gidrometeoizdat, 2005. - 525 p.

Often a generalized criterion of drought is considered to be the level of decline in the yield of the main crop. Productivity in each specific year is formed under the influence of a complex of factors that can be divided into two components: the level of crop farming and weather conditions. [26] [27]

However, all these proposed methods do not always detect drought, and do not fully reflect the effect of drought on crop productivity. It can be said that there is no one universal method or index suitable for all natural zones of the Central Asian region. Therefore, in the territory under consideration there is a need to assess the regional significance of the main criteria for the parameterization of droughts, as well as to assess their impact on crop productivity relative to the climatic norms of a particular region (taking into account the bioclimatic potential).

2.3 Methods of parameterization and monitoring of droughts based on RSE (remote sensing of the Earth)

The analysis of aridity conditions according to the data of remote sensing of the earth from space in the Central Asian region is based on the use of special generally accepted complex parameters - vegetation indices.

The methods for their calculation are based on the different reflectivity of green biomass in the visible (RED) and near infrared (NIR) spectral ranges.

Table 3 shows the main indices that are most widespread in the region under consideration.

Table 3 *Main vegetation indices most common in the CA region*

Index Name	Symbol	Calculation formula	Initial information for calculation	Availability of information for its calculation
Normalized Differential Vegetation Index [28]	NDVI	$NDVI = \frac{NIR - RED}{NIR + RED}$	Low and medium spatial resolution satellite data (NOAA-AVHRR, SPOT-IV, MODIS), air temperature	Available
Vegetation Index [29]:	VCI	$VCI = \frac{NDVI_i - NDVI_{\min}}{NDVI_{\max} - NDVI_{\min}}$		
Integral Vegetation Index	IVI	$IVI = \sum_{i=1}^{18} NDVI_i$		
Integral index of vegetation conditions	IVCI	$IVCI = \frac{IVI_i - IVI_{\min}}{IVI_{\max} - IVI_{\min}}$		
Drought Index [30]	ID	ID = (T4d + T4n) / NDVI		

The drought space monitoring system was tested on the territory of the Akmola region of Kazakhstan in the vegetation period of 2011. The technology was tested by the JSC "National Center for Space Research and Technology" (JSC «NCSRT») together with the LLP «Scientific and Production Center for Grain Management named after A.I. Barayev». During operation, it was confirmed that operational and seasonal monitoring technologies provide early diagnosis of drought and allow its development to be monitored. The early identification of areas affected by drought makes it possible to take timely measures to mitigate its effects and reduce damage[31].

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[26] Baysholanov S.S. On the frequency of droughts in grain-sowing regions of Kazakhstan // Hydrometeorology and ecology. No. 3. Almaty, 2010. RSE "Kazhydromet", p 27-38.
[27] Dmitrieva L.I. Evaluation of temporary variability of crop yields / Methodological guidance / -Odessa: OGMI, 1985. -19 p
[28] Meshcherskaya A.V. Drought Index and Crop Productivity // Meteorology and Hydrology. - 1988. - No. 2. - P. 91–98
29 Kogan F.N. Remote sensing of weather impacts on vegetation in non-homogeneous areas // Int.Journal of Remote Sensing. – 1990. – Vol. 11. – P. 1405–1419
30 Shcherbenko E.V. Remote methods for identifying agricultural drought // Modern problems of remote sensing of the Earth from space, 2007. Issue 4. T. 2. P. 408-419.
[31] Spivak L.F., Vitkovskaya I.S., Batyrbaeva M.Zh., Muratova N.R., Kauazov A.M. Space drought monitoring in Kazakhstan: analysis of long-term remote sensing data // Earth from space: the most effective solutions. Vol. 14, 2012, from 15-23.

To analyze long-term changes in the state of vegetation, which include desertification processes, an additional requirement is to ensure coverage of the entire territory with homogeneous satellite data. Currently, the above requirements are most consistent with satellite data of medium and low spatial resolution.

3. REVIEW OF MODERN RESEARCH ON THE DROUGHT CHALLENGES OF IN THE CENTRAL ASIAN REGION

3.1. Republic of Kazakhstan: Drought Research Survey

The study of droughts in Kazakhstan received quite a lot of attention. Monitoring of the state of the environment is carried out by the Republican State Enterprise (RSE) " Kazhydromet " based on observations on the state network of meteorological and hydrological observations. Today, this organization has a monopoly on basic information about the state of the atmosphere, hydrosphere, and environmental pollution. Free access to primary monitoring data is limited. This information is a commercial product and is sold. This fact makes it very difficult to conduct research on the patterns of drought in Kazakhstan and on the basis of this to create an effective adaptation system.

Scientific research in this area is carried out mainly in the RSE Kazhydromet, Kazakh National University named after al-Farabi (KazNU), Institute of Geography MES RK, JSC «NCSRT» MES RK.

In 2008 - 2010, Kazhydromet carried out the research work “Research and forecasting of droughts in Kazakhstan”.

As part of this work:

- The nature of the general and regional atmospheric circulation was investigated, and circulation factors contributing to the onset of drought in both the northern and southern grain-growing regions of Kazakhstan were identified;
- The characteristic of meteorological, agrometeorological and hydrological conditions that contribute to the formation of droughts in Kazakhstan, the laws of their spatial and temporal distribution;
- Long-term trends in changes in the conditions of moistening the region are determined;
- The frequency of atmospheric and soil drought in the territory of Northern Kazakhstan for the period 1971-2007 was studied;
- Based on the analysis of the indices and indicators of droughts calculated during the work, a system of representative indicators is proposed that must be used when monitoring droughts. Moreover, a number of indicators were calculated for the territory of Kazakhstan for the first time. A generalized catalog of droughts in the territory of Northern Kazakhstan for the period 1971-2010 was compiled in electronic form.

In 2015-2017, the KazNU commissioned by the Science Committee of the MES RK carried out the project “Justification and development of technology for managing the risks of droughts as one of the most important factors of food security in the Republic of Kazakhstan”.

As a result of this project, the following main results were obtained:

- Development of theoretical, methodological and technological foundations of drought risk management based on analysis, taking into account the best world achievements in the field of hydrodynamic modeling of atmospheric processes, their statistical interpretation, risk management theory, methods of remote sensing of the Earth.
- Development of a hydrodynamic model of early (one season advance) drought prevention based on hydrodynamic modeling of extreme temperatures and atmospheric aridity indices.
- Development of a model calibration system, as well as verification of simulation results based on the calculation and study of the statistical characteristics of atmospheric circulation reproduced by prognostic models, as well as ground and space monitoring data.
- Conducting a detailed analysis of the state and dynamics of the main characteristics of large-scale atmospheric circulation and the state of the underlying surface under global and regional climatic

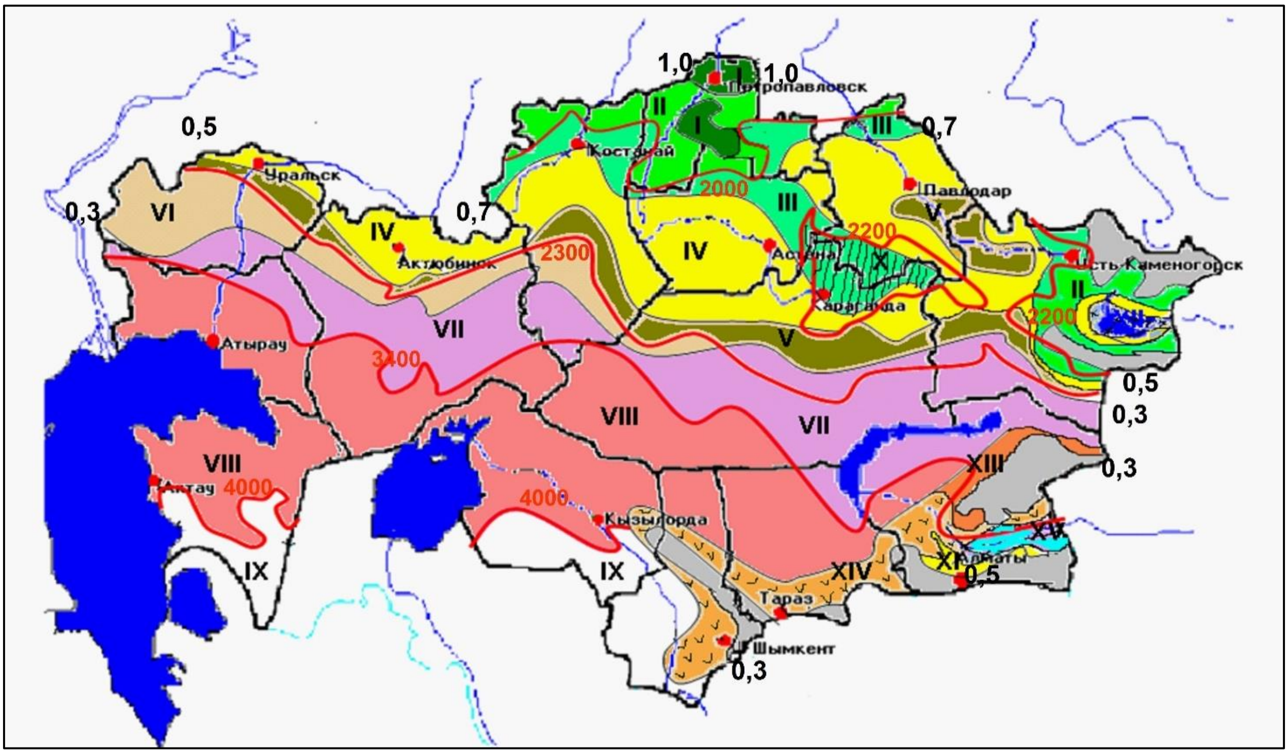
changes in order to identify prognostic patterns of occurrence of atmospheric aridity based on a comprehensive analysis of the general atmospheric circulation, long-distance communications and the temperature of the World Ocean.

- Creation of a model of spring wheat resistance to drought in terms of productivity and grain quality depending on the geographical region of cultivation and the year of cultivation, and its cartographic interpretation is presented.
- Conducting a pilot assessment of the effect of atmospheric aridity on the adaptive potential (yield and grain quality) of spring wheat.
- Creation of an expert system for early (one season advance) drought prevention based on a comprehensive analysis of the results of hydrodynamic modeling, the results of studying large-scale atmospheric circulation and the state of the underlying surface, as well as space monitoring data.

In the course of that work[32], the drought was estimated by the average regional yield of spring wheat for 1966-2010, based on the calculation of the proportion of weather in the formation of the crop, for 8 major grain-growing regions of Kazakhstan. It was noted that the territories of the regions of Kazakhstan have a significant extent in latitude, and can be located in several natural zones. Accordingly, in such an area drought has a different intensity.

Long-term practice has shown that the hydrothermal coefficient of Selyaninov calculated for the period May-August (HTC 5-8) is the most suitable for assessing drought in Kazakhstan.

In 2015-2016 in the framework of the research work “Agroclimatic resources of the Republic of Kazakhstan under the conditions of climate change” carried out by the Branch of the Institute of Geography LLP of MES RK, an assessment of agroclimatic resources was carried out, as well as a series of agroclimatic maps for the regions of Kazakhstan were constructed (Fig. 2[33]).



[32] Baysholanov S.S. On the frequency of droughts in grain-sowing regions of Kazakhstan // Hydrometeorology and ecology. № 3. Almaty, 2010. RGP "Kazhydromet, C. 27-38.

[33] On the approval of the criteria and characteristics for determining adverse natural phenomena The order of the acting Minister of Agriculture of the Republic of Kazakhstan dated February 27, 2015 No. 9-2 / 174

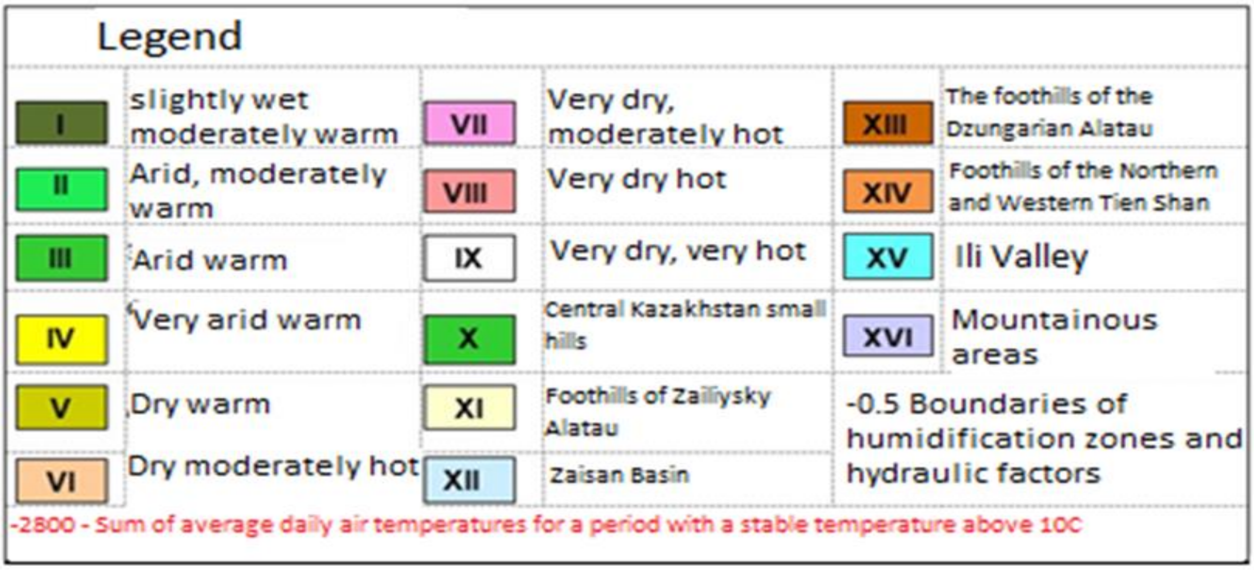


Figure 2 Agroclimatic zoning of the territory of the Republic of Kazakhstan

Analysis of the influence of adverse meteorological phenomena on crop yields showed that the share of atmospheric and soil droughts is about 80%, rain and hail - 14%, frost - 2%, severe frost and strong winds - 1[34].

It was shown that the negative potential consequences, especially for grain production, depend on the intensity of droughts, area and time scales of their impact (Fig. 3).

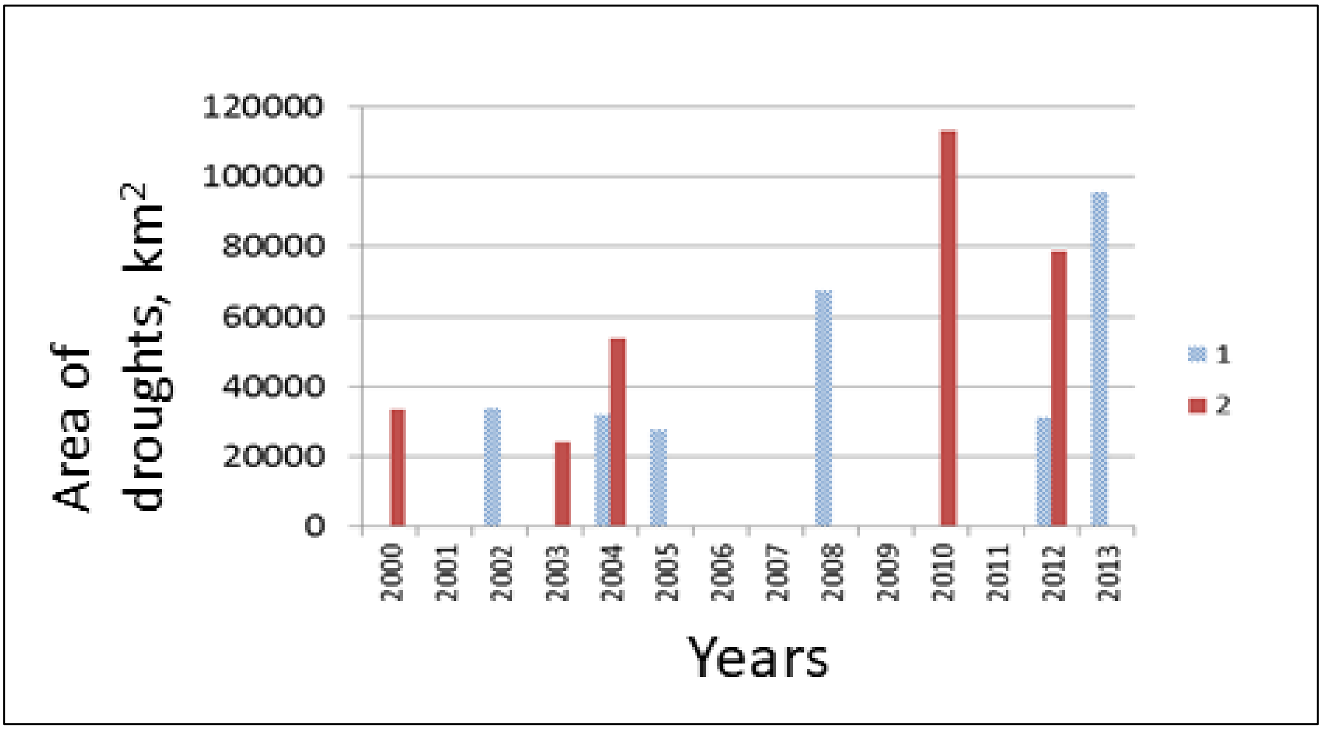


Figure 3 Distribution of agricultural droughts over the area with a decrease in the average yield of grain crops to 20 % (1 - weak drought) and by more than 20 % (2 - average drought) in 2000–2013 in the region of Northern Kazakhstan

For Kazakhstan, the destructive power of medium-intensity agricultural droughts should be attributed to a characteristic area of 100,000 km2. The impact of strong soil droughts covers the territory an order of

[34] WMO, 2014

magnitude greater (for example, 2010). According to other experts, the characteristic linear size of droughts reaches 1000 km (106 km2)[35].

Geo-portal of space monitoring of droughts in the Republic of Kazakhstan.

Since 2001, the National Center for Space Research and Technology JSC (hereinafter JSC «NCSRT») has been developing algorithms, methods and GIS technologies for solving a number of applied agricultural problems, including drought monitoring[36].

Since 2012, the representative office of the United Nations Development Program (UNDP) in the Republic of Kazakhstan implemented the project "Improving the resilience of the wheat sector in Kazakhstan to climate change to ensure food security in CA." Within the framework of the project, a pilot version of the drought space monitoring geoportal was created. The main goal of creating the geoportal is to provide interested Kazakhstan users (farmers, regional akimats and the Ministry of Agriculture) with information about the drought.

The project allowed the development of an integrated Internet-accessible geographic information system (WebGIS/Geoportal) and a drought early warning system, as well as the introduction of modern methods of monitoring and analysis of drought using remote sensing technologies in the agricultural sector of the Republic of Kazakhstan.

The main functions of the geoportal: The "Space Drought Monitoring" web-GIS allows users to view and analyze spatial data obtained by remote sensing methods using conventional web browsers. Web GIS implements functions: map navigation, spatial analysis, graphing, histograms, tables, information retrieval, geocoding, etc. To work in the Cosmic Drought Space Monitoring web GIS, the user does not need specialized software or a GIS specialist qualification.

Using the "Visualization and Graphics" section, you can select and display on the map as a raster layer, according to the generally accepted scale, NDVI data for various dates with eight-day averaging during the growing season from 2000 to 2017 (Figure 4).

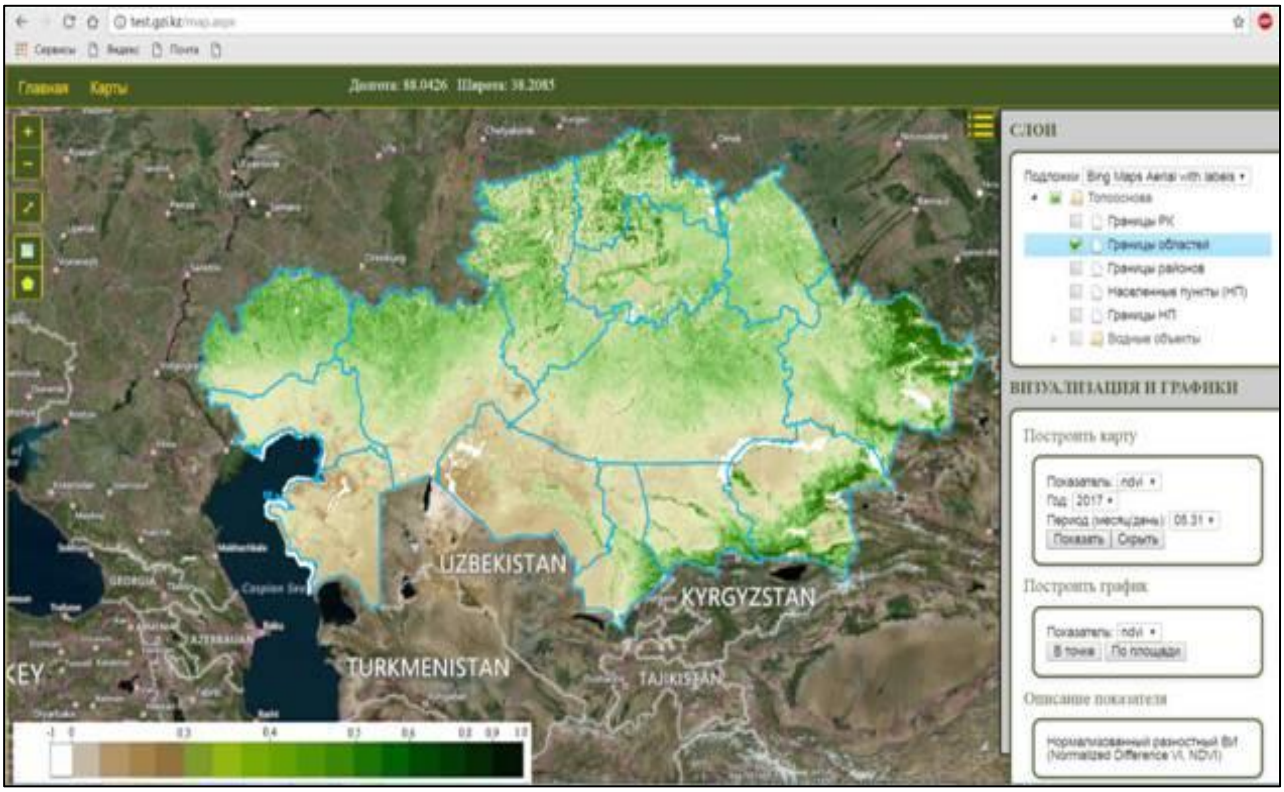


Figure 4 NDVI raster layer data with eight-day averaging over the selected period

35 Rusin I.N. Natural disasters and their forecast capabilities. Tutorial. - SPb: RGGMU, 2003 .-- 140 p.
36 http://zasuhi.gzi.kz/man 2.aspx

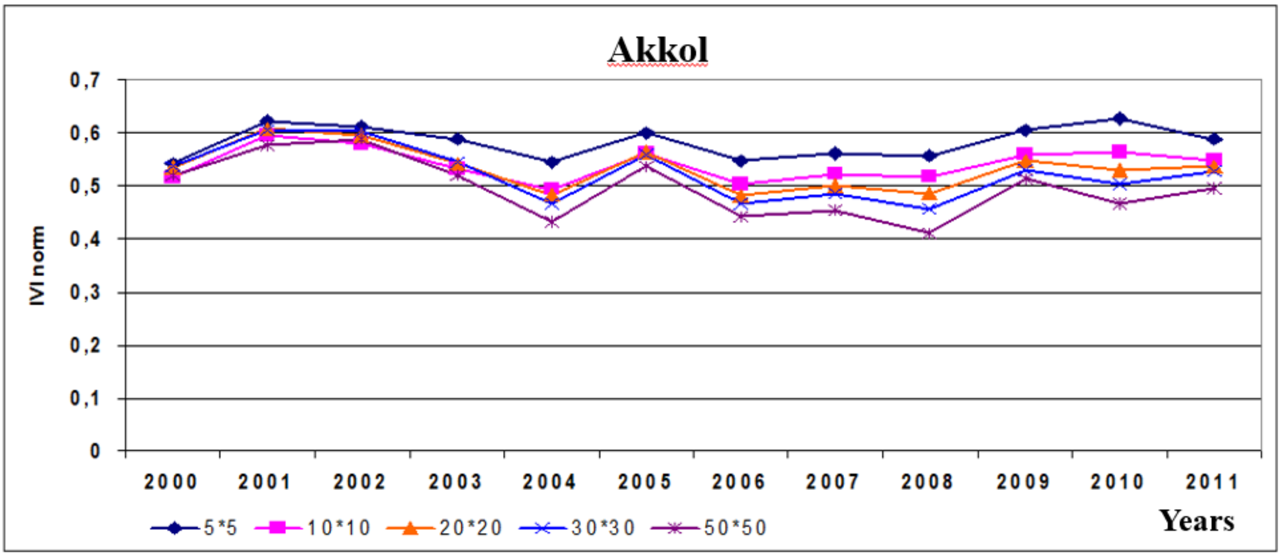
The main type of data presented on the geoportal is vegetation indices. The Vegetation Index (VI) is an indicator calculated as a result of operations with different spectral ranges (channels) of a remote sensing system, and related to the vegetation parameters in a given pixel of the image. The effectiveness of VI is determined by the characteristics of reflection; these indices are derived primarily empirically.

The functioning of the Geoportal ensures the achievement of the following results:

- the accuracy of assessing the degree and area of drought spread has improved;
- increasing of productivity and quality of labour of specialists due to their exemption from paperwork;
- improving of information support for research information of farmers, akimats and the Ministry of Agriculture;
- simplifying the exchange of scientific information on drought between government bodies and other interested organizations.

As an example, below is an example of some results of drought monitoring carried out in the JSC «NCSRT» (Fig. 5, 6).

To monitor droughts in satellite images around the selected meteorological stations (hereinafter MS), were distinguished rectangular sections of various sizes (5*5 km, 10*10 km, 20*20 km, 30*30 km, 50*50 km), the centers of which are MS. The long-term values of normalized vegetation indices IVI, averaged over the area of these sites, are determined.



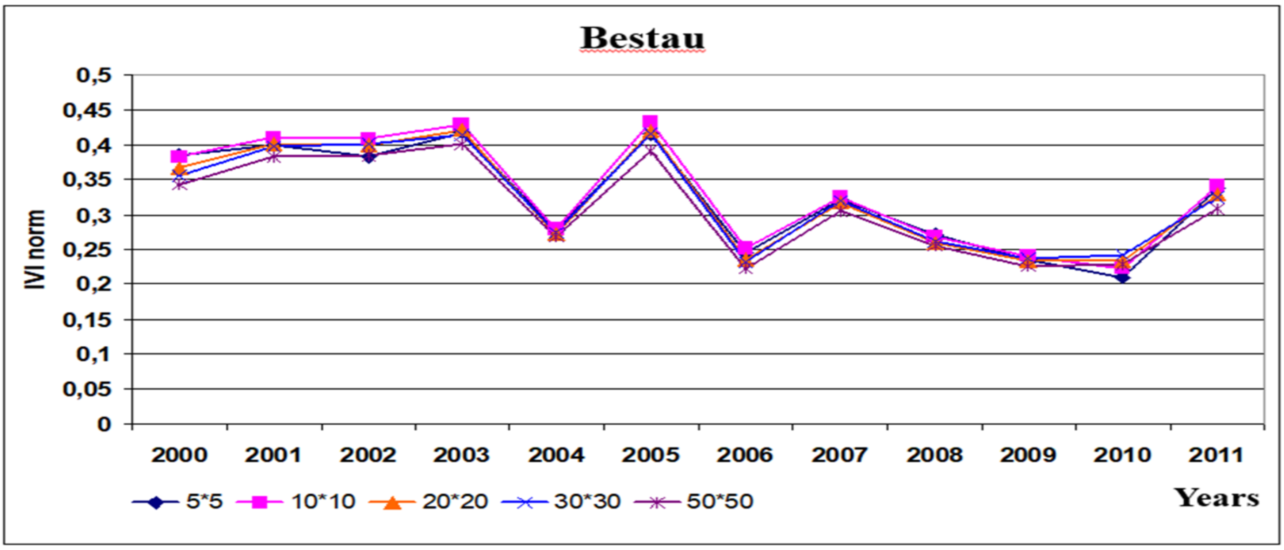
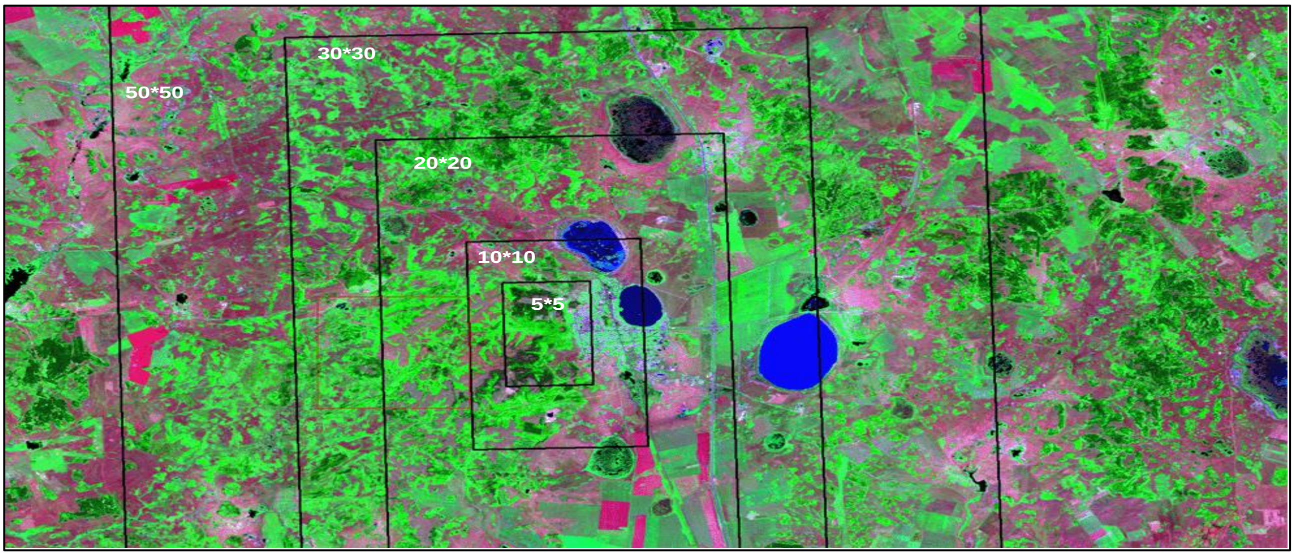


Figure 5 Long-term dynamics of the values of the vegetation index IVI for sites of various sizes

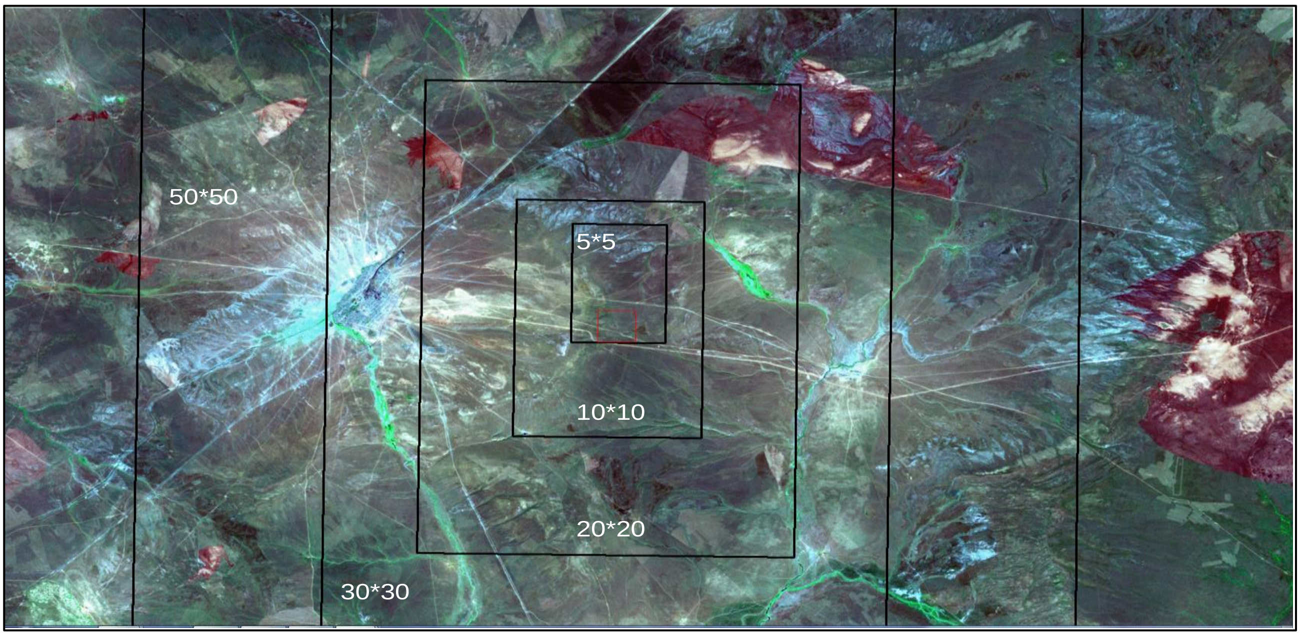
It should be noted that the largest scatter between IVI values in windows of various sizes is observed for Akkol MS, while the two other MS's do not differ significantly in IVI values. In addition, the nature of the long-term changes in IVI in Akkol differs from the IVI distributions for Bestau and Karaukelty MS. For each selected MS, information is provided on the long-term values of the hydrothermal coefficient (HTC) and Standardized Precipitation Index (SPI) for April-September (6 months) for the period 2000-2012. HTC is used in agricultural climate assessment to identify areas of different moisture supply of crops.

On the territory of the Akmola region, test sites 5*5 km in size were determined, the centers of which coincide with MS, within which the long-term distributions of satellite integrated vegetation indices calculated over the area of these sites over the period 2000–2012 were calculated.

Akkol



Karaukelty



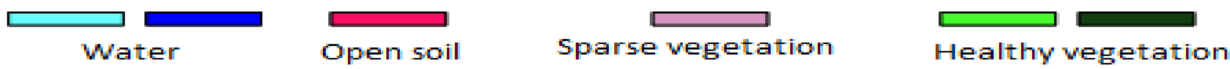


***Figure 6** Fragments of RGB composites constructed from LANDSAT satellite images for a number of MS*

An analysis of the dependence of the seasonal distributions of vegetation indices on moisture indices was carried out for 13 MS in Akmola region for the period 2000-2012 according to the following group of parameters:

1)ground information

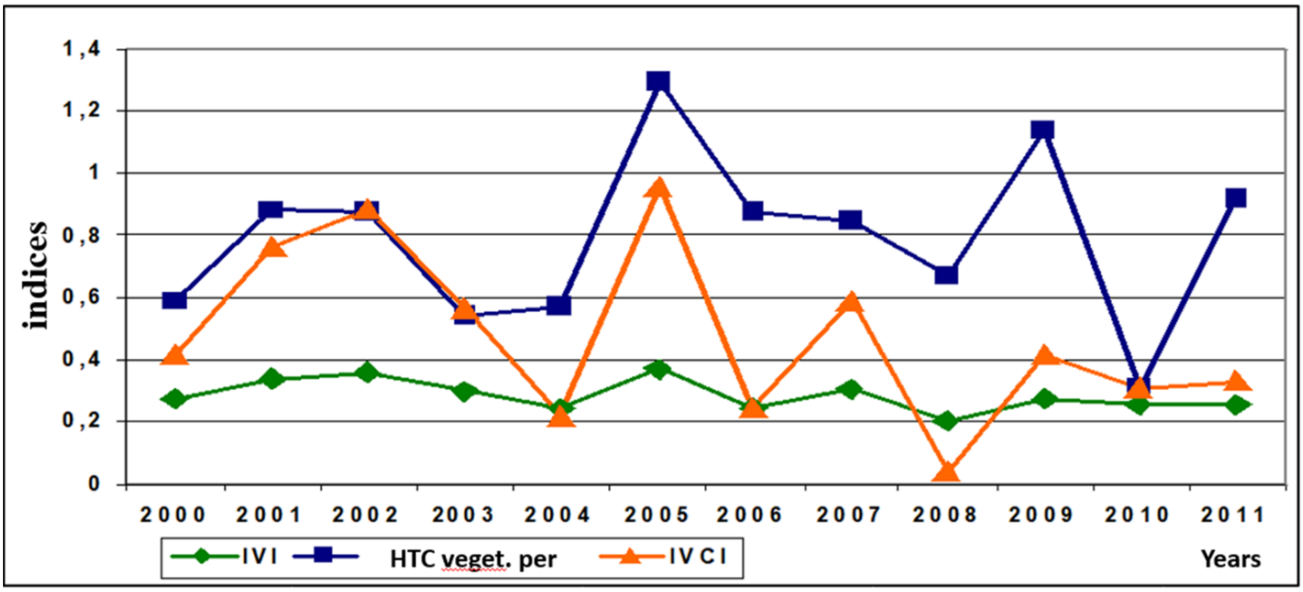
- SPI values - monthly and 6-month (April-September);
- HTC values are seasonal (April-September);

2) satellite information

- differential vegetative indices NDVI, VCI - every decade during the vegetation period (April-September);
- integral vegetative indices IVI, IVCI - seasonal.

Figure 7 shows the comparative dynamics of the HTC, IVInorm, and IVCI indices for MS Kokshetau and MS Atbasar. Similar data were plotted for all selected weather stations.

Kokshetau



Atbasar

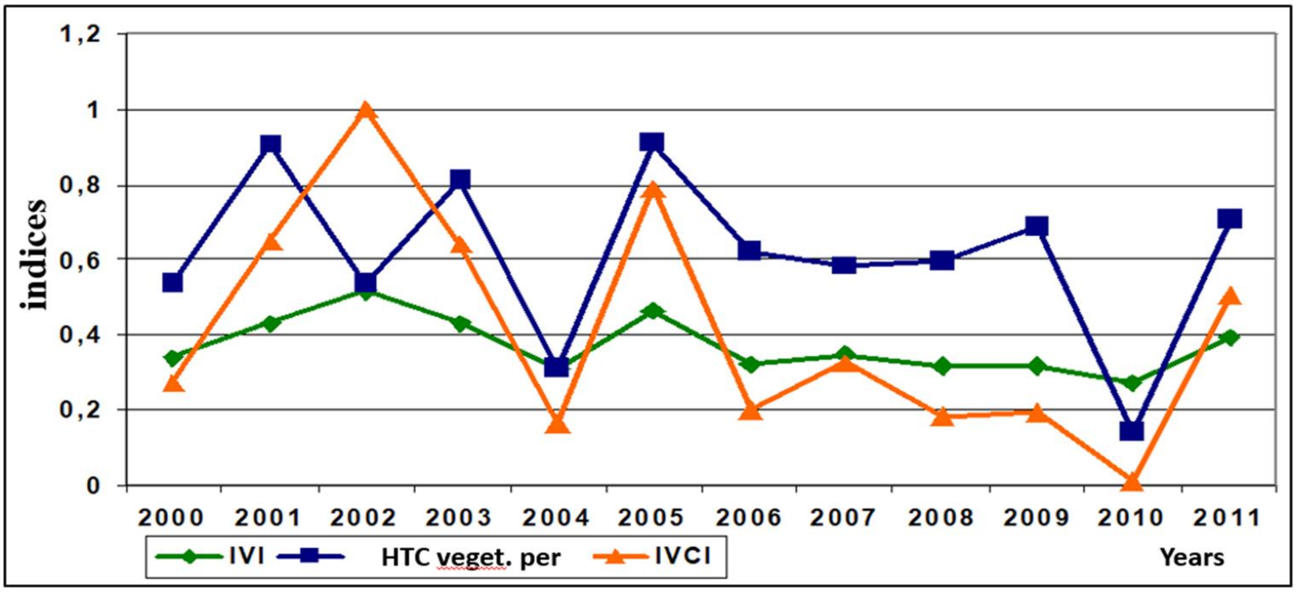


***Figure 7** Dynamics of satellite vegetation indices and HTC.*

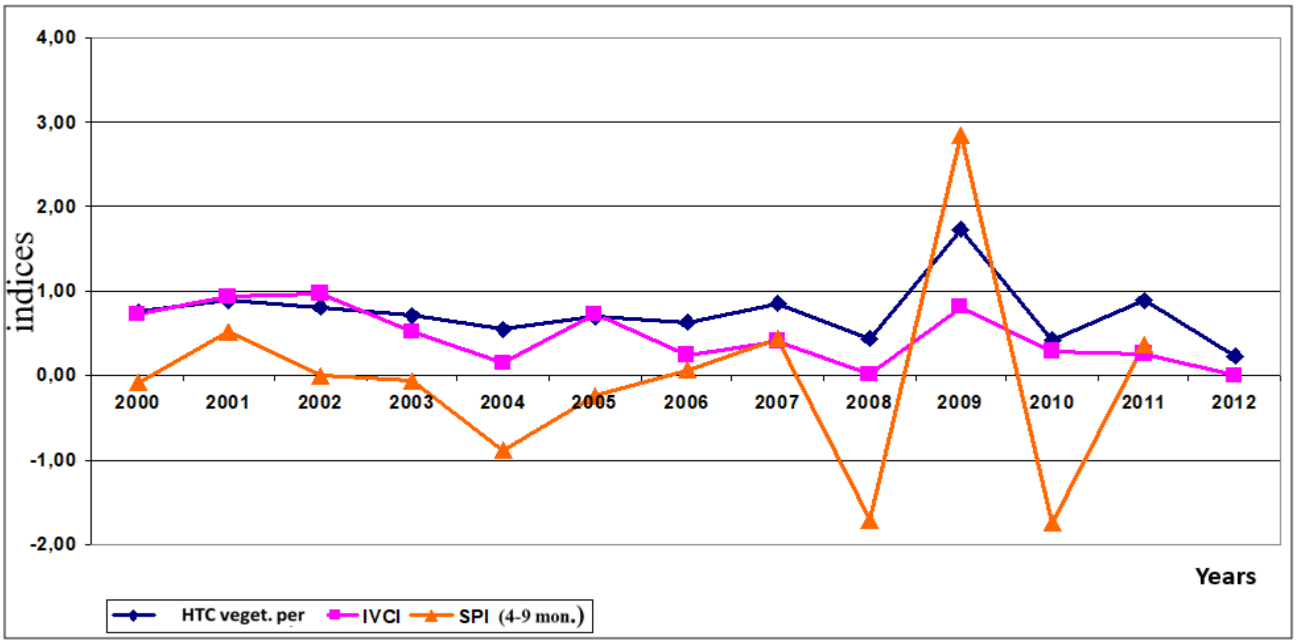
The graphs show a good agreement between the HTC and IVCI indices, whose behavior is similar. Comparison of only a pair of these indices allows us to evaluate their features, Figure 8 (for example, MS Zhaksy and MS Zhaltyr).

Studies have been conducted to detect patterns in the distributions of monthly average values of the index of vegetation conditions VCI and monthly values of the rainfall index SPI. However, no patterns were revealed.

IVI values are normalized to 10 to bring in the same scale with other indices. As can be seen from the figure, the IVI values are less pronounced while maintaining general trends, therefore, the IVCI index was chosen to compare satellite data with ground-based data.

Figures 8-9 show the results of calculations of the IVCI, HTC, SPI indices.

Stepnogorsk



Zhaksy

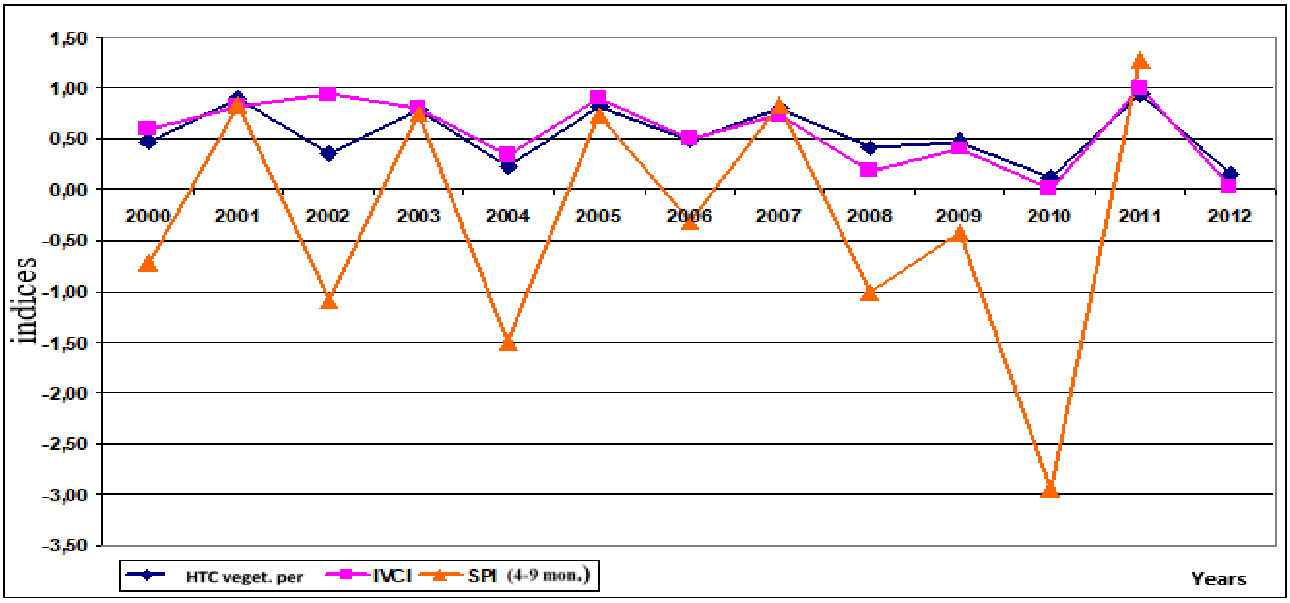
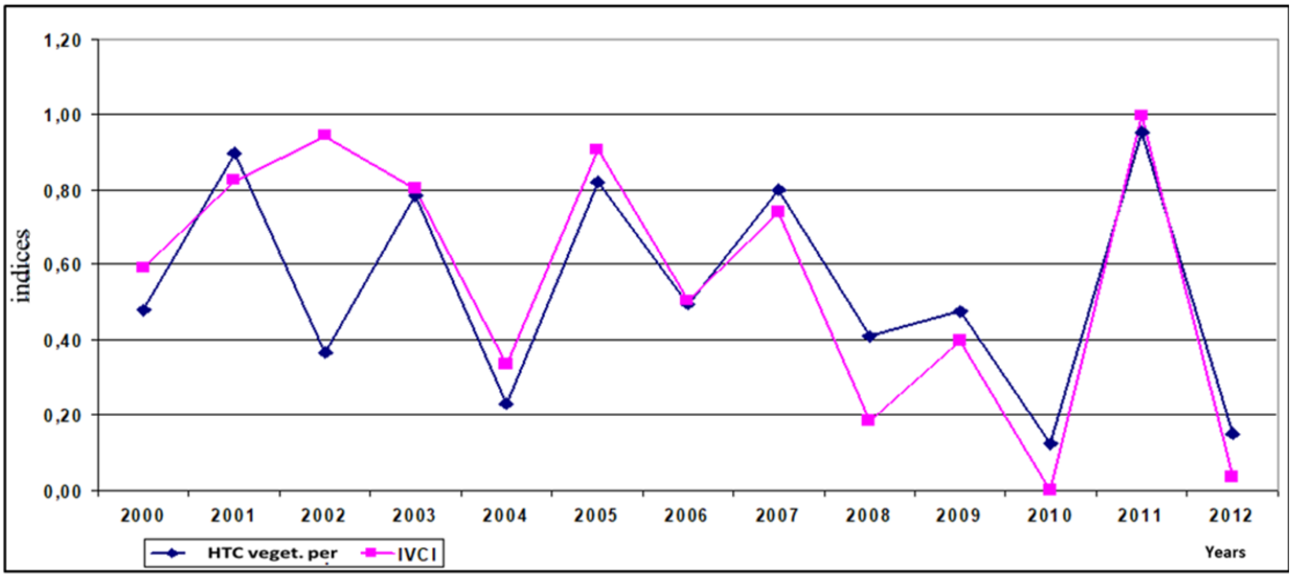


Figure 8 *Long-term dynamics of the HTC, IVCI, SPI indices for MS of Akmola region*

Zhaksy



Zhaltyr

Figure 9 The dynamics of indices and HTC IVCI for MS Zhaksy and MC Zhaltyr

3.2. Kyrgyz Republic: Drought Research Survey

In 2013, under the UNDP project "Climate Risk Management in Kyrgyzstan", the Climate Profile of the Kyrgyz Republic was prepared and adopted. The purpose of the profile is to analyze the first stage of actions to adapt to climate change, first of all, the level of observed and expected climate changes and the degree of their impact on the Kyrgyz Republic for the subsequent effective implementation of the necessary adaptation actions.

On the issue of drought monitoring, the profile for Kyrgyzstan recommends an approach using the following indices:

- The Standardized Precipitation Index (SPI), as the most common drought monitoring index in world practice;
- Standardized Precipitation and Evapotranspiration Index (SPEI);

- Coefficient of humidification by Ivanov.

Thus, an attempt was made to solve the problem of modeling possible changes in the ranges of deserts and semi-deserts with predicted climatic changes based on an analysis of the ratios of the annual precipitation to evaporation predicted for the future. For this, the analyzed territory should be provided with sufficiently reliable and detailed data on temperatures and precipitation, as well as some others, for a fixed initial period of time.

Based on the Coefficient of humidification by Ivanov for the conditions of the Kyrgyz Republic, the profile calculated the changes in moisture conditions in Kyrgyzstan for future periods for various scenarios of climate change[37].

In 2014, an article was published by Chinese scientists from the Institute of Soil Science, Agrochemistry and Economy of Irrigation Water, the Academy of Agricultural Sciences of the Xinjiang Autonomous Republic of China and the Urumqi Institute of Desert Meteorology of the Chinese Meteorological Bureau[38].

According to 9 weather stations of the Kyrgyz Republic located in different climatic and orographic conditions for the period 1971-2000, the aridity of the territory of Kyrgyzstan was calculated using the Palmer index and the spatial distribution of the average drought index for this period is presented.

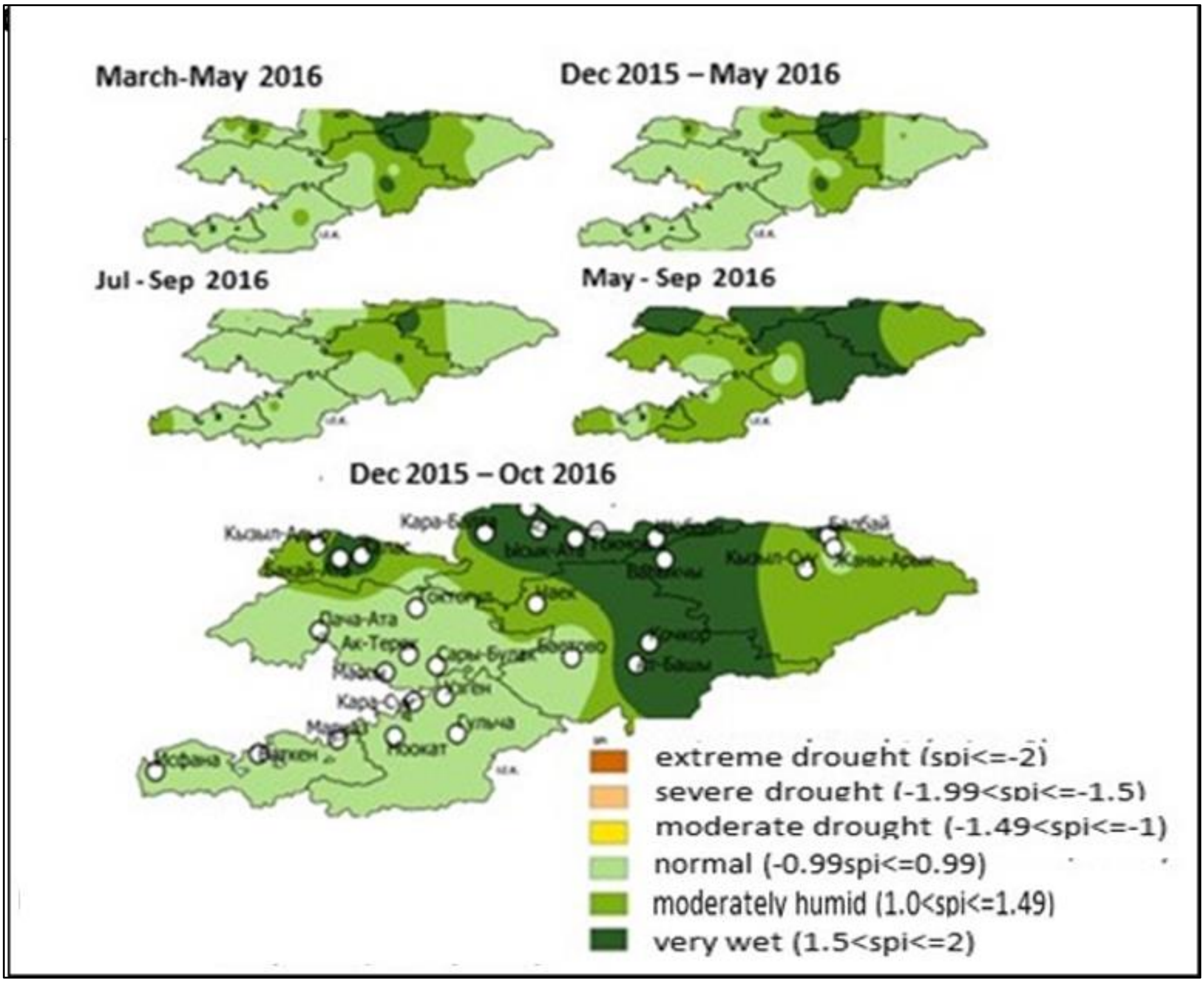


***Figure 10** The value of the SPI drought index for 2015-2016*

[37] Climate profile of the Kyrgyz Republic. - Ilyasov Sh., Zabenko O., Gaydamak N., Kirilenko A., Myrsaliev N., Shevchenko V., Penkina L. - B. 2013 - 99 p. Appendix 5

[38] Ding Feng, Pu Shenhai, Zhao Yong, Ma Xueqing, Geng Qinglong, Wang Xingyun. Analysis of the spatio-temporal characteristics of meteorological drought in Kyrgyzstan. Bulletin of the Kyrgyz National Agrarian University named after K.I. Scriabin. Bishkek, No. 3 (32). - 2014. - pp. 66-76.

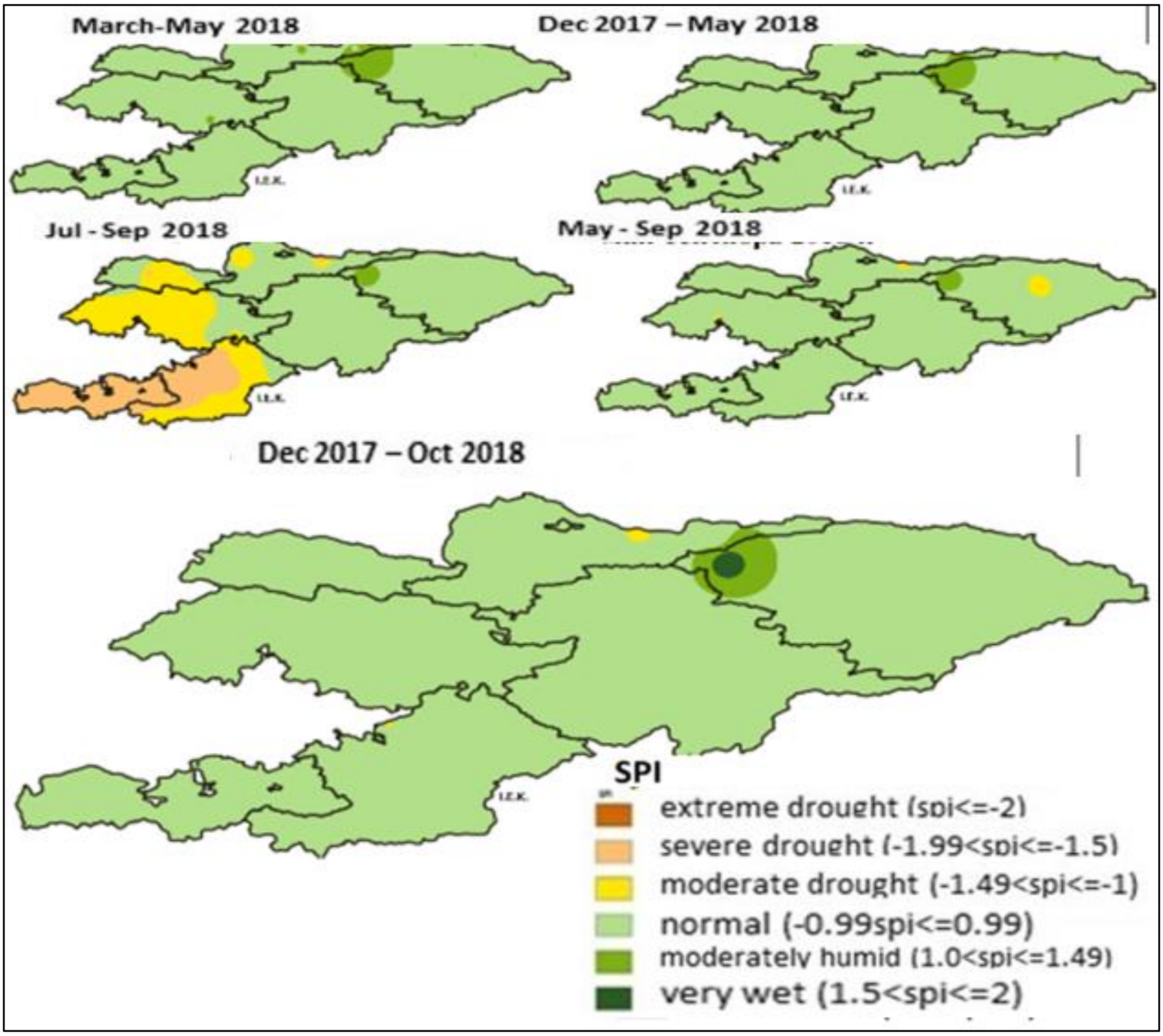


Figure 11 *The value of the SPI drought index for 2017-2018.*

The results of the studies showed that droughts gravitate towards the northwestern part of the country, the Palmer drought intensity index undergoes insignificant changes in the wet and dry seasons of the year, which is confirmed by an additional analysis of materials from weather stations of the Kyrgyz Republic for 1971-2000.

Due to the limitation of actual meteorological data for weather stations of the Kyrgyz Republic, the authors were unable to conduct localized corrections of the PDSI drought index in combination with the real situation in Kyrgyzstan and recognized the results of the analysis digestive. At the same time, the authors recognized that the index they use is not suitable for a mountainous country.

Since 2015, Kyrgyzhydromet has been calculating the SPI. For this, a specialized precipitation base was created in the department of agrometeorology at thirty agrometeorological posts for the period 1927–2018. In fig. 10 -13 shows the mapped index calculation results for 2013-2014[39] years. By using the calculated SPI values, maps of the distribution of this indicator by agrometeorological posts for individual years by months of the main spring-summer period of the growing season of grain crops were constructed. The calculated SPI values were interpolated by the method of inverse weighted distances (IDW) and their analysis showed a significant similarity with the agrometeorological assessment of drought conditions.

[39] E.K. Isaev, Sh.A. Omurzakova. On the possibility of identifying and modeling droughts in Kyrgyzstan. Bulletin of the Kyrgyz-Russian Slavic University; KRSU. 2019.No 11- C. 174-176.

For additional monitoring of drought, we used data from the MODIS satellite with a spatial resolution of 250 meters and constructed maps of the vegetation index NDVI (Normalized Difference Vegetation Index) and the average annual index of vegetation health (Mean VHI), which allows the user to estimate the total degree of drought for the entire vegetation period, studying health vegetation and the effect of temperature on the condition of plants. An analysis of the VHI map confirmed that in 2014, drought was observed in the agricultural zone, which negatively affected the productivity of crop production and animal husbandry.

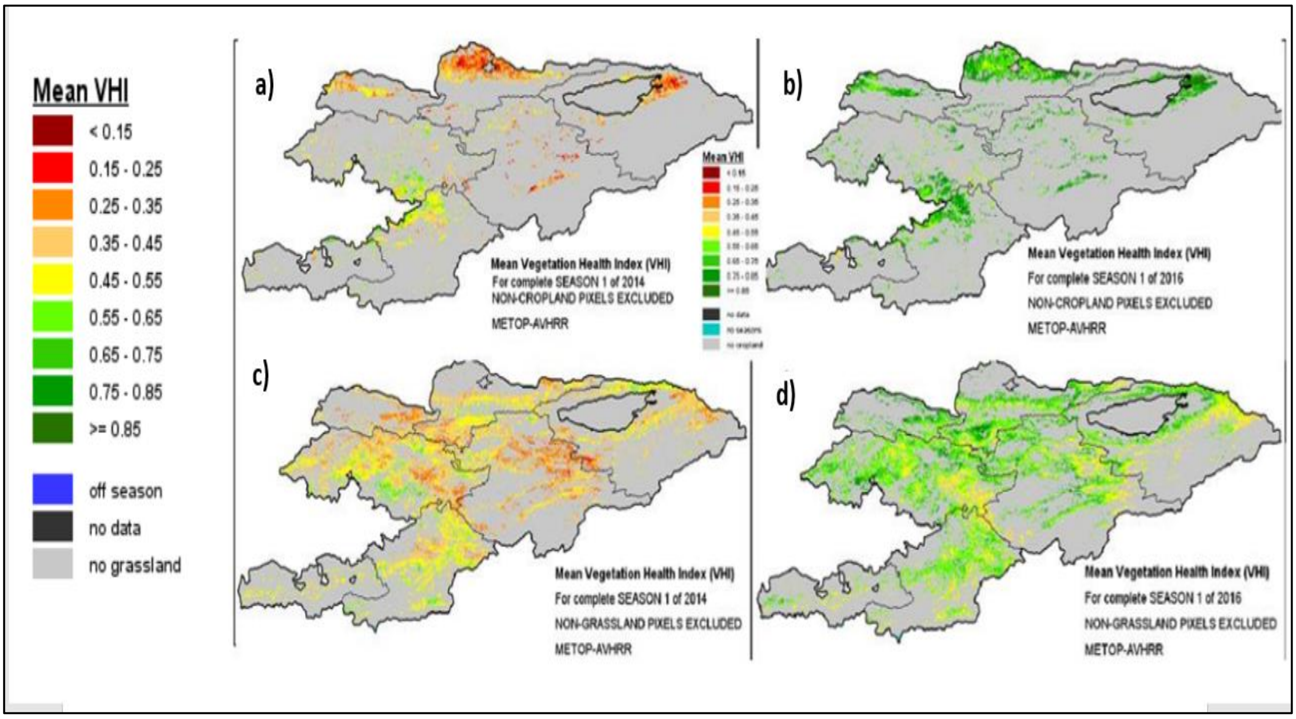


Figure 12 The value of the average annual VHI index.

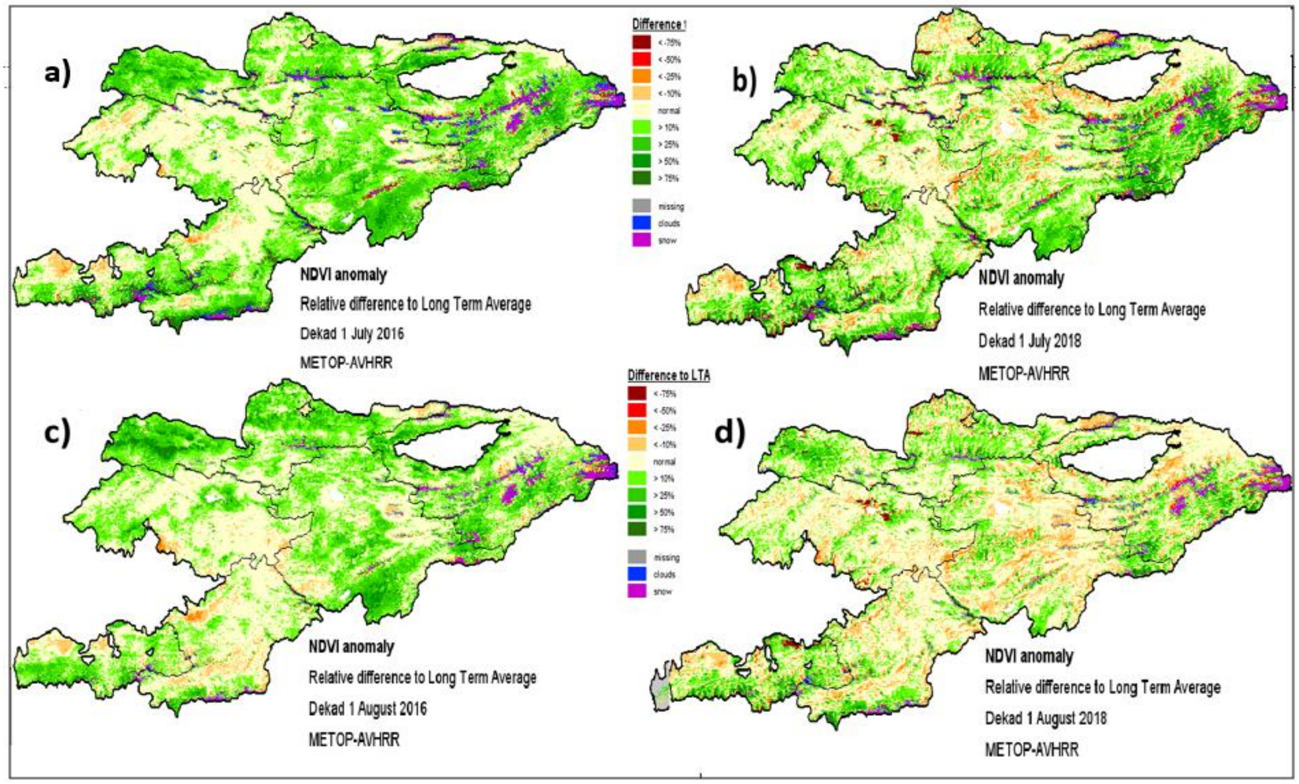


***Figure 13** NDVI Anomaly Value*

This conclusion is confirmed by the data of the National Statistics Committee of the Kyrgyz Republic, according to which in 2014 a low yield was observed throughout the territory of the Kyrgyz Republic. But the normalized difference index of vegetation (NDVI) is not sufficient for direct monitoring of drought and the NDVI anomaly is usually supplemented, which indicates a change in current weather conditions for vegetation. An analysis of the value of the NDVI anomaly showed that at the beginning of August 2016 and 2018, aridity was observed in some areas of the Batken and Jalal-Abad regions, which was confirmed by SPI calculations, but at the same time practically did not affect the yield of grain crops in these areas.

This, apparently, is explained by the fact that more than 60% of the territory of the agricultural zone of Kyrgyzstan is located in the zone of irrigated agriculture, where soil drought is partially stopped by irrigation. An additional analysis of water flow and river runoff during the drought period showed that there is a quite satisfactory similarity of the distribution of SPI with the average values of water flow in the rivers, as well as with grain yields. This indicates the possibility of using SPI in monitoring and forecasting hydrological, agrometeorological and meteorological droughts and that it is closely related to the yield of grain and leguminous crops and the average values of water flow in the rivers of Kyrgyzstan.

In the future, Kyrgyzhydromet plans to continue research on monitoring and modeling drought in Kyrgyzstan. To forecast hydrological, agrometeorological, meteorological droughts, a fairly accurate forecast of the amount of precipitation and temperature for a month-season-year is needed. In this regard, it is planned at Kyrgyzhydromet to introduce a model for a long-term forecast of precipitation and temperature, where the output of the model will serve as initial data for the drought and yield model. The use of the Palmer index in monitoring droughts in Kyrgyzstan, in addition to continuous and accurate series of observations, requires calibration of incoming and complementary coefficients across the republic to take into account its altitude dependence and orographic conditions, which is impossible without high-quality ground-based agrometeorological observations.

3.3. Republic of Uzbekistan: Drought Research Survey

Over the past two decades, Uzbekistan has experienced several extreme droughts, which destroyed between 50% and 75% of the crop. During the severe drought of 2000-2001 cereal production decreased to 14%, other crops - to 45-75%. The damage inflicted is estimated at approximately 130 million US dollars.

Climate change scenarios predict that the frequency of occurrence of droughts in Uzbekistan and their intensity will only increase. In the framework of the joint project of UNDP/AF and Uzhydromet “Ensuring Climate Stability of Farmers and Dekhkan Farms Located in the Dry Areas of Uzbekistan”, an early warning system for drought is being improved.

In 2017, as part of the project, equipment was installed to modernize the observational meteorological network consisting of 10 meteorological stations, which made it possible to improve the system of early warnings and ensure preparedness for the consequences of extreme hydrometeorological phenomena. In addition, the project will automate water level monitoring systems at two key posts - Tuyamuyun and Kipchak. The drought early warning system makes it possible to determine the projected amount of water resources this year in the upper reaches of the mountain rivers of Uzbekistan located in the zone of formation of natural flow, as well as in the lower reaches of the Amu Darya - areas of intensive water use for various needs, primarily for irrigation of agricultural land.

The hydrometeorological network of Uzbekistan to a lesser extent than in other countries of the Central Asian region has been reduced after the collapse of the USSR. As a downstream country, focused mainly on irrigated agriculture, Uzbekistan is heavily dependent on the water regime of its rivers. Low water on the rivers of Uzbekistan is formed with a low amount of precipitation in the zone of runoff formation and elevated air temperatures during snow accumulation. The following are accepted as an indicator of hydrological drought for the conditions of Uzbekistan:

- provision of water flow during the growing season (April-September);
- the amount of water reserves in the snow cover in the mountains at the end of February and March.

Years with water consumption of 90% and less than normal (long-term average values) are considered to be low-water.

To forecast the hydrological drought in Uzbekistan in the lower reaches of the Amu Darya river, new methods and approaches have been developed for their further inclusion in the drought early warning system (DEWS), based on the joint use of runoff simulation results in the zone of its formation and statistical approaches, such as regression and discriminant analysis, optimal averaging method and others.

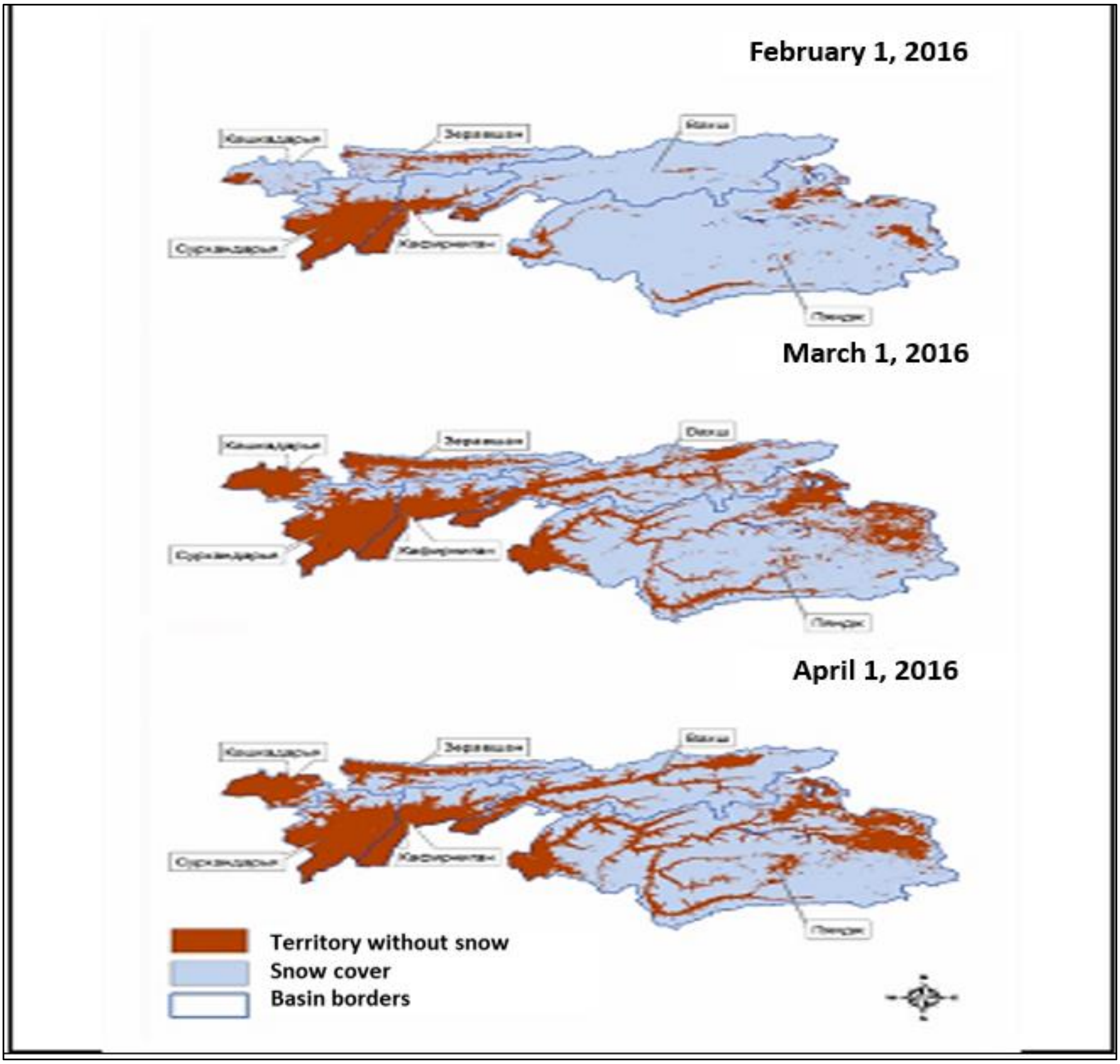


Figure 14 *Monitoring the state of snow cover in the upper Amu Darya in 2016*

Snow accumulation in the upper reaches of the Amu Darya river in the zone of runoff formation, as one of the main sources of river nutrition, is a good indicator of expected water content. Therefore, to predict water availability in the lower reaches of the Amu Darya river, it is important to assess the state of the snow cover using the calculation results from the model of snow cover formation in the mountains and remote sensing data. Figure 21 shows the dynamics of changes in the snow-covered areas of the upper Amu Darya mountain basins, obtained on the basis of satellite information for various periods – on the 1st of February, March and April 2016[40].

[40]Pak A.V. Development of a drought early warning system for the lower Amu Darya. - Bulletin of the Adaptation Fund project "Adaptation to Climate Change in Karakalpakstan", No. 1, 2015. - P. 3-4.

To assess the expected water content of the lower reaches of the Amu Darya river, a fairly simple approach has been developed using a Standardized Precipitation Index (SPI) and the Pedya's aridity index, when the expected water content is estimated based on the calculation of the indices. Testing this approach showed that estimates of the justification of the expected water content are 70-95%.

Another approach to solving this problem is based on a discriminant analysis that estimates, based on actual data on air temperature and precipitation, the probability of expected water availability - low-water (LW), medium-water (MW) and high-water (HW) years (Fig. 15 shows as an example grouping of years by water content, obtained by precipitation).

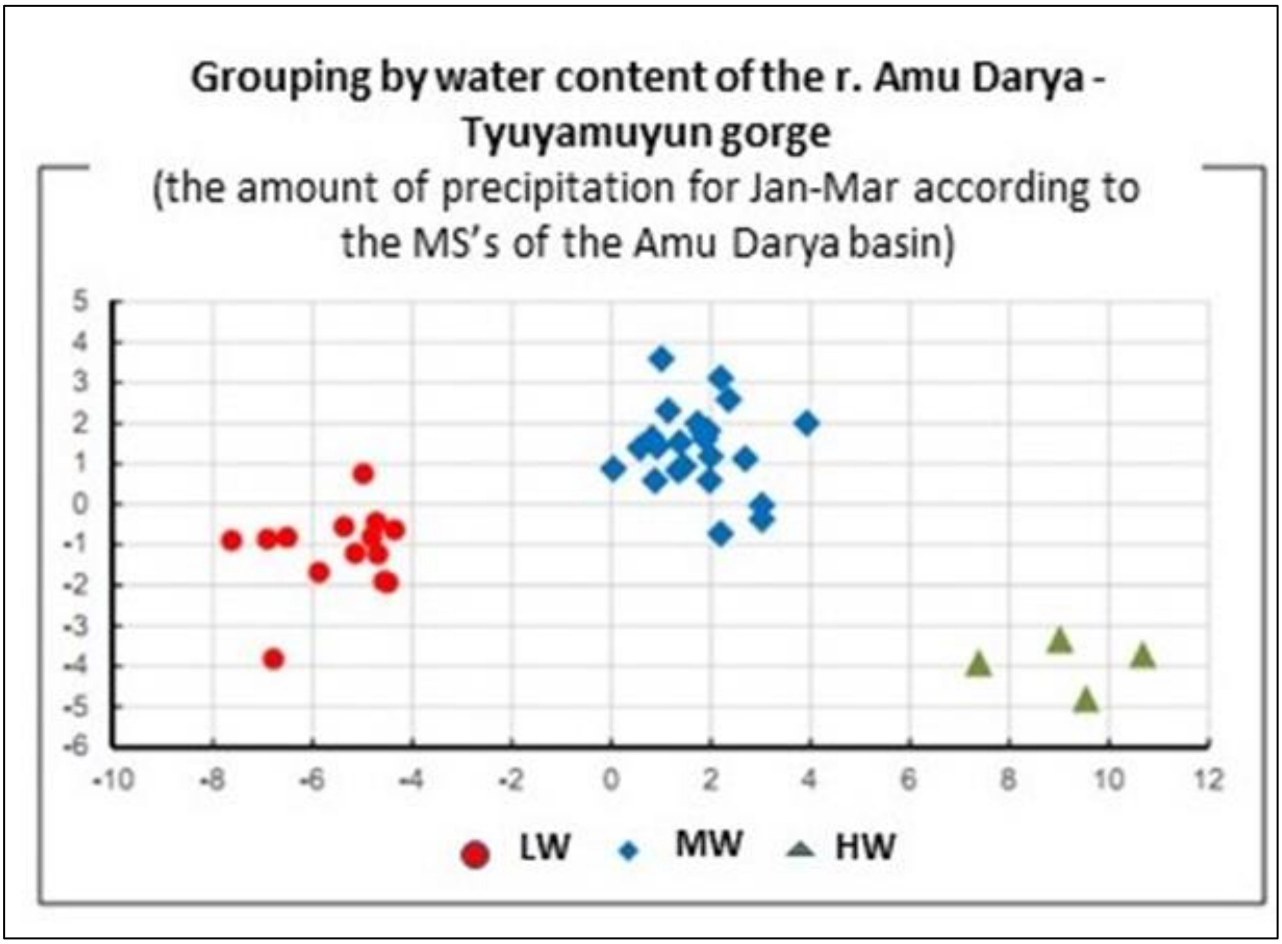


Figure 15 *Grouping of years by water availability based on discriminant functions (by MS of the Amu Darya basin)*

The developed forecasting methods and approaches for the lower reaches of the Amu Darya river provide a solution to two of the main forecasting tasks — the assessment of expected water availability and the forecasting of monthly and vegetative runoff (April - September).

This diagram shows the grouping of years obtained on the basis of discriminant analysis in three groups - LW, MW and HW. The justification for the qualitative assessment of water availability based on discriminant analysis is 88-100%. Two approaches have been developed to quantify the water content of the lower reaches of the Amu Darya in the Tyuyamuyun gorge - optimal averaging and linear multiple regression methods using the following data:

- monthly and seasonal (January - March) air temperature and precipitation values at weather stations of the Uzhydromet reference observational network;
- calculated drought indices for actual air temperature and precipitation for weather stations of the Uzhydromet reference observational network;

- snow reserves calculated for the model for the mountain basins of Kashkadarya and Surkhandarya (runoff formation zone);
- vegetation runoff calculated from the model (April - September) for the mountain basins of Kashkadarya and Surkhandarya (runoff formation zone);
- snow areas for various periods (from December to March) obtained from TERRA-MODIS satellite data for the mountain basins of the upper Amu Darya.

Using the considered methods makes it possible to issue a forecast of runoff from January to March and to predict vegetative and monthly runoff in the lower reaches of the Amu Darya river from April to September. The verification of forecasting methods carried out for the period 2011-2015 showed that the accuracy of runoff forecasts ranged from 80 to 100% (Fig. 16).

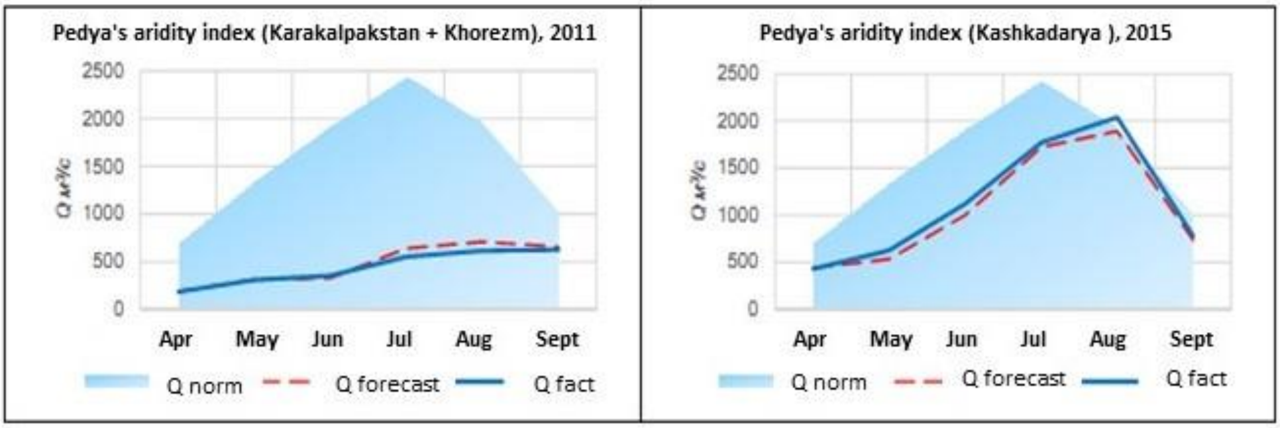


***Figure 16** Combined hydrographs of the predicted and actual runoff r. Amu Darya - Tuyamuyun gorge (the norm is the average long-term values of the monthly and vegetative runoff (from April to September)).*

The results of the practical use of the developed methods for forecasting runoff provide grounds for their integration into the early warning system for drought and recommendations for use in preparing prognostic information for interested users.

To forecast hydrological drought in Uzbekistan, the SPI and Pedya's aridity index are used, due to the simplicity of its calculation and the availability of standard meteorological data[41].

These indices are of a statistical nature, they are a measure of the deviation of the current values of meteorological parameters (one or more) from their distribution on a selected base interval and are used to monitor changes in aridity conditions over long time intervals.

Attempts are now being made to simultaneously use different indicators of aridity. Keeping track of both short-term changes in aridity (from several days to several months), essential for agriculture and forestry, and long-term changes (from several months to several years) with hydrological consequences are of great interest in the context of climate change.

For a monthly analysis of the changes that occur, both quantiles of these indices averaged over different time intervals (from 1 to 60 months) and combinations of these indicators are used. Built on the basis of the SPI and Pedya's index drought vulnerability maps, the most vulnerable zones can be identified. Figure 24 shows, as an example, drought vulnerability maps using the indicated indices for the Kashkadarya region, obtained on the basis of their extreme values (95% and 5% security, respectively).

One of the criteria for meteorological or atmospheric drought is considered to be a deficiency of water vapor saturation of more than 50 hPa. For the territory of Uzbekistan, the following scale of values of daily air

[41] Climate risk profile of Uzbekistan. Tashkent - 2015.

humidity deficit was adopted as an indicator of the intensity of atmospheric drought: strong - 61-70 hPa and > 80 hPa - very strong.

To analyze the observed changes in atmospheric drought in Uzbekistan for the past (1971-2000) and present (2001-2013) periods, actual data on the number of days at 32 meteorological stations located in all administrative regions of the republic were used. They were factual material for the analysis and generalization of the state of the atmospheric drought indicator in Uzbekistan (Fig. 17). The largest number of days with atmospheric drought in Uzbekistan is observed in Bukhara, Surkhandarya and Kashkadarya regions, where a large number of days a year with air temperatures above 40 ° C are also observed.

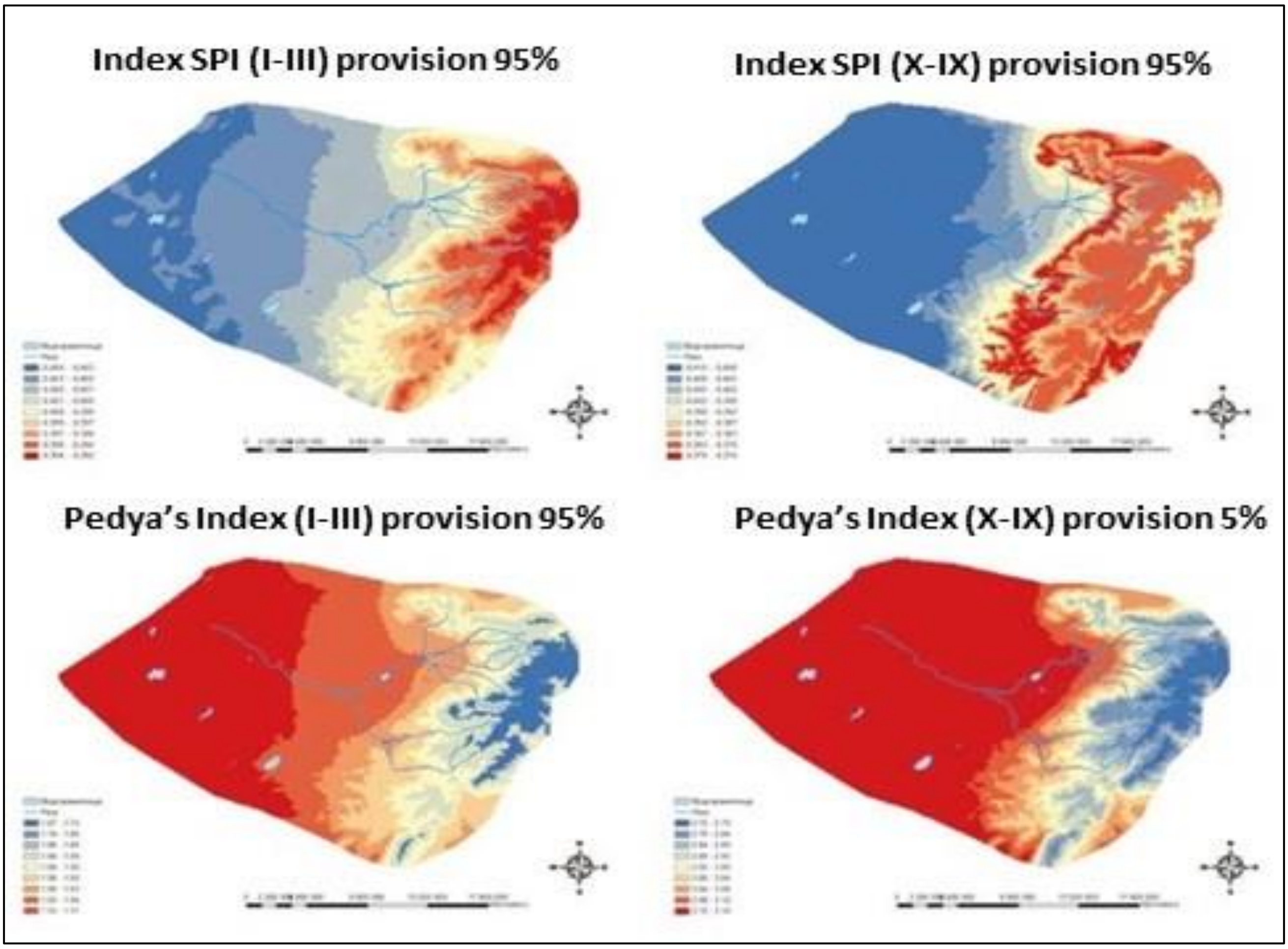


Figure 17 *Drought vulnerability maps of the Kashkadarya region of Uzbekistan*

Meteorological drought. One of the criteria for atmospheric drought is considered a deficiency of saturation of water vapor of more than 50 hPa. For the territory of Uzbekistan, the following scale of values of daily air humidity deficit was adopted as an indicator of the intensity of atmospheric drought: strong – 61-70 hPa and > 80 hPa - very strong.

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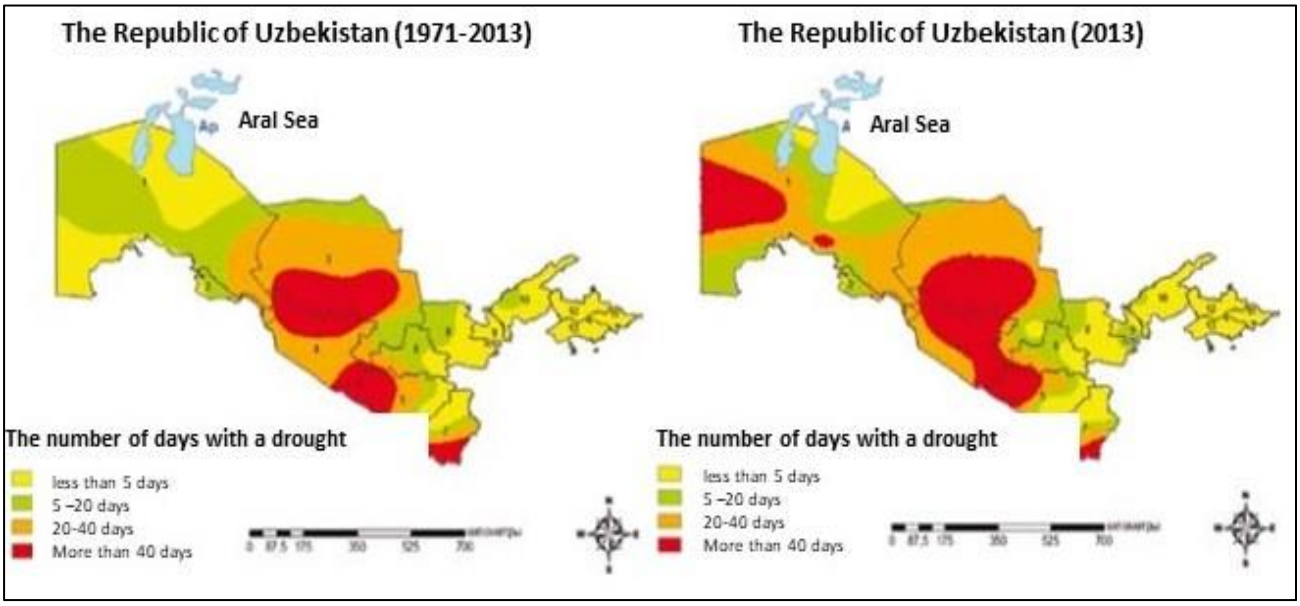


Figure 18 *Maps of the distribution of the number of days with an indicator of atmospheric drought*

These drought vulnerability maps are constructed using a GIS system based on the drought indices SPI, Pedya's index and E ≥ 50 hPa and allow one to clearly identify the most vulnerable zones of the territory[42].

4. OPPORTUNITIES FOR CREATION IN CENTRAL ASIA THE DROUGHTS EARLY WARNING SYSTEM FOR MANAGEMENT PURPOSES

4.1. Opportunities and difficulties in creating a drought early warning system in Central Asia

Droughts cannot be prevented even with a good prediction. But timely identification according to clear criteria contributes to the adoption of the most appropriate in the current circumstances managerial and economic decisions aimed at reducing damage.

Fundamentally, the task of predicting drought consists of solving two successive problems: the first of which is the forecast of the level of air temperature and the amount of precipitation, and the second is the conversion of the predicted values of air temperature and amount of precipitation into any drought indices that best characterize the humidification conditions in a given local point.

Prediction of humidification conditions, especially for a long period ahead, belongs to the class of complex scientific and practical problems, since there are still no reliable methods for long-term forecasting of air temperature, and especially the amount of precipitation. Since drought occurs with a long-term deficit of precipitation, the so-called extended forecast (for a period of 10-30 days), long-term forecast (for a period of 30 to 60 days) are relevant from the point of view of its forecasting. Moreover, in connection with the global climate change, the regional climate forecast (for a period of more than 2 years) becomes important, on the basis of which it would be possible to assess the change in humidification conditions.

The drought early warning system is a tool for assessment, monitoring, warning and decision-making, supported by the necessary information platform, which ensures the dissemination (warning) and exchange of necessary information. The goal of the Drought Early Warning System (DEWS) is to provide decision makers with correct data and needed emergency information.

[42] Climate risk profile of Uzbekistan. Tashkent - 2015.

Extreme events such as droughts have different spatio-temporal scales and are due to various physical processes. There are various very conflicting points of view on the causes of their occurrence. Some authors attribute the appearance and development of stable anomalies of atmospheric circulation and related weather extremes to orographic instability[43]. Another approach considers the barotropic instability of the mean flow as the main mechanism of low-frequency variability (LFV)[44]. A number of authors emphasize the important role of synoptic-scale eddies[45][46]. In addition to the internal dynamics of the atmosphere, the role of external factors, primarily the temperature of the ocean surface, is also studied[47]. The question remains open about the role of natural variability of the climate system and anthropogenic factors in the formation of extreme meteorological values and their spatio-temporal variability.

On the monthly and seasonal time intervals, based on the analysis of global and regional data of hydrometeorological observations and reanalysis, the relationships of weather extremes with the LFV of the ocean system - atmosphere and atmospheric circulation are traced[48]. The nature of the atmospheric circulation regimes and extreme weather phenomena is being actively studied using hydrodynamic models of varying degrees of complexity, including ensemble hydrodynamic systems. The methods of automatic classification, including tubing and factor analysis with rotation, are widely used to identify atmospheric circulation regimes, to identify large-scale structures and associated extreme quantities.[49]

In the past 10 years, hydrodynamic systems based on the use of ensembles have become a new important source of information on extreme meteorological phenomena. Methodologically, the use of forecast ensembles, or ensemble forecasting systems (EFS) is justified by the inevitable errors in the initial state estimates and the imperfection of the developed hydrodynamic models[50]. As a rule, fundamental considerations regarding the instability of atmospheric processes are added: inaccurate knowledge and imperfection of models are projected onto flow instability. Since, from a mathematical point of view, the problem is a boundary problem, errors can be added to the listed factors in the description of the boundaries. As a rule, ocean surface temperature fields are considered as “variable” boundaries. The scatter of the trajectories obtained with the help of ensembles allows us to judge possible scenarios for the development of atmospheric processes and extreme events.

The use of ensembles of hydrodynamic forecasts together with observational data allows us to expand the range of methods for studying the problem of extreme meteorological phenomena and raise the question of their statistical predictability. In the study of extrema (emissions) of independent identically distributed random variables, the conclusions of the well-known Gnedenko theorem on extreme types of distributions obtained in 1943 are used. Numerous examples of the widespread use of these results are given in the work[51], where a new type is studied in detail - the exponential distribution. In addition to the generally accepted means: median, mode and mathematical expectation, a new type of average was introduced, called the characteristic extremum. The properties of extremes are inextricably linked with problems of exceeding of high levels[52] or positive or negative emissions when crossing a certain level from below or above[53].

[43] Cessi P., Speranza A. Orographic instability of nonsymmetric baroclinic flows and nonpropagating planetary waves // Journal of the Atmospheric Sciences. - 1985. –Vol. 42. - PP. 2585-2596

[44] Frederiksen J.S. The role of instability during the onset of blocking and cyclogenesis in Northern Hemisphere synoptic flows //Journal of the Atmospheric Sciences. – 1989. –Vol. 46, №. 8. – PP. 1076-1092.

[45] Higgins R. Schubert S. Simulated life cycles of persistent anticyclonic anomalies over the North Pacific: role of synoptic-scale eddies // Journal of the Atmospheric Sciences. – 1994. –Vol. 51, № 22. – PP. 3238-3260.

[46] Sheng J., Derome J. Dynamic forcing of the slow transients by synoptic – scale eddies: an observational study// Journal of the Atmospheric Sciences. –1993. –Vol. 50, № 5. – PP. 737-751.

[47] Hoskins J., Karoly D. The sready linear response of a spherical atmosphere to thermal and orographic forcing// Journal of the Atmospheric Sciences. –1981. –Vol. 38. – PP. 1179-1196.

[48] Hurrell JW Decadal trends in the North Atlantic Oscillation regional temperatures and precipitation // Science. - 1995. - No. 269. - PP. 676-679.

[49] Ward MN, Navarra A. Pattern analysis of SST-forced variability in ensemble GCM simulations: examples over Europe and the Tropical Pacific // Journal of Climate, 1997. - Vol. 1. –PP. 2210-2220.

[50] Muravyov A.V., Kulikova I.A. Forecast ensembles: methods, problems and prospects // Meteorology and hydrology. - 2005. - No. 3. - p. 5-23.

[51] Gumbel E. Statistics of extreme values. - M.: Mir, 1965.- 450 p.

[52] Leadbetter M., Rotsen H., Lindgren G. Extremums of random sequences and processes. - M.: Mir, 1989.- 392 p.

[53] Tikhonov V.I. Emissions of random processes. - M.: Nauka, 1970.- 392 p.

Distributions of extreme values can be used in modeling and forecasting extreme events, for example, droughts and floods, extreme temperatures, precipitation, and other meteorological values.

The use of parametric methods involves a priori knowledge of the theoretical law of distribution of the studied quantity or its determination from empirical data, which necessitates checking the consistency of empirical data and the selected theoretical law. However, given the amount of data available, it is difficult to obtain statistically stable estimates of the main characteristics of the processes. The presence of large archives of model calculations and reanalysis partially solves the problem, although it does not completely remove the problem of the significance of the estimates obtained. Since the selective effect is sometimes significant, it is necessary to use robust statistics, various randomizations, and formulate the conclusions in terms of exploratory analysis[54]. Difficulties in determining a priori distributions make it necessary to resort to nonparametric methods for estimating position and scattering using characteristics such as medians and quantile ranges. So, for example, in work[55] the determination and identification of emissions and extreme values is based on quartile analysis and threshold values.

Thus, the analysis of modern research on the theoretical aspects and difficulties of creating a mechanism for early warning of droughts showed that there is still a lot of uncertainty regarding issues of climate change and the conditions for the formation of extreme weather phenomena in the Central Asian region. Accordingly, a set of research is needed in the region for detailed study of the conditions for the formation of droughts based on a comprehensive analysis of processes in the ocean-atmosphere-land-cryosphere system. An integrated approach using hydrodynamic, statistical and synoptic methods can serve as one of the most acceptable options for solving this problem.

Appendix 3 shows the main integrated systems for monitoring the state of vegetation cover, crops, predicting their productivity and early warning of droughts used in world practice.

4.2. The main activities in the Central Asian region on the improvement of existing monitoring systems and creating an early warning system

Despite the above difficulties in the process of creating an early warning system in the region, attempts are being made to overcome them.

All countries of the Central Asian region have adopted National Action Programs (NAPs) to combat desertification. The programs identified the country's main priorities for the implementation of the UNCCD and a number of measures, the adoption of which was supposed to contain the processes of desertification, degradation and the prevention of droughts. One of such measures was the creation of an observation and control system on desertification and drought problems and the introduction of modern monitoring methods. The study of desertification processes and assessment of their impact on the environment are carried out by specialists in the framework of grants and international projects, but these works were not conducted on an ongoing basis and are episodic in nature.

In the framework of the National Action Programs (NAPs) to combat desertification, which were prepared: in Kazakhstan and Turkmenistan in 1997, in Uzbekistan in 1999, in Kyrgyzstan and Tajikistan - in 2000, the NAPs include different directions, but the main goal this cooperation was the harmonization of subregional interests, the solution of problems of mutual use of cross-border resources and the prevention of possible conflict situations, the expansion of regional and international exchange of information and experience, the development and implementation of joint programs and sustainable improvement of the socio-economic conditions of the region.

In the process of creating a system for monitoring and evaluating desertification processes, as well as creating an early warning system and mitigating the effects of droughts, it is necessary to resolve the following:

[54] Tukey D. Analysis of the results of observations. Exploratory analysis. - M.: Council with some radio, 1981. - 350 p.
[55] Muravyov A.V., Kulikova I.A., Kruglova E.N. Distribution of extreme atmospheric circulation characteristics according to reanalysis and hydrodynamic modeling // Meteorology and Hydrology. - 2009. - No. 7. - p. 33-47.

- Development and creation of the necessary information base for launching drought monitoring and early warning systems for the drought prevention;
- Integration into the existing drought monitoring system a comprehensive approach with the use of land and remote sensing methods;
- Development of general and special indicators for the drought prevention with consideration of climate change, surface structure and topography of the region countries;
- Compilation of short- and medium-term forecasts on the dynamics of glaciers and water resources;
- Establishment and effective use of the drought early warning system for agricultural and population needs;
- Development of new and adaptation of traditional methods to combat land degradation and drought based on the use of population capacity;
- Assessment and forecast of damage from desertification and drought.

To some extent, these tasks were partially solved in the countries of the region, but the creation of an effective system for monitoring droughts and DEWS encountered the following difficulties:

- Insufficient monitoring network density especially in the flow formation zone;
- Insufficient development of the component of automatic hydrometeorological measurements in the current existing monitoring network;
- Lack of primary and accessible monitoring databases in electronic form, often data is stored on paper;
- Difficulties in access and exchange of information between countries and departments;
- Lack of feedback from the most vulnerable community for drought monitoring and DEWS operation;
- Lack of a methodology for integrated monitoring of droughts, experience in its implementation and analysis;
- The fragmentation of methodological and methodological information directly or indirectly related to risk assessment, drought prevention, adaptation and mitigation;
- Difficulties in financing the reorganization of hydro services in the development, adaptation and testing of drought indices.

When disseminating information and prompt notification, the following problems occur:

- The notification is carried out at the level of key ministries and departments, and there is no systematic notification of end users;
- The information in the distributed sources is intended for specialists and is difficult for end users to understand;
- Weak awareness of various user groups about drought risks, water-saving technologies and DEWS;
- The difficulty of prompt notification of end users due to the lack of reliable and affordable means for obtaining information.

An example of creating such a system is the analysis of the results of world practice of modeling drought monitoring (Appendix 3).

The main technical problem for updating the aridity indices for the territories of the Central Asian countries will be a rare network of agrometeorological stations, their outdated equipment and an observation program. To calibrate the indices, observations of the state and humidity on its surface and various depths and evaporation are necessary, and the development of drought models requires an accurate hydrological forecast, as well as a forecast of air temperature and precipitation for a long period. Calculation of aridity according to the simplest indices and supplementing them with satellite monitoring data by the hydrometeorological services of Uzbekistan, Kazakhstan and Kyrgyzstan is possible now and so far, it forms the basis of the DEWS in these countries.

4.3 Climate risk management and adaptation mechanisms. Measures to reduce drought vulnerability that used in the region

Climate Risk Management (CRM) is an integrated approach to addressing short-term variability and long-term climate change. It includes both elements of adaptation to changing climatic conditions and mitigation of impacts on climate change, as well as issues of natural disaster risk reduction. In Central Asian countries, work is underway to manage climate risks and prioritize adaptation to possible changes in climatic conditions.

The following are examples of such studies.

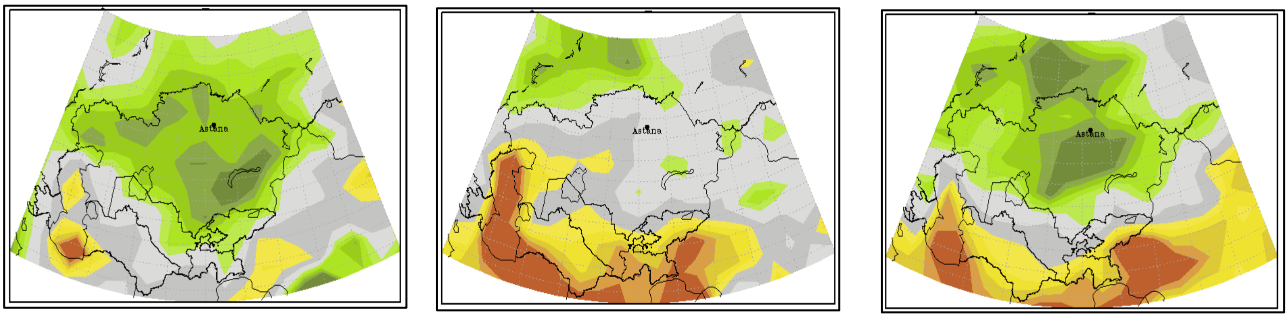
Republic of Kazakhstan

Of interest is the work on creating a system for the early diagnosis of droughts for control purposes based on a computationally effective semi-Lagrangian global finite-difference model of general atmospheric circulation[56].

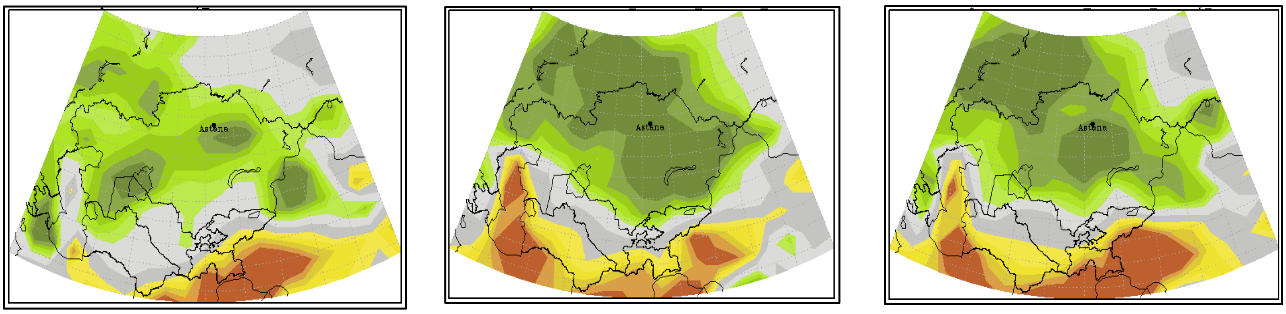
Recent studies have revealed a number of important potential sources of intra-seasonal predictability that offer hope for progress in this area [57] [58] [59].

Figure 19 shows prognostic maps of the spatial distribution of the atmospheric aridity index Si, proposed by Pedya for October, November, December 2016 and January 2017, as well as for the seasons October – December 2016 and November 2016 - January 2017.

. a) b) c)



d) e) f)



[56] Drought risk management technologies in the Republic of Kazakhstan: monograph / V.G. Salnikov, I.A. Kulikova, E.A. Talanov, G.K. Turulina, S.E. Polyakova. - Almaty: Kazakh University, 2018. - 196 p.

[57] Kiktev DB, Tolstykh M.A., Mirvis V.M. On the predictability of extreme meteorological phenomena on time scales prior to the season // Collection of reports “Extreme floods in the river basin. Cupid: forecasts, reasons, recommendations. " - M: Roshydromet, 2014. - P.54–66.

[58] Tischenko V.A., Kozeltseva V.F., Kuznetsova N.N. The recurrence of dry periods in Moscow in the warm half-year // Transactions of the Hydrometeorological Research Center of the Russian Federation. - 2016. - Issue. 359. - p. 161-177.

[59] Michaelides Ed.S. Precipitation: Advances in measurement, estimation, and prediction. - Berlin-Heidelberg: Springer Verlag, 2008.- 540 p.

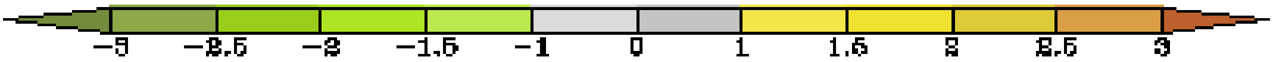


Figure 19 Hydrodynamic forecasts of the atmospheric aridity index: a) for October 2016, b) for November 2016, c) for December 2016, d) for January 2017, e) for October - December 2016. , f) for November 2016 - January 2017. The forecast was compiled on September 30, 2016

Another important source of information about a possible drought is the EFI (Extreme Forecast Index)[60], calculated on the basis of ensemble forecast information. The EFI is a continuous measure of the difference between a specific predictive model (empirical) and the corresponding climate model probability distributions of a meteorological parameter.

EFI calculation is a form of probabilistic interpretation of the results of ensemble prediction systems. In this case, extremes are determined not with respect to the observed, but to the model climate.

Estimates of the quality of forecasts of atmospheric aridity parameters

Examples of span diagrams for SPI indices calculated from reanalysis data and historical forecasts for the winter, spring, summer, and autumn seasons for Kostanay, Irtyshsk, Atbasar, Uralsk, Astana, and Aktobe stations are shown in Figure 20. The quartile analysis of SPI indices allows us to draw the following main conclusions. The largest number of emissions and extreme values, both according to model and actual data, occurs in winter and spring.

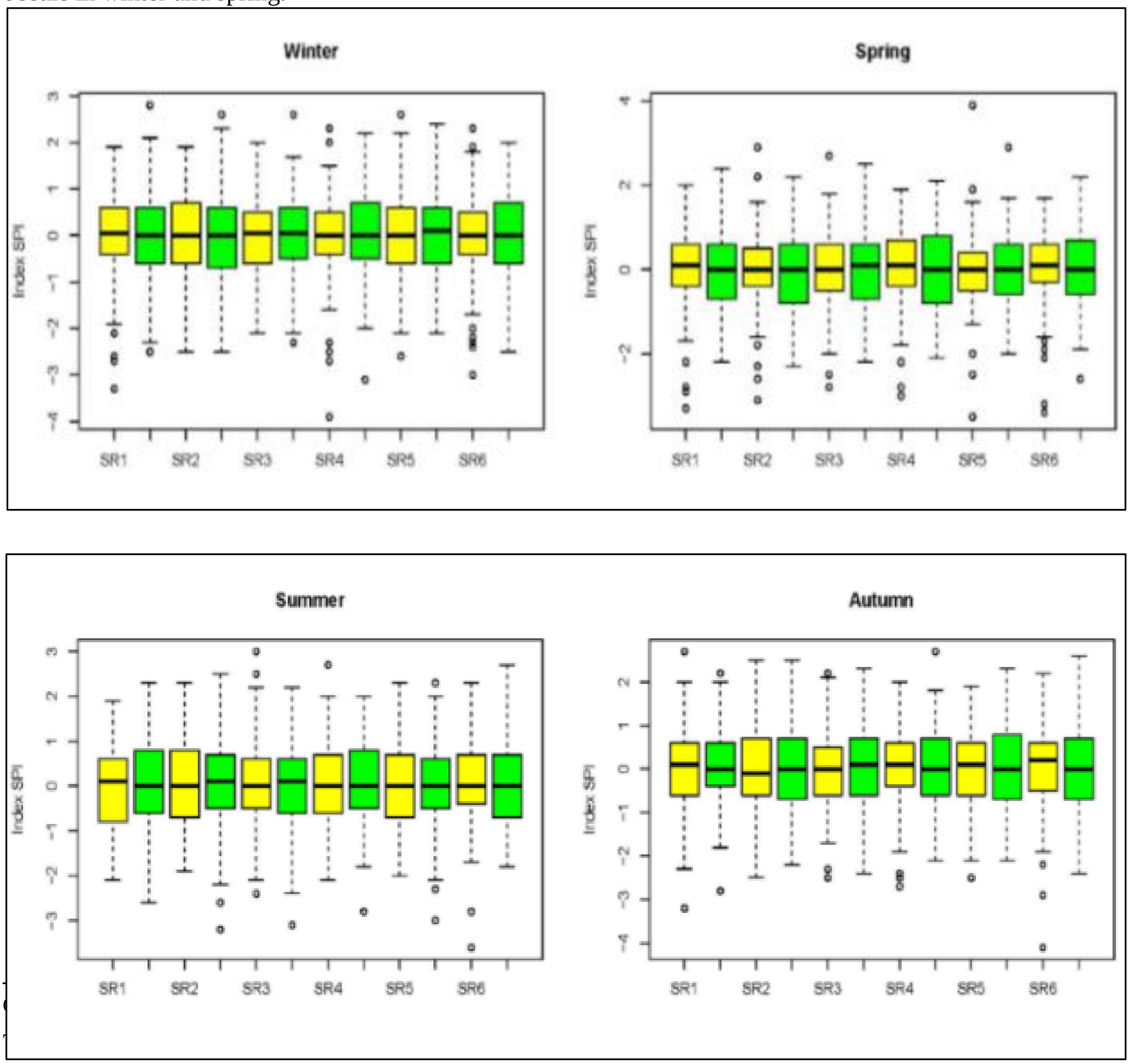


Figure 20 Span diagrams for SPI indices calculated from reanalysis data (highlighted in yellow) and modeling on a monthly time interval (highlighted in green) for winter (top left), spring (top right), summer (bottom left) and autumn (bottom right) seasons for Kostanay (SR1), Irtyshsk (SR2), Atbasar (SR3), Uralsk (SR4), Astana (SR5) and Aktobe (SR6) stations

This circumstance is associated with the instability of atmospheric circulation, primarily in the west (Aktobe station), as well as in the northwest (Uralsk station) and the north of Kazakhstan (Kostanay station). At the same time, most of the emissions are in the region of negative values of the SPI index, which indicates a trend of prevalence in these regions of cyclonic forms of atmospheric circulation, which are associated with extreme humidification conditions.

In the summer, when the circulation conditions become more stable, the number of emissions decreases. In all seasons of the year, the distribution of model data and reanalysis data within the intervals of moderate aridity and moderate moisture content is in fairly good agreement with each other. In the region of extreme values, a useful signal was not detected. All calculations were carried out using the R - statistical analysis system.

Kyrgyz Republic

Drought monitoring at the official level in Kyrgyzstan was not carried out, therefore, in the Climate Profile of the Kyrgyz Republic[61] an approach was applied to the assessment and management of climate risks in agriculture using instead of climate parameters

Harvest = f (climatic parameters)

some generalization of them (for example, indices of drought and humidity), i.e. yield assessment based on changes in indices that comprehensively characterize climatic conditions and obtain species models:

Harvest = f (index)

This methodology has not been previously applied in the Republic and Kyrgyzhydromet does not regularly determine moisture and drought indices on a regular basis, in contrast to neighboring republics. Therefore, it takes some time to master the software for calculating the indices and choosing the most effective of them, in terms of the impact on the productivity of the main crops.

The available data on economic damage and yield allow us to conduct a risk analysis using this approach, both directly on the change in yield, and to obtain an estimate of economic damage when changing climatic characteristics.

This approach allows us to drastically reduce the number of parameters included in the statistical model, which increases the statistical validity of the results in small samples. In addition, the introduction of regular calculations of drought and humidity indices into practice is a necessary element of the crop insurance system. An undecided disadvantage (which is also characteristic of the previous approach) is the difficulty of taking into account the influence of other (except for climatic) factors on productivity.

According to this methodology, calculations were carried out based on the initial data on accounting for the situation in agriculture, monitored by the National Statistical Committee. The check was carried out primarily for crops, the data for which are quite detailed, i.e. they have few passes and are more often used on non-irrigated lands. Based on these conditions, wheat, barley and corn for grain were selected as the most vulnerable and calculations were carried out aimed at establishing a connection between the observed climatic changes and a decrease in crop yields due to the adverse effects of drought and water shortages.

The calculations resulted a slightly paradoxical conclusion that the increase in the adverse effects of drought on the yield of these crops with the observed trends in climate change is reducing and, in the future, we should expect a reduction in the impact of this type of phenomenon on the agriculture of Kyrgyzstan.

[61] Climate profile of the Kyrgyz Republic. - Ilyasov Sh., Zabenko O., Gaydamak N., Kirilenko A., Myrsaliev N., Shevchenko V., Penkina L. - B. 2013 - 99 p.

The project "Integrated management of natural resources in drought-prone and saline agricultural production landscapes of Central Asia and Turkey (CACILM-2)" in the field of drought risk management in agriculture in Kyrgyzstan identified the following problems:

- Inconsistency of the existing monitoring network, with an increase in the number and scale of manifestations of hazardous natural processes and phenomena that affect agriculture and food security;
- Lack of a risk assessment system with a clear distribution of functions and responsibilities of disaster risk management (DRM) institutions;
- Poorly developed decision-making practice based on risk analysis;
- Disaster risk assessment is not taken into account when planning socio-economic development, especially at the rural level;
- Low level of information exchange between risk management and public awareness of disasters;
- Lack of regulations and standard operating procedures for public authorities and local governments in the field of early warning and response;
- Weak training of specialists in monitoring and risk assessment, especially in the field of application of geographic information technologies.

The developers of the project made recommendations:

- To approve the methodological foundations of DRM and the conceptual foundations of sectoral programs and plans for disaster risk reduction in agriculture and water;
- Develop guidelines for monitoring and evaluating food safety, conduct training for specialists;
- Development and approval of methods for assessing damage to agriculture from natural disasters;
- Introduce a system of indicators of economic, technical and social effectiveness of structural measures;
- Conducting research on the promotion of agricultural insurance against natural disasters;
- Introduction of soil drought model; introduction of SPI model of atmospheric drought;
- Organize the 3D-PAWS assembly process.

Republic of Tajikistan and Republic of Uzbekistan.

The basic strategy for adapting agriculture to climate change and drought is provided in the National Insurance Claims under the UN Framework Convention on Climate Change.

Appendix 2 provides some characteristics of the climate risk profile for Tajikistan and Uzbekistan.[62]

CONCLUSION

An assessment of drought problems and drought monitoring models in Central Asia showed that the geographic location of the region determines high exposure to climate-related natural disasters. About 75% of the territory can be called insufficiently protected from natural disasters. The largest number of victims - up to 70% - in the region is suffered from droughts.

An analysis of the available materials for the region showed that in the countries of Central Asia, separate studies are conducted on the study, monitoring and early warning of droughts. But they are unsystematic, episodic.

There is no single definition of drought in the region. At the moment, quite a lot of approaches are used to parameterize droughts, which have regional and departmental differences. This does not provide uniform information on droughts, allowing for spatial-temporal analysis. The decision to use a particular drought index is most often made based on the availability of information necessary for calculation.

[62] Climate risk profile of Uzbekistan. - 2015.- 88 p

On the other hand, it can be concluded that there is no one universal method or index suitable for all natural zones of the Central Asian region. Therefore, in the considered territory there is a need to assess the regional significance of the main criteria for the drought parameterization, as well as to assess their impact on crop productivity relative to the climatic norms for a particular region (taking into account the bioclimatic potential).

There are certain difficulties in the region with access to the primary information needed to drought modeling monitor. Particularly difficult situation with information on soil moisture. These data are in most cases are sporadic. Regular systematic observations of soil moisture are not carried out in the region. There are also no systematic observations of other processes of heat and moisture exchange in the near-surface layer, in particular, observations of evaporation from the surface of the soil and water surface.

At present, the opportunities for providing information to study the drought challenges in the Central Asian region have significantly improved thanks to the support of international donors who made significant investments in modernizing meteorological and hydrometeorological observation systems and data exchange in Central Asia, as well as in enhancing the capacity of Hydrometeorological Service employees to use new technology. The whole range of measures enabled significant improvement of the quality of monitoring and conditions for the development of drought early warning systems in the Central Asian region.

At the same time, despite the attempts to develop and improve modern systems for monitoring and predicting droughts in advance, as well as ensuring preparedness and mitigation of consequences, at the time of the study, the region lacks a real system for effective drought modeling.

Certain efforts are made in the countries of the region at the state, legislative, and institutional levels to reduce vulnerability. However, the region lacks a comprehensive program to reduce drought vulnerability.

RECOMMENDATIONS

Potentials to minimize damage from droughts in the Central Asian region include: early warning systems for the likelihood of droughts; informing interested farmers about the risk of drought; establishing a sustainable land management system, including land use planning.

Other measures to minimize damage include: improving state supervision of water supply, irrigation and drainage systems; protection of infrastructure from climatic influences; improving education and public awareness.

In addition, there is a need for increased awareness to build capacity for the sustainable management of drought risks in order to reduce vulnerability.

Thus, the challenges faced by the countries of the Central Asian region in developing national risk-based drought management programs are complex and require political will and coordination within and between different state levels, as well as with a large number of stakeholders, which should be involved in the program development process.

In accordance with The Drought Management Guidelines[63], the main elements of a national drought management program are in the following areas:

- Development of standard approaches within the context of regional adaptation to assess vulnerability and impact;
- Implement effective drought monitoring and early warning systems;
- Strengthening preparedness and mitigation;
- Implement emergency and recovery responses that reinforce the goals of the national drought management program;
- Understanding of the drought risk and the cost of inaction to mitigate their existing and increasing impacts of climate change.

[63] National Drought Management Policy Guidelines: A Template for Action. Integrated Drought Management Program WMO № 1164, 2014

The overall objective of country and regional drought policies and preparedness plans is to mitigate the effects of droughts by identifying key activities, groups or regions most at risk, and developing mitigation measures and programs that reduce their vulnerability.

This policy should aim to provide the government with effective and systematic means of assessing drought conditions, developing mitigation measures and risk reduction programs in advance of drought, and developing response options that minimize the burden on the economy, environmental damage, and social stress during periods of drought.

Drought preparedness plans should include three critical components that complement each other and represent an integrated institutional approach addressing short-term and long-term management challenges and mitigation measures for drought:

- comprehensive early warning system;
- procedure for assessing risks and impacts;
- mitigation and response strategies.

To improve hydrometeorological monitoring, forecasting and early warning systems for drought, the implementation of the following main measures is necessary:

1. Development and creation of the necessary unified and open information base for the functioning of the drought monitoring system and its early warning, further identification and elimination of gaps in the observation network, restoration of agrometeorological networks, saturation of the network with automatic weather stations;
2. Development and implementation of a specialized observing program for agrometeorological stations, taking into account the application of observational results to develop drought indicators and supplement remote sensing data with ground-based information;
3. Introduction of an integrated approach to the existing drought monitoring system using land and remote methods and its testing under local conditions;
4. Compilation of accurate short- and medium-term forecasts on the dynamics of glaciers, snow reserves and water resources;
5. Development of general and special indicators for the prevention of drought, taking into account the characteristics of the climate, surface structure and topography of the countries of the region;
6. Creation and effective use of the drought early warning system based on instrumental data for the needs of agriculture and the population;
7. Involvement of the population and public organizations in the collection of data, the creation of community and intermediate early warning systems, including analysis of information from official and informal organizations in districts and communities, with a view to their role as agents of local early warning systems in drought prone areas;
8. Development of monitoring products that are better suited to the needs of specific end users in drought preparedness and mitigation programs, facilitating the exchange and coordination of information at the regional and local levels and among the population;
9. Improving data management: developing regional projects to solve pressing problems, coordinating the activities of regional institutions, general coordination of regional projects approved by the heads of states of Central Asia.

Appendix 4 contains gaps in environmental policy and adaptation to climate change in Central Asian countries in the context of the drought problem and possible ways to solve them for water management and agriculture.

One of the effective tools that can help countries in the region to develop drought preparedness and mitigation plans is the best practices of the national drought management programs[64], where this process was divided into 10 steps.

[64] High-level Meeting on National Drought Policies (OECS) Scientific Paper: Best Practices for a National Drought Management Program. Geneva March 11-15, 2013

This step-by-step approach has been adjusted and presented below as one of the approaches designed to help Central Asian countries in the process of developing a national drought control program:

Step 1 - To appoint a commission or working group on the national program to combat drought.

Step 2 - State or define the goals and objectives, responsible performers, resources and expected results of a national risk-based drought management program.

Step 3 - Strive to ensure stakeholder participation, identify and resolve conflicts between the main sectors of water consumption.

Step 4 - List available data and financial resources and identify at-risk groups.

Step 5 - Prepare/write the main points of the national drought control program, including the following elements:

- Monitoring, Early Warning and Forecast;
- Risk and Impact Assessment;
- Mitigation and Response.

Step 6 - Identify research needs and fill institutional gaps.

Step 7 - Integrate the scientific and political aspects of drought management.

Step 8 - Advocate for a national drought management program and improve public awareness.

Step 9 - Develop educational programs for all age groups and interest groups.

Step 10 - Assess and review the national drought management program.

Appendix 5 provides an approximate set of recommendations in the field of developing policies and proposals for the necessary political decisions. (policy recommendations) aimed at managing drought risks.

All of them are divided into 4 main groups: institutional, technological, improving water supply, demand management. Accordingly, in each of these sections a set of proactive measures in relation to a possible drought, operational measures that are expedient to implement directly during a drought can be distinguished. Finally, there is a list of recommended measures after droughts.

Thus, the main provisions of the national drought management program require periodic evaluation and review in order to ensure the inclusion of new technologies, take into account lessons learned from recent drought events, as well as changes in vulnerability and the like

Countries are encouraged to periodically evaluate their national drought control programs, conduct drought management exercises to ensure the highest level of coordination between government departments or ministries, and at various levels of governmental and non-governmental organizations, and also accordingly to carry out a review and updating of programs.

APPENDIX 1

MAJOR PROJECTS
on disaster risk management, combating drought and desertification and improving the early warning system for droughts in Central Asia according to the National Communications of Central Asian countries.

Project name	Funding Agency / Local Partners	Terms of implementation	Amount of financing, USD	The main results of the project
Uzbekistan				
Support for the implementation of the UN Convention to Combat Desertification (UNCCD) in Asia, regional	BMZ / GTZ Kazakhstan, Uzbekistan 2001-2007	2007-2010	5,200,000	Support was provided for capacity development to fulfill the obligations of the UN Convention to Combat Desertification in Uzbekistan.
Central Asian Countries Initiative for Land Management (CACILM) - UNCCD	GEF/ADB, UNDP, UNCCD and other donors ATP CACILM / Government of the Republic of Uzbekistan	2007-2010	30,000,000	A number of projects have been implemented to improve land productivity, while maintaining their environmental functions and increasing water use efficiency as an adaptation measure.
Land Improvement Project in Bukhara, Navoi and Kashkadarya Regions	GEF/ADB/CACILM Phase 1, MAWR	2008-2013	3,000,000	Improvement of the land reclamation state through the implementation of technical and institutional measures, as well as the adaptation of technologies and the use of best practices in SLM and water conservation.
Strengthening the capacity of the Republic of Uzbekistan to manage natural disaster risks	UNDP, EU (ECHO)/ Ministry of Emergencies of the Republic of Uzbekistan, Academy of Sciences of the Republic of Uzbekistan, Uzhydromet	2010-2014	1,867,200	Assistance of the Ministry of Emergency Situations, the Academy of Sciences, the Mahalla Foundation (public) in creating a sustainable mechanism to reduce the risks of natural disasters, improved staff skills, material and technical potential.
CACILM Capacity Building	GEF/UNDP/UNCCD/ GIZ/ Republic of Uzbekistan	2011-2013	780,000	Increased capacity to develop and implement an integrated approach and strategies to combat land degradation within the framework of the National CACILM Framework Programs.
Promoting the modernization of hydromet services in CA regional	Finnish Meteorological Institute / Uzhydromet	2011-2013	526,225 euros	WMO Regional Training Center (Tashkent) is equipped with modern equipment. NMHS specialists trained.
UNDP Project "Management of Climate Risks in Uzbekistan", regional	UNDP / Uzhydromet, Ministry of Economy, etc.	2011-2014	800,000	The project was implemented in Kashkadarya region: a drought early warning system was developed, and water consumption for farmers at the local level was improved. The capacity of employees of the Drought Management Center in Uzhydromet has been increased.
Modernization of hydrometeorological services in CA, regional	World Bank/Uzhydromet	2012-2016	2,000,000	It is planned to strengthen systems and methods for early warning of hazardous events in the mountainous regions of Central Asia; equipping with equipment for international transmission and interpretation of meteorological data, including using the COSMO model.
Ensuring climate stability of farms and dekhkan farms located in arid regions of the Republic of Uzbekistan	Adaptation Fund (AF) UNFCCC, UNDP/ Uzhydromet	2014-2019	5,190,878	Institutional and technical capacity development for drought management and its early warning; implementation of measures to introduce climate-resistant practices within the farms of the Republic of Karakalpakstan.
Climate Data Conservation in Uzbekistan	Government of the Republic of Korea (through WMO) / Uzhydromet	2015-2016	628,000	It is planned to transfer archived climatic data from Uzhydromet from paper to digital format; creation of a single climate database

Integrated management of natural resources in drought-prone and saline agricultural landscapes (CACILM/CACILM 2)	GEF/FAO/Uzhydromet	2016-2018	2,000,000	The project aims to mitigate the effects of drought in areas of high risk of desertification in the face of climate change, improve salinity management, and demonstrate climate-resistant agricultural technologies (SMART).
Kyrgyzstan				
Climate Risk Management (CRM) in Kyrgyzstan	UNDP BCPR	2010-2015	4,500,000	1. Create appropriate conditions for the implementation of CRM principles at the systemic, institutional and individual levels. 2. Demonstrate climate-friendly pasture management in the Suusamyr Valley. 3. Knowledge management and lessons learned for CRM.
Hydrometeorological Services Modernization Project in Central Asia CAHMP	WB\Kyrgyzhydromet	2012-2018	6,000,000	1 Strengthening the technical and organizational capabilities of the NMHS of Central Asia to receive, store and exchange information; 2 Improving the regional system of training education and advanced training of personnel: 3 Improving service quality by improving weather forecasts, storm warnings and climate change assessment
Regional Environment Program for Central Asia (EURECA) Component 2: Forest and biodiversity management, including environmental monitoring: FLERMONECA	EEC Kazakhstan Kyrgyzstan Tajikistan Turkmenistan Uzbekistan	2013-2015	4,800,000 Euro	Strengthening regional cooperation and partnerships with Europe on sustainable use of natural resources, forest and biodiversity management, including environmental monitoring.
Strengthening institutional and legal capacities to improve the national monitoring and environmental information management system	UNDP / GEF	2016- 2018	950,000	Expected results of the project: 1. Improving policy tools and legislation for effective monitoring and decision-making. 2. Institutional strengthening. 3. Raising awareness of the values of the global environment.
Food Security and Vulnerability Mapping	UK Department for International Development (DFID)	2014	293,927	Develop and disseminate the National Atlas on Food Security and Vulnerability at the national and subnational levels to increase understanding of food security goals, gaps, challenges and opportunities.
Program "Transboundary Water Management in Central Asia"	Countries of Central Asia, German Federal Foreign Office	2009-2017	21,000,000 Euro	Components: Promoting regional institutional cooperation. Improving the management of transboundary river basins.
Tajikistan				
Sarez Lake Breakthrough Risk Reduction Project	WB, Agahan Foundation, Sweden	2000-2006		A monitoring system for the lake was created, 30 priority hydroposts and weather stations in the zones of runoff formation were refurbished and repaired, snow gauges and routes were restored, the hydrological department for working with satellite images and the Regional Center of Hydrology at IFAS was strengthened. Automated systems (Hydropro, GE-1) have been introduced to digitize and maintain hydrological databases and yearbooks. Assisted in the calibration of instruments.
Modernization of Tajhydromet network	WB	2009	12,000,000	Large-scale modernization of the observing network and improvement of hydrometeorological services.
"Water unites" CAWa	Germany / Tajhydromet	2009-2014		AMS installation was completed in Zeravshan and Ayvadzh, gas stations were installed on the Abramova glacier (Kyrgyzstan) instead of a complex automatic station for forecasting the flow of the river. Vakhsh

Kazakhstan				
Climate risk management in Kazakhstan	GEF / UNDP RK	2010-2014		Strengthening the institutional framework, technical capacity for managing climate change risks, and opportunities through integration at the national, subnational, and local levels.
UNDP Central Asian Multinational Climate Risk Management Program.	GEF / UNDP RK	2011 - 2014		Strengthening countries' technical capacity to deal with climate action; - Sharing knowledge and integrating climate risk issues into regional development processes; - Synthesis and further development of the knowledge system on the glaciers of CA.
Capacity building in areas of sustainable development through integration of climate change issues into strategic planning in the Republic of Kazakhstan	GEF / UNDP RK	2009-2014		Strengthening the capacity of national partners to effectively participate in the international negotiation process on climate change issues, in particular, Kazakhstan's entry into Annex B of the Kyoto Protocol; - Supporting the activities of the Government of the Republic of Kazakhstan in fulfilling obligations for the post-Kyoto period after 2012 and preparing a national low-carbon development strategy and integrating principles into national development policies and strategies; Supporting climate change adaptation activities in Kazakhstan and integrating climate change adaptation issues into basic development policies and strategies;
Climate Change Adaptation Program	SGP GEF			The main objective of this program is the practical development of organizational and managerial decisions on adapting economic activities to changing climate conditions. This program is being implemented in 10 countries of the world, including Kazakhstan. In each country, the program adapts to local conditions and in Kazakhstan, the implementation of the program is carried out with a focus on agriculture. In addition, there is a thematic focus on combating land degradation.
Advancing climate change adaptation and mitigation strategies in CA	German Federal Ministry of Environmental Protection / CAREC	2010-2011		The project is aimed at strengthening the potential of the Central Asian countries in forming common positions on the main issues of international negotiations and in promoting regional interests in developing new and revising existing national strategies by developing a common understanding of the further negotiation process. Supporting the development of a common position of Central Asian countries on climate change is a way to accelerate their dialogue and decision-making on the most pressing climate change problems in the region.
Modernization of Kazhydromet network	WB	2014 - p.t.		Large-scale modernization of the observing network and improvement of hydrometeorological services.

APPENDIX 2

KYRGYZSTAN, TAJIKISTAN, UZBEKISTAN CLIMATE RISK PROFILES

KYRGYZSTAN CLIMATE RISK PROFILE

(Climate profile of the Kyrgyz Republic. - Ilyasov Sh., Zabenko O., Gaydamak N., Kirilenko A., Myrsaliev N., Shevchenko V., Penkina L. - B.2013 - 99 pp.). The profile was prepared as part of the UNDP project "Climate Risk Management in Kyrgyzstan"

Sector or type of activity	Adaptations and ways of risk management
Improving the regulatory framework	Additions and corrections to: ▪ Ecological, Land, Forest and Water codes of the Kyrgyz Republic; ▪ Rules for the development, implementation, monitoring, evaluation and control of strategic development plans; ▪ Predictive schemes of spatial development of the country, state programs, territorial development programs, strategic plans of state bodies to ensure the integration of policies to reduce risks to climate change in the strategic planning system of the republic.
Institutional strengthening	▪ Creation of a structural unit in the Ministry of Agriculture, which will oversee the sustainable use of pasture territories; ▪ Creation of sustainable mechanisms of self-government of the rural population, aimed at the joint and efficient use of agricultural territories in private and state ownership; ▪ Creation in the structure of SAEPF of a department for adaptation of forestry to the risks of climate change and strengthening control over the state of wildlife forests, their conservation and use; ▪ Increasing the functional responsibility of state authorities by specifying the official duties of officials whose quality of execution affects the timely identification of emerging climate threats and enhances the adaptive capacity of the country, individual regions and settlements; Changing the institutional foundations of the water supply and water use system at the national and basin levels.
Improving technical standards and regulations	▪ Improving the systems of accounting and rationing of water use in agriculture and other sectors of the economy; ▪ Establishment of limits for the consumption of natural resources and sanctions for exceeding them, taking into account climate change forecasts.
Improving financial and economic mechanisms	▪ Creation of national and territorial funds for adaptation and reduction of risks to climate change; ▪ Development of the insurance system, introduction of index insurance services; ▪ Creation of a system of micro-loans for the implementation of adaptation projects; ▪ Creation of a system of state control of spending budget funds for local adaptation, connecting the public to these activities through "hot lines"; ▪ The introduction of benefits for vulnerable sectors and segments of the population combined with quotas.
Improving information tools	▪ Creation of an information and analytical center in the field of climate change with a coordinating body for climate change; ▪ Formation of an information database for modeling, predicting the effects of climate change on the population, sectors of the economy and ecosystems, allowing science-based decisions in the field of adaptation; ▪ Inclusion of special disciplines in the programs of existing educational institutions on the efficient use of natural resources, vulnerability to the effects of climate change, assessment and forecasting of natural risks, and improving adaptive capacity; ▪ Conducting companies in the media (primarily central government) on climate change in the Kyrgyz Republic and improving the adaptive capacity of the economy, population and ecosystems;

	▪ Raising awareness of decision makers and the country's population about the risks of climate change by creating television programs, information sheets, and recommendations on adaptation methods.
Increasing human resources. Improving education and research systems	▪ Strengthening monitoring of the natural processes of climate change in the Kyrgyz Republic and strengthening cooperation in this matter with the countries of Central Asia; ▪ Monitoring of anthropogenic factors contributing to increased natural risks, and research to reduce them; ▪ Improving the methodology for assessing the reduction of risks from climate change in regions and sectors of the economy of the republic, developing a system of indicators to determine the level of regional exposure to climatic risks and the effectiveness of measures to mitigate these risks; ▪ Studies to assess mudflow hazard, droughts, and other hazards associated with the risk of natural disasters from climate change; ▪ Research on the effects of climate on human health; ▪ Research in the field of increasing the efficiency and competitiveness of the agro-industrial complex in a changing climate; ▪ Monitoring and assessment of the bioecological state of agricultural lands, their productivity on the basis of ground and space information; ▪ Assessment of the impact of climate change on agricultural and natural ecosystems and their adaptation; ▪ Development of recommendations on the use of agroclimatic information in relation to phytomelioration, taking into account climate change; ▪ Development of a monitoring system for pasture lands to assess their bioecological status, productivity and energy intensity, taking into account anthropogenic impact and climate change based on the use of GIS technology. ▪ Studying the effects of anthropogenic impacts on soils (desertification, degradation, pollution, erosion, etc.) and methods for the conservation, rational use and reproduction of soil fertility; ▪ Research and development of methods for stabilizing the humus state of soils, as one of the priority adaptation approaches; ▪ Studies to assess the impact of climate change on the productivity of major crops and livestock productivity, assess the vulnerability of agroecosystems and rural populations.

TAJIKISTAN CLIMATE RISK PROFILE

(Third National Communication of the Republic of Tajikistan on the UN Framework Convention on Climate Change. Dushanbe, 2014. - 167 p., TAJIKISTAN: A Case Study of Socio-Economic Development under Climate Change // Naila Mustaeva, Henry Vies, Benjamin Mor, Abdulhamid Kayumov - 2015.)

Sector or type of activity	Adaptations
Agriculture	▪ the formation of policies aimed at moving from the controlling to the stimulating function of the state and improving the regulatory framework and taxation in the agricultural sector, taking into account its importance and vulnerability in the context of climate change; ▪ increasing the responsibility of state and local authorities for violation of land use rights and the exclusion of state intervention in the adoption of production and business decisions by agricultural producers; ▪ strengthening state control in the field of agricultural product safety; ▪ development of organic farming, certification system and incentives for producers; selection and introduction of drought-resistant varieties of cereals, legumes and other crops; ▪ increasing the efficiency of water use in agriculture; ▪ creation of a guarantee fund for insurance of the agricultural industry in case of emergency ▪ the impacts of climate change, vulnerability and adaptation and in the face of climate change,

	▪ improvement of existing and construction of new backup storage facilities for crop and livestock products; ▪ development of selection and seed production taking into account climate change; ▪ improving the epizootic situation, the fight against pests and agricultural diseases in the face of climate change; ▪ raising awareness and access of rural population, farmers and other agricultural entities to information on climate change.
Priority tasks and needs for water management	▪ widespread application of the principles of integrated water resources management (IWRM); ▪ gradual transition to a method of water resources management within hydrographic boundaries, rather than administrative units; creation of basin commissions and departments; ubiquitous development of water user associations; ▪ increasing the efficiency of irrigation canals by lining their bed, especially in areas of high-water filtration; ▪ the use of differentiated and water-saving water tariffs and a phased increase in electricity tariffs to fully cover the costs of operating irrigation systems; ▪ differentiation of payments for water and its delivery depending on specific conditions; ▪ construction of reservoirs in narrow mountain ravines to generate electricity, store water and manage flood and flood risks; ▪ development of standards and ensuring minimum environmental river flow; ▪ conservation and expansion of the area and density of forests in the catchment areas of rivers.
Farmers' income protection	▪ protecting crops from natural hydrometeorological phenomena and increasing income from several crops per year due to the widespread introduction of greenhouse facilities; ▪ crop protection from diseases and pests, preferably using biological methods; ▪ introduction of drought tolerant crops and consideration of agroclimatic conditions; improving the reliability of agricultural insurance, creating insurance stocks of seeds and self-help groups for farmers with accumulative funds to deal with the consequences of emergencies. ▪ water-saving irrigation technologies, retention and use of rainwater; efficient waste management and composting.

UZBEKISTAN CLIMATE RISK PROFILEV

Sector or type of activity	Adaptations
Agriculture	**Development of the following technologies:** **Technologies for efficient water use:** ▪ introduction of a water metering system and improvement of the water distribution system; ▪ improving the traditional method of watering; ▪ the use of water-saving technologies (drip irrigation). **Technologies for the efficient use of land:** ▪ minimum tillage with preliminary restoration of the arable layer; ▪ Improving soil preparation using laser planning and deep loosening. **Agroforestry measures:** ▪ reducing the load on desert pastures by improving forage production; efficient use of pastures by applying pasture rotation; ▪ land improvement in arid areas through the creation of pistachio plantations ▪ optimization of crop placement, taking into account increasing water scarcity (reduction in the proportion of moisture-intensive crops); ▪ adjustment of water consumption patterns and norms based on scientific data; ▪ maintaining the layout of fields, the introduction of cost-effective irrigation methods

Priority tasks and development needs of the Uzhydromet observational network	▪ development and optimization of the monitoring system for snow cover; ▪ optimization and technical re-equipment of the agrometeorological observation network (at least 30 stations), in connection with the increased need for agrometeorological information to assess the risks of climate change in agricultural production and to develop adaptation measures; ▪ development and implementation of an early warning system for drought, extreme temperatures and other dangerous natural phenomena in a changing climate; ▪ creation and functioning of a system of advanced training for Uzhydromet employees and other interested parties on climate change issues at the WMO Regional Training Center; ▪ expansion of scientific and applied research related to the issues of regional climate change and assessment of its impact on economic sectors, with the development and implementation of weather forecasting methods of different lead times and dangerous hydrometeorological phenomena that meet user needs.
Climate system monitoring, long-term change assessment	▪ studies of regional atmospheric circulation under climate change. ▪ development of guidelines for the calculation of specialized climatic parameters and their regionalization; updating of technical documentation for the use of specialized climatic parameters. ▪ development of models and evidence-based recommendations to assess the situations that arise during the formation and use of water resources in connection with climate change. ▪ building forecast models of regional climate change. - Improving methods for predicting hazardous hydrometeorological phenomena (mudflows, floods, avalanches, droughts, etc.) using remote sensing data (satellites, locators). ▪ assessing the impact of climate change and anthropogenic factors on desertification and drought.

APPENDIX 3

RESULTS OF AN ANALYSIS OF WORLD PRACTICES FOR DROUGHT MONITORING MODELING

Monitoring system	Resources used	Database	Access to the information
Foreign crop monitoring systems			
PECAD system (USA)			
Designed to predict crop production: crop area estimation and crop yield forecasting. Focused on the users who needs generalized data in general about the country's agricultural situation	Low and medium spatial resolution satellite data (NOAA-AVHRR, SPOT-IV, MODIS) meteorological data, crop models and official government reports	Created CADRE database management system. It contains a large archive of satellite imagery and weather information, which is used by 29 in crop models. The system allows a comparative analysis of the data of the year under review with a multi-year series of data from previous years.	Information for different countries about the growing conditions and assessment of crop productivity in real time can be obtained through the Crop Explorer web interface.
Food and Agriculture Organization of the United Nations (FAO)			
The Global Food and Agriculture Information and Early Warning System (GIEWS) provides information on the current growing season, import volume, and estimates and projections of expected crop yields.	Vegetation indices are obtained from NOAA satellite information. Precipitation data provided by the European Center for Medium-Range Weather Forecasts (ECMWF).	VHI Vegetation Health Index Maps and Agricultural Stress Index (ASI). ASI is developed by FAO. The index shows the intensity of agricultural drought and assesses the impact of conditions on the growth and development of vegetation. The service provides maps of the spatial distribution of anomalous NDVI (NDVI Anomaly).	GIEWS provides brief overviews of the food situation. The “Earth Observations” section presents maps of the spatial distribution of seasonal, vegetation indicators, and precipitation and anomalous NDVI. FAO has developed the FAOSTAT service (http://faostat3.fao.org/home/E) in which real-time statistical information can be obtained for any country.
Satellite monitoring system for agricultural land, MARS project (Monitoring of Agriculture with Remote Sensing)			
Designed for global agricultural monitoring and food security assessment. Currently, the project consists of four areas: GeoCAP , AGRI-ENV, AGRI4CAST and FoodSec	The project activities are based on experience in the field of crop modeling, agrometeorology, geospatial analysis. Satellite, meteorological data, statistical analysis tools and agrometeorological models are used. The main areas of work of AGRI4CAST are: 1. monitoring of crops and forecasting productivity; 2. modeling of crop development	For operational and research tasks in the AGRI4CAST project, the following plant production process model and modeling systems are developed and used: The CGMS (The Crop Growth Monitoring System) system monitors the weather, collects and processes meteorological data, which, along with statistical information, are used in the plant growth modeling block. Crop growth model WOFOST (World Food Studies), used by CGMS and provides an assessment of biological variables related to yield: biomass accumulation, the onset of phenological development phases	The main MARS product is newsletters that contain information on the current and forecasted situation of crop development in various regions of the world. - a review of areas with unfavorable conditions for the development of crops; - overview of agrometeorological parameters; - weather forecast; - the condition of crops according to satellite information; - forecast crop yields in general for each country.
The platform called CropWatch launched in 1998 and was created by the Institute of Aerospace Information Studies at the Chinese Academy of Sciences.			
The platform is based on observation satellites and ground stations, which allow independent assessment of grain growth, as well as yield and related information at both global and national levels.	CropWatch uses remote sensing data in combination with selected field data to determine key indicators of crop production: planted area, yield, crop condition, seedling intensity and drought threat.	CropWatch data processing is highly automated and the resulting products provide in turn new types of input data for assessing food security.	China launched the Digital Belt and Path program at the aforementioned institute. The aim of the program is to introduce the use of a monitoring platform in the countries of the New Silk Road. The Chinese platform for remote agricultural monitoring has begun to provide services in 147 countries and regions of the world.

Russian crop monitoring systems			
System of the Space Research Institute of the Russian Academy of Sciences (SRI RAoS): satellite service VEGA.			
VEGA. Two systems have been created: VEGA-Science (http://scivega.ru/) and VEGA-PRO (http://pro-vega.ru/). VEGA- Science is focused on information support of scientific research in the field of assessing the state of vegetation cover. VEGA-PRO is intended for the analysis of satellite observation data when assessing the state of vegetation and its operational monitoring as part of solving applied problems.	VEGA works with a rather large archive of data satellites received from Terra and Landsat satellites (resolution 250 and 28m, respectively). Data from MODIS instruments installed on TERRA satellites is updated daily throughout the CIS countries. Methods for assessing the state of vegetation are based on an analysis of the time series of the vegetative index NDVI. Based on the analysis of the comparative course of the vegetation index, a technology for monitoring the effects of drought on vegetation has been developed. Analysis is available for subjects, areas, and fields. Meteorological information is only informative and is not used in methods for assessing the status of crops.	The service has formed long-term archives of homogeneous data and organized a constant automatic update of information. The service provides the ability to work with satellite data and the results of their processing for monitoring the status of crops	To work with the data of the VEGA service, a specialized site http://vega.smislab.ru/ has been developed. Currently, the analysis of crops in the VEGA service can be carried out both for a single point, and for any user-specified polygon. For a detailed analysis of winter and spring crops on the service posted newsletters. Also, methods for predicting yield based on the search for a year-analogue are being developed. Monitoring results are available for the CIS countries and can be used as the basis for making managerial decisions in the field of regulation of agricultural markets and risks both at the level of individual countries and at the international level.
The list of services for the analysis of the state of crops of the company "ScanEx"			
This is the leading company in the Russian Federation that receives satellite images, develops image processing software and creates geoportals for working with spatial data. The service is located on the geoportal www.kosmosnimki.ru. Users have the opportunity to work with highly detailed satellite images with a resolution of 2.5 - 6 meters. To do this, the user must provide information on the location of agricultural land.	To monitor the development of crops in the system, NDVI composites of agricultural land of the following satellites or their combinations are available: - MODIS (resolution 250 m); - UK-DMC2 (resolution 22 m); - SPOT (resolution 2.5 - 10 m). Also on the website are available the dynamics graphs of the vegetative index NDVI for each field, which are formed upon request and a table of values of the vegetative indices.	The ScanEx Center currently offers the following services for the analysis of the state of crops: 1. Cartographic assessment of the quality of seedlings of crops. 2. Assessment of the spring state of winter crops - the quality of wintering. 3. Monitoring the status of agricultural plants during the period of active vegetation.	Operational information on the dynamics of the development of crops is provided with a frequency of 3 to 4 days. We use monitoring systems with a wide coverage of high (20 - 30 m) spatial resolution, suitable for calculating vegetation indices: DMC-2. CosmosAgro is a paid service, its annual customer service is 449,000 rubles. Given the level of development and profitability of farms, it is unlikely that this price will be affordable.
The system of remote monitoring of agricultural land of the agro-industrial complex (SDMZ APK).			

It was developed in 2012 with the participation of Sovzond to provide information support to the work of the Ministry of Agriculture of the Russian Federation. It is intended to obtain information on the state of agricultural lands and vegetation on these lands, using modern remote sensing data. The project is being finalized.	The system provides work with the following information: satellite information, ground-based observations, meteorological data. Sources of satellite information are: - data from Landsat satellites; - data from the MODIS radiometer; −Monitoring survey of medium resolution (22 m) with spacecraft UK-DMC-2, Deimos-1, Nigeriasat -X; - high-resolution survey (6.5 m) on operational requests in response to signals from places about occurring adverse events for crops, natural disasters by the RapidEye satellite group - shooting ultra-high resolution (0.5 m) for households selected as reference, spacecraft WorldView-1,2, GeoEye-1	Satellite data is fully automated. To obtain objective information that is as independent as possible from the subjective opinions of specialists, a special system of automated work with data is implemented in the SDMZ APK. Its basis is the technology for constructing automated systems for collecting, processing, archiving and presenting remote sensed data, created at SRI RAoS. The system implements information products that make it possible to assess the condition and productivity of crops — maps and graphs of vegetation indices by regions and districts. On them and graphs, you can monitor the progress of vegetation.	Information service (http://sdmz.gvc.ru). The system implements information products that allow assessing the condition and productivity of crops. Based on satellite data, maps and graphs of vegetation indices are available for regions and districts. Using these maps and graphs, you can monitor the intensity and progress of vegetation development, as well as obtain estimates of yield and gross yield in the current year. While the system is implemented only for the Russian Federation.
Operational satellite system for monitoring the state of crops of Roshydromet.			
ARRIAM has developed and successfully operates an operational system for monitoring the status of crops using satellite information for an autonomous receiving-hardware and software-methodological complex.	As initial information, data from NOAA meteorological satellites were used.	One of the system output products is NDVI distribution maps for a given territory. They allow you to monitor the dynamics of the development of vegetation cover throughout the growing season. For a qualitative assessment of the conditions for growing crops, a procedure has been developed for assessing the condition of crops in three grades: poor, satisfactory and good.	This system is quite informative and successfully works. It primarily provides an assessment of the state of crops in the territory in the form of percent of areas with different conditions. Reduction of ground-based agrometeorological observation points requires a significant change in the current system

APPENDIX 4

MAJOR GAPS in environmental policy and adaptation to climate change in Central Asia in the context of drought problem and possible solutions to water management and agriculture

Gaps	Possibilities
Water resources	
▪ Lack of legal regulation in the water sector on adaptation to climate change at the national level; ▪ Lack of intersectoral dialogue on possible conflicts related to the use of water resources and water scarcity, as well as weak inter-institutional interaction in the field of water use at both local, national and regional levels; ▪ Lack of policy instruments for the efficient and economical use of water resources in sectors such as agriculture, water supply and sanitation. For example, a weak system of water accounting and control over the use of water resources in cities and towns; ▪ Lack of investment to address technical issues, such as obsolete irrigation systems, degradation of water supply and sanitation, and the lack of modernization of irrigation infrastructure, taking into account future risks associated with climate change and, especially, temperature increase; ▪ Weak awareness and technical support in the implementation of effective and economical methods of water use, for example in the field of irrigation and water conservation; ▪ Low efficiency of implementation of interstate agreements on the use of water resources due to a conflict of interests between countries located in the upper and lower reaches of transboundary rivers.	▪ Development of agreed guidelines for adaptation in the water sector to climate change for the purpose of water conservation and rational use of water, establishing an intersectoral dialogue; ▪ Creation of a political platform for the efficient and economical use of water; ▪ Improving management methods, including economic mechanisms for water use and water resources control at local and national levels; ▪ Creation of incentives for the restoration of water supply and sanitation infrastructure, the modernization of irrigation infrastructure, taking into account the risks associated with climate change, attracting public and private sources of financing, as well as international assistance; ▪ Assessment and development of specific measures to adapt water management to the needs of local mountain communities, including training farmers in effective methods of using water resources, such as spraying and drip irrigation, with active state and donor support; ▪ Capacity building of national and regional organizations for effective interaction and coordination of cooperation in transboundary river basins.
Agriculture	
▪ National agricultural programs poorly address climate change impacts or there is no adaptation measures, especially in mountainous areas; ▪ Low level of technical measurement of the effectiveness of adaptation measures; ▪ Support for adaptation to climate change by public and private institutions, including donor ones (crop insurance, development of early warning systems, financial support systems, etc.) remains low; ▪ Poor access of farmers to information on the impact of climate change on agriculture, including in 115 mountain zones of the region (lack of water for irrigation, increased salinization and soil erosion,	▪ Development or updating / addition of national agricultural programs and other regulatory documents, taking into account adaptation mechanisms in the context of climate change; ▪ To realize the potential of agriculture in the field of adaptation to climate change, reforms are needed - such as strengthening farms, developing small and medium enterprises, modernizing obsolete irrigation infrastructure, developing veterinary, advisory services and agricultural insurance systems, as well as providing medium and long-term agricultural loans; ▪ Given that climate change affects meteorological conditions (temperature increase, changes in precipitation, soil moisture, etc.) and agricultural productivity, crop insurance - crop and livestock

reduced pasture productivity and grain yield, livestock disease); ▪ Poor awareness of farmers about best practices for adaptation and agricultural practices, including mining and livestock farming, in the face of climate change; ▪ Insufficient efforts to strengthen modern knowledge of climate change in mountain ecosystems among local communities and the integration of traditional and local knowledge.	products - can protect farmers from devastating economic damage; ▪ Farmers also need new techniques, technologies and investments to ensure access to the best, locally adapted crop varieties both in the mountainous zones and on the plains. Drought and heat resistant varieties of crops adapted to increased salinity and early ripening of crops, as well as adapted species of domestic animals, will allow farmers to achieve not only higher productivity, but also become more adapted to climate change. ▪ The impact of climate change on the agricultural sector varies among countries in the region, but natural disasters, such as floods, droughts, excessive rainfall, landslides, etc., cause significant damage to all agriculture and can affect the food security of the region as a whole. ▪ Among the preventive measures in Central Asia, one can point to the creation of early warning systems and the strengthening of a unified scientific and information base. The importance of organizing networks of systematic observation of climate change and the need for a scientific approach to the development of the agricultural sector in order to adapt are generally recognized.

APPENDIX 5

RECOMMENDATIONS in the field of policies development and proposals for the necessary political decisions

Long-term	Application in the following sectors (*)	Short-term	Application in the following sectors (*)
INSTITUTIONAL			
Sustainable provision of timely hydrometeorological information for the study of patterns of drought and the development of early, medium and long-term warning methods	**A, C, R/E, F**	Drought monitoring and forecasting. Development of early, medium and long-term warning methods	**A, C, R/E, F**
Support for research aimed at describing the severity, spatial extent, trends, duration of droughts and their consequences for the social, environmental and economic aspects of the development of a region / country.	**A, C, R/E, F**	Scientific and applied research in the field of monitoring and forecasting droughts. Development of early, medium and long-term warning methods	**A, C, R/E, F**
Information exchange mechanism for improved mitigation of drought risks	**A, C, R/E, F**	Raising awareness of drought-dependent target groups	**A, C, R/E, F**
Creating a drought risk management system	**A, C, R/E, F**	Introduction of drought insurance systems.	**A, C, R/E, F**
Improving the education system and advanced training of specialists and interested target groups (farmers, entrepreneurs, etc.)	**A, C, R/E, F**	Development of educational programs for various levels of education	**A, C, R/E, F**
Settlement of the legal and institutional framework. Water laws and directives on possible actions in special circumstances in dry years	**A, C, R/E, F**	Development of critical threshold levels of droughts, forecasting future water use for distribution by zones	**A, C, R/E, F**
Creating a risk management system	**A, C, R/E, F**	Provide an understanding of effective decision-making in the context of drought risk management.	**A, C, R/E, F**
Tools and methodologies for early warning and decision support for drought preparedness planning and policy development.	**A, C, R/E, F**	To introduce legislative amendments guaranteeing free access to primary hydrometeorological information to increase the effectiveness of scientific and applied research	**A, C, R/E, F**
Development of a National Drought Program	**A, C, R/E, F**	Advocate for a national drought management program and improve public awareness	**A, C, R/E, F**
TECHNOLOGICAL			
Obtaining new strains of crops to increase their resistance to drought	**A, C, R/E, F**	Water-saving tillage technology	**A, C, R/E, F**
Development of a set of measures to protect zones with an increased risk of drought.	**A, C, R/E, F**	Possible change in planting dates and crop area structure, taking into account prognostic recommendations	**A, C, R/E, F**
The optimal ratio of winter and spring crops	**A, C, R/E, F**	Inventory and increase the efficiency of groundwater use. Afforestation to reduce wind erosion	**A, C, R/E, F**
In order to reduce risks for the energy sector, it is advisable to diversify energy sources, to intensify work on the development and implementation of alternative energy sources.	**A, C, R/E, F**	Sowing crops growing in drylands.	**A, C, R/E, F**
___________	**A, C, R/E, F**	Mechanisms for improving energy efficiency. Restrictions on its consumption.	**A, C, R/E, F**

IMPROVEMENT OF DELIVERY			
Identification of proposed additional or alternative sources of water	**A, C, R/E, F**	Development of regulatory legal acts increasing the degree of responsibility for the state of reservoirs regardless of ownership	**A, C, R/E, F**
Technical optimization of water resources	**A, C, R/E, F**	Protecting water supply infrastructure and traditional water supplies	**A, C, R/E, F**
Artificial rainfall	**A, C, R/E, F**	Activation of scientific and applied research in the field of active effects on the atmosphere	**A, C, R/E, F**
Wastewater treatment and reuse	**A, C, R/E, F**	Increased water collection and storage capacity (reservoirs)	**A, C, R/E, F**
Locate potential water sources and establish a network of reserve sources.	**A, C, R/E, F**	Redistribution of water resources	**A, C, R/E, F**
Improvement of the irrigation system (aqueducts and canals)	**A, C, R/E, F**	Government support measures to restore the irrigation system in risky areas	**A, C, R/E, F**
DEMAND MANAGEMENT			
Adoption of regulatory documents on supplementary and scarce (limited) irrigation	**A, C, R/E, F**	Water-saving irrigation methods (drip, sprinkler ...)	
Development of a set of motivational measures for investments in water-saving technologies	**A, C, R/E, F**	Water recirculation	**A, C, R/E, F**
Inventory of private wells and agreement on the public use of these wells	**A, C, R/E, F**	Double distribution networks of drinking water supply	**A, C, R/E, F**
Development of drought alert procedures	**A, C, R/E, F**	Vulnerability assessment and recommendations to water users	**A, C, R/E, F**
Multi-year regulation reservoir	**A, C, R/E, F**	Joint use	**A, C, R/E, F**

(*) **A** - Agriculture; **C –** Crop Production, **R/E -** Recreation/ Environment, **F –** Food security