

Building the Central Asia Drought Information System in Kyrgyzstan: Progress and the Way Forward

Feasibility Study

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1. Preface

as steps towards the implementation of the Asia-Pacific Action Plan on Space Applications for Sustainable Development 2018-2030. The projects combine capacity building and technical support activities in the areas of disaster risk reduction and agroecosystem resilience.

Drought is one of the toughest challenges that stifle the achievement of the Sustainable Development Goals (SDGs) in Central Asia. Drought events can have various causes, be characterized by different course and have different consequences depending on weather and climate conditions, infrastructure and the level of preparedness. Drought is almost impossible to prevent, but it can be predicted, and its damage can be mitigated.

Drought events can cause serious and often irreparable damage to the ecology and economy of a country, affecting multiple domains of life. Generally, agriculture and waterculture bear the brunt of drought-related losses. However, being a multidimensional natural disaster, drought is also characterized by the accumulation of so-called “cascading risks”. Prolonged lack of soil moisture can dry the land out, destroying crops and making the land unsuitable for farming. Drying of vegetation increases the risk of wildfires. The dry regime contributes to the growth of the insect pest population. In the long term, all these effects of drought lead to land degradation, desertification and aggravation of the overall climate situation. The decrease in water levels in reservoirs leads to problems with natural irrigation and reduces the generation of electricity from hydroelectric power plants. Thus, a prolonged and severe drought can cause serious problems of a comprehensive nature - in the environment, in the business and financial sectors of the economy, as well as in the service sector, for example, in the field of tourism.

The theme of drought in Central Asia has been studied by several United Nations System organizations, including the Secretariat and the specialized agencies, such as FAO, WMO, UNDP, UNCCD and others. Those publications are of great importance, but a detailed consideration of the drought problem is required to attain specific objectives in the context of each individual country. The purpose of this report is to draw the attention of stakeholders to the possibilities of Earth Observation, Remote Sensing and Geographic Information Systems (GIS) as innovative means of effectively monitoring drought, as well as to assess the current state of preparedness to use these technologies and draw up recommendations for their most effective implementation, affecting the organizational, technical and legislative aspects of this topic.

This publication is dedicated to the Kyrgyz Republic, as one of the countries in which the pilot projects “Enhancing the capacity of the developing countries in Central Asia on effective use of space applications for drought monitoring and early warning through the Regional Drought Mechanism” and “Central Asia Drought Information System” of the United Nations Economic and Social Commission for Asia and the Pacific funded by the Russian Federation. These projects contribute to the achievement of SDGs 6, 11, 13 and 15 and are being implemented

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Cover: Kyrgyzstan, Sentinel-2 satellite image

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1.5. List of Acronyms

- AIR CAS – Aerospace Information Research Institute of the Chinese Academy of Sciences
- AIT – Asian Institute of Technology
- ASCAT – Advanced Scatterometer
- ASIS – Agriculture Stress Index System
- API – Application Programming Interface
- AVHRR – Advanced Very High-Resolution Radiometer
- CADIS – Central Asian Drought Information System
- CAIAG – Central-Asian Institute for Applied Geosciences
- CESDRR – Center for Emergency Situations and Disaster Risk Reduction
- CIS – Commonwealth of Independent States
- CNES – National Centre for Space Studies
- DEM – Digital Elevation Model
- ESA – European Space Agency
- ESCAP – United Nations Economic and Social Commission for Asia and the Pacific
- EVI – Enhanced Vegetation Index
- FAO – Food and Agriculture Organization of the United Nations
- GIEWS – Global Information and Early Warning System on Food and Agriculture
- GIS – Geographic Information System
- GIT – Geospatial Information Technology
- GNSS – Global Navigation Satellite System
- GPM – Global Precipitation Mission
- HTC – Hydrothermal Coefficient of Selyaninov
- JAXA – Japan Aerospace Exploration Agency
- KRIHS – Korea Research Institute for Human Settlements (KRIHS)
- MES – Ministry of Emergency Situations
- MODIS – Moderate Resolution Imaging Spectroradiometer
- MSI – Multi-Spectral Imager
- MSRI – Mountain Societies Research Institute
- NASA – National Aeronautics and Space Administration
- NOAA – National Oceanic and Atmospheric Administration
- NDDI – Normalized Difference Drought Index
- NDVI – Normalized Difference Vegetation Index
- NDWI – Normalized Difference Water Index
- NIEWS – National Information and Early Warning System on Food and Agriculture
- NIR – near-infrared
- NRIAM – National Research Institute of Agricultural Meteorology, Russian Federation
- NRSC IRIMHE – National Remote Sensing Center of Information and Research Institute of Meteorology, Hydrology and Environment
- OGC – Open Geospatial Consortium
- OLI – Operational Land Imager
- PRC – People’s Republic of China
- RAM – Rapid Access Memory
- RVI – Radar Vegetation Index
- SDGs – Sustainable Development Goals
- SFA – Singapore Food Agency
- SNPP – Suomi National Polar-orbiting Partnership

SMS – Short Message Service
SPEI – Standardized Precipitation-Evapotranspiration Index
SPI – Standardized precipitation index
SRC – scientific research institute
SRTM – Shuttle Radar Topography Mission
SWI – Soil Water Index
TCI – Temperature Condition Index
UAV – unmanned aerial vehicle
UN – United Nations
UNCCD – United Nations Convention to Combat Desertification
UNEP – United Nations Environment Programme
USGS – United States Geological Survey
UNITAR – United Nations Institute for Training and Research
USSR – Union of Soviet Socialist Republics
VIIRS – Visible Infrared Imaging Radiometer Suite
VHI – Vegetation Health Index
VSWI – Vegetation Supply Water Index
WIS – Water Information System
WMO – World Meteorological Organization
WMS – Web Mapping Service
WFS – Web Feature Service

1.6. Disclaimer

The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area, or of its authorities, or concerning the delimitation of its frontiers or boundaries. Where the designation “country or area” appears, it covers countries, territories, cities or areas. Bibliographical and other references have, wherever possible, been verified. The United Nations bears no responsibility for the availability or functioning of URLs. The opinions, figures and estimates set forth in this publication should not necessarily be considered as reflecting the views or carrying the endorsement of the United Nations. The mention of firm names and commercial products does not imply the endorsement of the United Nations.

2. Executive Summary

2.1. Introduction and Purpose of the Publication

Effective disaster risk management is impossible without timely detection. The task of detecting slow-onset disasters is much more technically challenging than that of rapid-onset events (wildfires, floods, landslides) due to the absence of pronounced visible signs for the former category.

Drought, being a slowly developing natural disaster, is difficult to detect, especially in its early stages. To make an objective conclusion about the presence and degree of drought in a particular area, it is necessary to develop a methodology for its detection, based on the principles of agrometeorology and hydrology, which requires obtaining quantitative measurements of certain physical variables. Moreover, for conducting comprehensive spatio-temporal analysis, a historical archive of those variables is required.

The study has two core objectives. Firstly, it aims to review and disseminate the results of a pilot project for the development of competencies of Kyrgyzstan officials and specialists in the field of monitoring drought events achieved in 2018-2022. Secondly, it describes priority areas for further capacity development activities in the field of drought mitigation for 2022-2023 and beyond. The description of priority areas ends with a list of brief recommendations for each topic

considered. The recommendations are addressed to all national and international structures interested in reducing the harmful effects of drought on the socio-economic development of Kyrgyzstan. When drawing up recommendations, special attention was paid to their practicability. Open data, including publications of specialized UN agencies, sets of normative documents, quantitative data from statistical portals of Kyrgyzstan and international organizations, was the main source of information for the study. Internal ESCAP research served as an additional source of material, as well as facts and opinions collected at various seminars, conferences, interviews within the UN system and government agencies in the Asia-Pacific region.

Drought events have intensified and increasingly threaten the sustainable development of Kyrgyzstan, harming the country's agriculture and many other sectors of the economy. High exposure is due to rising temperature peaks, lack of awareness, aging of agricultural and other infrastructure. This comes against a background of shared risks posed by climate change, natural disasters and the persistence of social inequalities exacerbated by the COVID-19 pandemic. In this regard, the development of a drought monitoring and early warning system appears appropriate. Numerous projects by the UN and other international organizations, as well as government measures to ensure food security and environmental sustainability, are bearing fruit, but their effectiveness could be increased through the introduction of high-tech solutions based on the use of space applications. World practice shows that for disaster monitoring purposes it is optimal to use remote sensing products together with data collected on the Earth's surface. One such solution should be a geographic information system for droughts, which is being developed within the framework of the project "Drought Information System for Central Asia, a pilot project", which is being implemented by ESCAP with the financial support of the Russian Federation.

2.2. Structure

The text of this publication includes two introductory chapters, a Preface and an Executive Summary. Chapters 3-7 serve as the core of the document.

Chapter 3 describes the current situation in Kyrgyzstan regarding the problem of drought and its monitoring, touching upon the geography of the country, its agriculture and drought history.

Chapter 4 is devoted to the drought-related organizational and technical environment. In particular, an overview of legislative initiatives and guidelines is provided, as well as some judgement on the degree of their development. It also lists most relevant stakeholders and their current activities. This topic is continued in Chapter 7, which proposes that these stakeholders play a concrete role in relation to the drought information system.

Chapter 5 reveals the essence of the process of drought monitoring through the modern means of ground and satellite observation. This explanation is accompanied by multiple examples of existing systems, tools and data sources at the national, regional and global levels. Best practices and approaches from some other states are discussed in the Section 5.3 of this

Chapter.

Chapter 6 is an overview of organizational, educational and technical activities carried out under the ESCAP pilot project on the implementation of a drought information system in Kyrgyzstan. The Chapter's key part is the block diagram of the future system proposed at an early stage of the project. Chapters 3-6 act as the basis for a conclusion that Kyrgyzstan does not own a comprehensive monitoring and early warning system for drought, and none of the existing solutions can be applied in this capacity. However, the country has sufficient legislative, organizational and technical prerequisites for the independent development of such a system with the participation of organizations and partner countries.

Chapter 7 proposes a plan for the operationalization of the drought information system, assigning it a working title "CADIS-Kyrgyzstan". The chapter proposes two options for system configuration, basing them on both existing capabilities and expected future developments. The chapter also provides strategic recommendations for improving national legislation, building up interdepartmental cooperation and enriching the country's overall technical base. The last group of recommendations may not be directly related to drought monitoring, but if properly implemented, the proposed improvements should enhance the quality of analysis.

3. Introduction

3.1. Problem Statement

3.1.1. Land and Water Resources of Kyrgyzstan

Kyrgyzstan has an area of 200,000 sq. km and spans approximately 1,000 km from west to east and 430 km from north to south. The country borders with Kazakhstan in the north, with China in the east, with Tajikistan in the south and southwest, and with Uzbekistan in the Fergana Valley. The geography, climate and specific distribution of land and water resources of Kyrgyzstan make it one of the most difficult countries in the world to monitor and predict drought events. Information on water bodies and croplands is vital for this task. The geography of these physical resources is presented as Figure 3.1.

Croplands and Water Resources of Kyrgyzstan

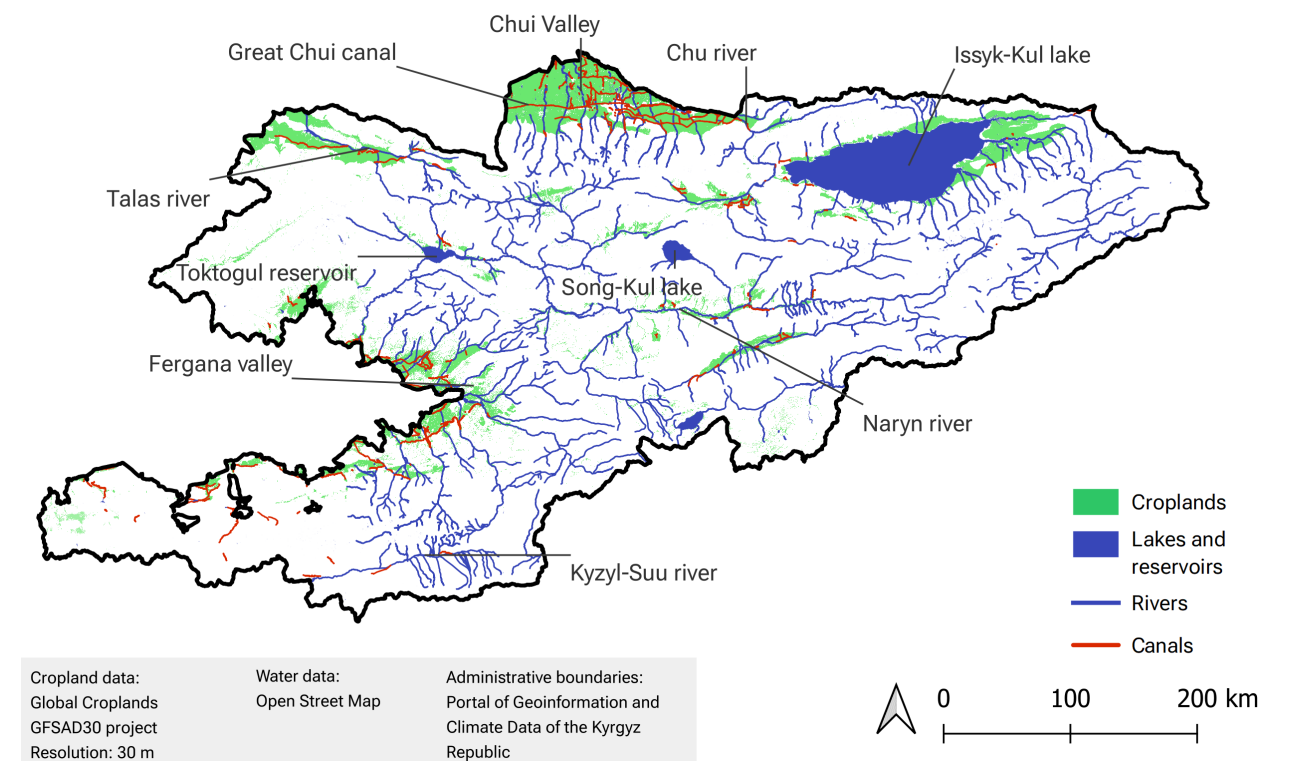


Figure 3.1

The climate of Kyrgyzstan is unique and diverse. Three to four climatic zones can be distinguished in the country, depending on the approach (by regions, by altitude). Each zone is characterized by a special temperature regime, soil properties, precipitation, winds and other components of the hydrological cycle.

Graded by altitude above sea level, the four climatic zones are: plains and hills (up to 1,200 m), medium mountains (1,201-2,200 m), highlands (2,201-3,500 m) and the nival belt (above 3,500 m). The relief is dominated by medium mountains and highlands, which occupy 66% of the territory, while plains and hills account for only 10%. The remaining 24% is occupied by permanent snow and ice cover (Figure 3.2).

Hydrology cannot be ignored in drought observation, especially in Kyrgyzstan, where about 90% of the country's consumed water resources are used for crop irrigation.¹ According to FAO, up to 20% of the unused arable land is not cultivated due to malfunctions of the irrigation network. The average irrigation system water loss is 27% and increases significantly in rural areas.² 76% of irrigated lands are watered by the means of small rivers. Rivers and reservoirs inevitably begin to deplete in cases of particularly prolonged and intense drought. Under hydrological drought, significant damage is inflicted not only on agriculture, but also on the country's energy industry, since electricity generated at hydroelectric power plants makes up at least a fourth of energy consumption in Kyrgyzstan.

3.1.2. Agriculture

Agriculture, namely crop production, is the most drought-sensitive sector of the Kyrgyz economy. According to various estimates, sown areas occupy 7-9% of the country’s territory. Due to the success of mass land privatization and the high proportion of the rural population (over 60%), land ownership in Kyrgyzstan is characterized by a high degree of decentralization.⁶ Three-quarters of the arable land is owned by smallholders and family farms, making planning and notification of the public very problematic.⁷

Elevation Classes of Kyrgyzstan

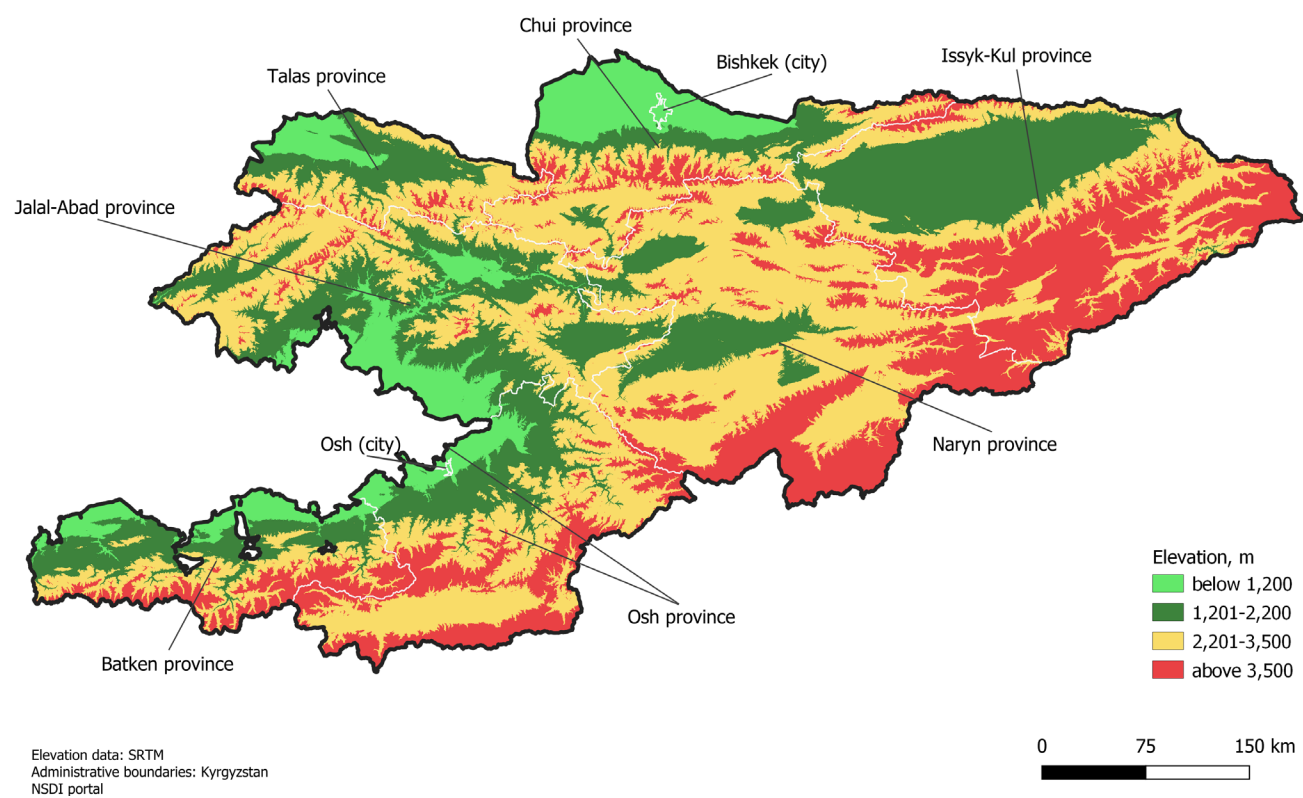


Figure 3.2

Since gaining independence in 1991, the population of Kyrgyzstan has seen a 50% increase, which could not but affect the domestic demand for agricultural products, the production rates of which, however, on average corresponded to the growth rates of the number and well-being of the population. Over thirty years, the annual production of potatoes and food melons in absolute terms has increased fourfold, vegetables – by 3 times, fruits and berries – by one and a half times (Figure 3.3). At the same time, grain yields remained at the same level, and only tobacco production experienced a significant reduction.³ As a result, the country fully provides itself with the regular “consumer basket” agricultural crops,⁴ except for bread products, for which about half of the wheat is imported from Kazakhstan.⁵ Such successes were achieved primarily due to the increase in yields, that is, the share of crops harvested per hectare, increased due to the reallocation of land under barley and tobacco in favor of food crops. Increased use of innovative chemical fertilizers also contributed to yield growth. The area of arable land, which expanded by 18%, remained comparable to the level of the year when Kyrgyzstan left the USSR in 1991. The Chui region hosts almost 40% of all arable land, which makes it the main producer of agricultural products.

Production Dynamics of Basic Food Crops and the corresponding Farmland Area in Kyrgyzstan in 1991-2021 (top), Farmland under core Food Crops in 1991-2020 (bottom)

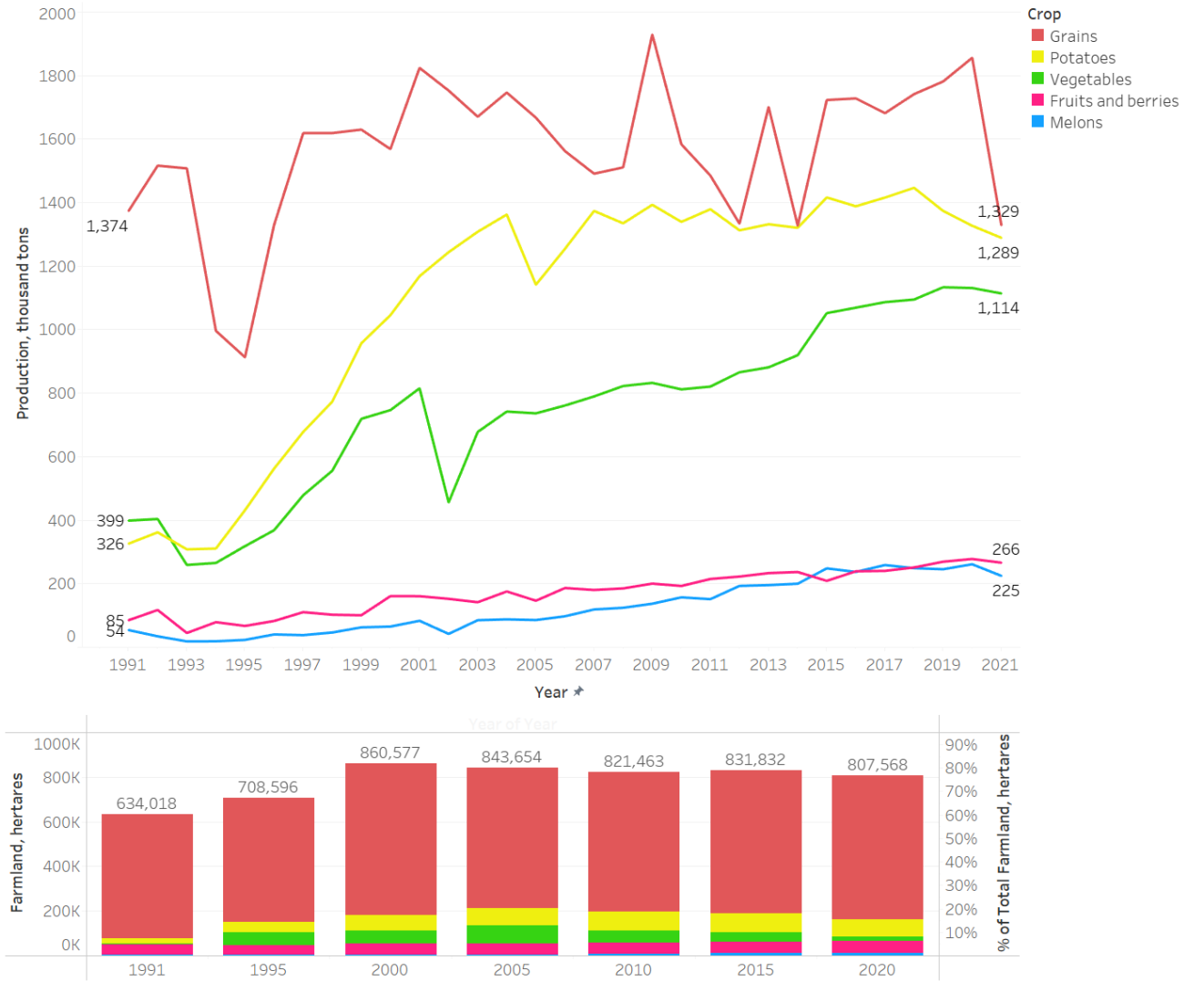


Figure 3.3

Spring crops are mainly grown in Kyrgyzstan. The growing season starts in May, peaks in the summer months, and ends in September-October.⁸ The largest cultivated area in the country is occupied by cereals, namely by corn, wheat, barley and rice. As of 2021, land under wheat accounted for 42% of all fields under the grain class, 38% of such fields were occupied by barley, and 18% - by corn. Rice and other cereals (millet, sorghum, rye, a mixture of cereals) do not belong to the core crops and occupy only 2.5% of the total area under the grain class. Wheat fields predominate in most regions of the country, with the exception of Jalal-Abad and Naryn oblasts, where larger areas are devoted to corn and barley, respectively. Corn is grown mainly in the south of the country and partly in the Talas region. Corn fields are almost completely absent in the Issyk-Kul and Naryn regions. From the point of view of crop productivity, there is a steady downward trend in wheat yields per hectare.

In addition to cereals, major crops grown in Kyrgyzstan are potatoes and other vegetables, food melons, fruits and berries. Almost all sugar beets and about 40% of all vegetables, melons and oilseeds harvested in the country are placed in the Chui region. About a quarter of fodder crops are sown there, allocated in a separate class⁹. Some of the latter, such as clover, can be harvested up to three times a year.

Crops Most Susceptible to Drought in Northern Kyrgyzstan

Severe drought was observed in the Chui region in 2021, while 2020 was a regular year. Yields of all major crops declined, except for fruits berries, which showed a slight increase. Thus, the productivity of commodity melons fell from 0.96 metric tons per acre (t/ac) to 0.74 t/ac, showing a decrease of 23%. Potato and vegetable yields declined by 6% and 12%, respectively. However, grain crops suffered the worst damage, losing 48% of production from 2020 to 2021.

In the neighboring Issyk-Kul region, in 2021, the yield of potatoes, vegetables, and fruits and berries did not change at all, while an average of 0.4 t/ac was harvested from grain fields, that is, 40% less. A similar situation is observed when comparing another pair of dry and wet years, namely 2014 and 2016. This data allows us to conclude that grain crops are most susceptible to drought in northern Kyrgyzstan.

Nationwide the most common cereals are wheat, barley and corn. All three species are represented in the Chui valley. In 2021, the drought hit wheat and barley yields equally hard, reducing yields by 62% in both cases. Corn fields were the least affected, showing an 18% drop (Table 3.1).

Productivity of Primary Grain Crops in the Chui Region, 2020-2021,t/ac

Region	Crop	2020	2021
Chui	Maize	3.01	2.48
	Wheat	1.12	0.43
	Barley	1.04	0.40

Table 3.1

Box 3.1

From the standpoint of climatic zones, the foundation of crop harvests comes from the plain and hill belt, which hosts 55% of total arable lands. Slightly more than half of these fields are in the Chui region, 18% belong to Jalal-Abad, 24% are equally divided between the Talas and Osh regions, with the rest remaining to the Batken state. Naryn and Issyk-Kul regions are located entirely above 1,200 m. 39% of land plots are located in the medium mountains, mainly in the Issyk-Kul and Naryn regions, especially abundant on the eastern shore of the Issyk-Kul Lake, in the valley of the Naryn River and along the banks of the Kochkor, Seek, Chygyshtay Karakol rivers. The remaining 6% of arable land is located mainly in the highlands of the Naryn region. There are practically no cultivated fields above 3,500 m (Figure 3.4).

Total Land Area (above) vs. Croplands (below) of Kyrgyzstan by Altitude Classes

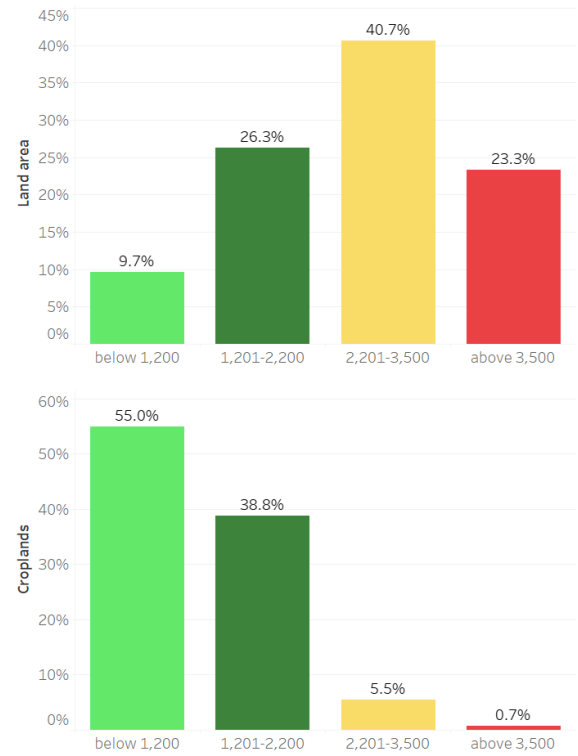


Figure 3.4

Despite the growth in agricultural production in Kyrgyzstan, the industry is hampered by numerous problems. The farmers’ low awareness of modern agrotechnical methods, mineral fertilizers and specialized seeds negatively affects labor productivity, which remains one of the lowest in the region. The irrigation system, created mainly during the Soviet era, has also been severely degraded.¹⁰

The majority of the country’s workforce is employed in the agricultural sector, but the sector’s role in the economy is not paramount – it has long since lost its leading position to trade and manufacturing. The share of farmers is declining in favor of other, predominantly urban, occupations that former farmers are engaged in both in the country and abroad. Migration is high, and the main flow of labor migrants is formed by the former hired agricultural workers.¹¹

3.1.3. Drought History

Kyrgyzstan is vulnerable to climate change, as evidenced by a 1.2°C increase in average annual temperatures over the past 20 years for the country’s territory, with oppositely directed forecasts for average monthly temperatures and precipitation¹². Over the past fifteen years, droughts have increased significantly, and were national in scope in 2008, 2012, 2014 and 2021. The streamflow of the Syr Darya river basin was 42-77% below the norm in 2021, which led to an acute shortage of water for irrigation. The rivers of the Chui valley, namely Ala-Archa, Alamedin, Issyk-Ata and Kegety, have dried up so much that many farmers have lost fodder crops due to lack of irrigation water, which has greatly affected livestock. The drought has had ecological repercussion – due to lack of water in reservoirs, a big number of fish and birds have been lost. As indicated in Figure 3.3, in all the dry years, the harvest of cereals, relying almost exclusively on natural irrigation, suffered significantly. According to FAO (Figure 3.5), drought most often occurs in the central parts of the Naryn and Jalal-Abad regions and in the north-west of the Talas region. The Naryn region regarded as the most prone to severe drought.¹³

Historic Drought Frequency with more than 30% of the Cropland affected in Kyrgyzstan

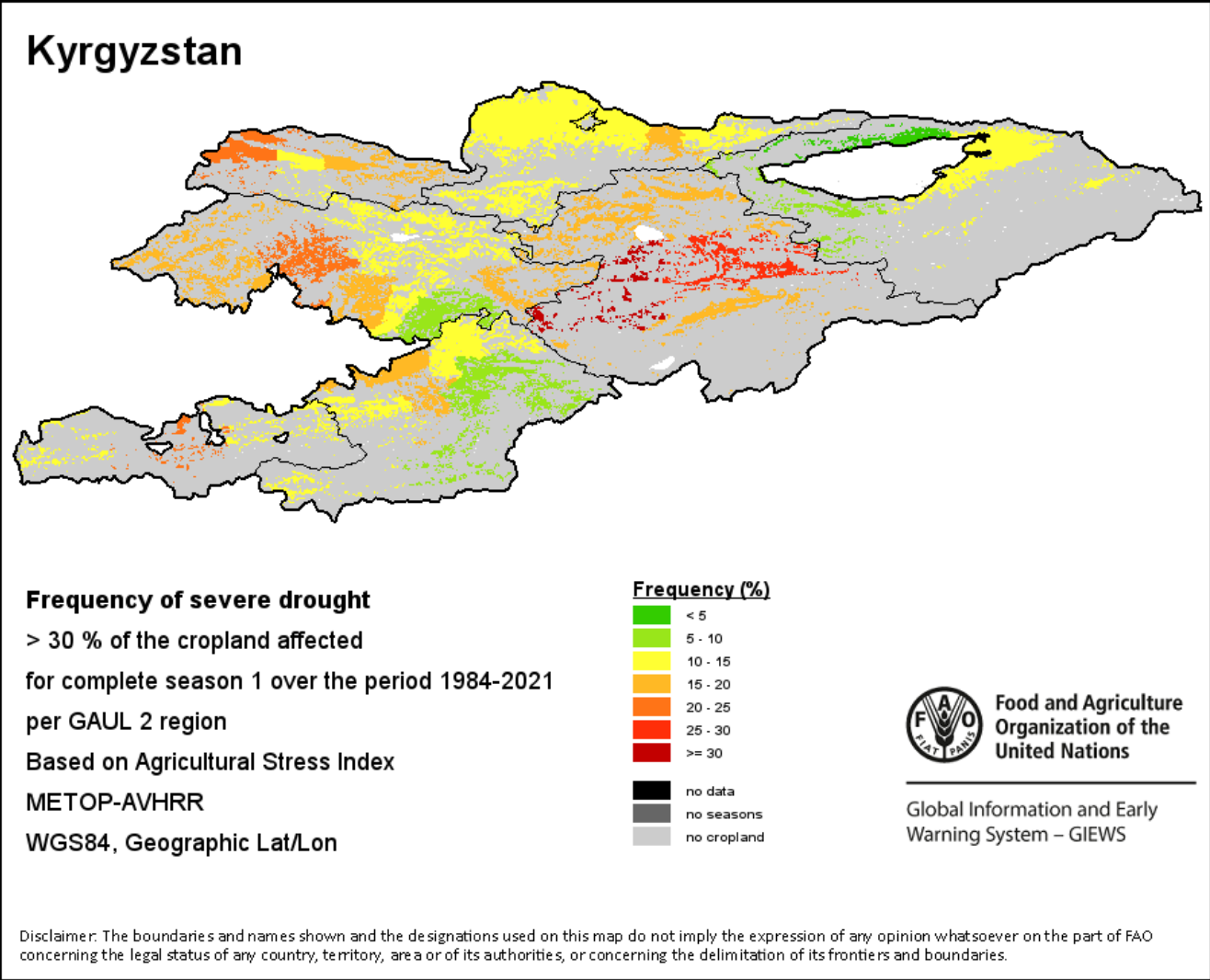


Figure 3.5

3.2. Scope of Research and Used Sources

Recognizing the importance of a comprehensive approach to the analysis of natural disasters, one of which is drought, the author dwells in detail on only one stage of the disaster response cycle, namely monitoring and forecasting. At the same time, technical, organizational, and legislative aspects of the problem are included in the consideration. A review of emergency response activities and mechanisms to reduce their detrimental effects is beyond the scope of this publication.

The author of the publication also conducted independent research using statistical tools and geospatial systems. The material of the study was the statistical tables of the National Statistical Committee of the Kyrgyz Republic, as well as sets of spatial data on the Earth, such as Global Croplands, ESA Worldcover, DEM SRTM.

A full list of sources is included at the end of this document.

4. Legal and Organizational Framework for Drought Management in Kyrgyzstan

4.1. Legislative Initiatives and Strategic Guidelines

4.1.1. Legal Framework

The creation of a state drought monitoring system was anticipated and legitimized by the Decree of the Government of the Kyrgyz Republic “On the Unified System for Comprehensive Monitoring and Forecasting of Emergency Situations in the Kyrgyz Republic” adopted in 2019.¹⁴ The concept postulates a comprehensive approach to disaster risk reduction, interpreting this area of public administration as an element of the Civil Protection doctrine. The document introduces a common approach, terminology and prescriptions for the creation of various technical systems, namely the procedure for their development, typification of monitoring types and objects, modes of operation of the Unified Disaster Management System.

The Concept of Comprehensive Emergency Protection of the Population and the Territory of the Kyrgyz Republic for 2018-2030 is seen as the guiding document for the above Decree.

The main objective of the Concept is to increase the efficiency of monitoring and response to emergencies by constantly improving the legal framework and the organizational structure of the responsible departments. It is important that the concept not only sets goals and has an action plan to achieve them, but also emphasizes the risks that jeopardize its implementation (insufficient funding and staff qualifications, an unstable situation within the country). The creation of a risk register as part of the plan for the implementation of the concept, which includes a qualitative assessment of the consequences and likelihood of various cataclysms, indicates the development of a systematic approach to counteracting natural disasters.¹⁵

Classification of Emergency Situations and the Criteria for their Assessment in the Kyrgyz Republic, issued as an annex to the above-mentioned Government Decree, introduce the definition of a gamut of natural emergencies closely related to drought events, as well as soil and atmospheric droughts.¹⁶ This classification (Table 4.1) is consistent with the first two elements of the more detailed and generally recognized drought classification used in most countries, subdividing this phenomenon into meteorological, agricultural, hydrological and socio-economic drought.¹⁷ Soil drought, defined in Kyrgyzstan as a lack of productive moisture in the upper layers of the soil, can be associated with the generally accepted definition of agricultural drought. Atmospheric drought, characterized in Kyrgyzstan by insufficient monthly precipitation, is consonant with the recognized term of meteorological drought. At the same time, the terminological equivalents of hydrological and socio-economic drought, which are often a more severe continuation of the cycle of the same drought, have not been introduced. In some cases of international practice, snow drought is also singled out as a separate category – the lack of wintertime snowfall. In fact, a snow drought can be equated to meteorological drought, but for a country with a distinctly continental climate, such as Kyrgyzstan, having information about winter precipitation is also very useful.¹⁸

The Law of the Kyrgyz Republic “On Food Security” sets a strategic task for the agro-industrial complex to fully satisfy the needs of the inhabitants of the Republic in basic food staples through domestic production.¹⁹ As mentioned earlier, farming consistently satisfies domestic demand with goods from the core “consumer basket” (with potatoes, vegetables and melons being actively exported). However, there is a significant gap between demand and domestic supply for bread, fruits, berries and vegetable oil. It should be noted that the drought directly affects

Elements of the Classification of Drought-related Emergencies in Kyrgyzstan, Fragment of the “Classification of Emergencies and Criteria for their Assessment in the Kyrgyz Republic”

№	Emergency origin	Physical manifestation	Damage assessment criteria
26	Soil drought	reserves of productive moisture in the 0-20 cm layer are 10 mm or less within two dekads	quantity of people affected (by age and gender), disruptions in daily activity, economic damage
27	Atmospheric drought	absence of effective precipitation (more than 5 mm per day) during the growing season for 30 consecutive days or more at a maximum air temperature above 30°C. On certain days (no more than 25% of the duration of the period), the maximum temperature below the specified values is allowed	

Table 4.1

the country’s traditional animal husbandry, causing damage to pastures where more than 6 million sheep and goats and about 1.7 million head of cattle graze. An important difference between national animal husbandry and crop production is that most pastures and hayfields are owned by the state and rural administrations (aiyl okmotu), which simplifies the processes of centralized emergency notification.²⁰

Article 71 of the Water Code of the Kyrgyz Republic provides for the creation of a unified information system for and warning on floods, droughts, mudflows and landslides. This provision was present in the original version of the law of 2005.²¹ Such capabilities have not been fully deployed. Unlike droughts, floods and mudflows are rapid-onset disasters, however, the nature of the studies necessary for their monitoring is fundamentally similar to approaches to identifying droughts due to the common sources of initial data (precipitation and temperature data obtained from satellites or meteorological posts). The Law of the Kyrgyz Republic “On the Development of Agriculture in the Kyrgyz Republic”, supplemented by guidelines for the introduction of progressive innovative technologies in the agro-industrial complex in 2021, reinforces the need to introduce a crop monitoring system.²²

4.1.2. Strategies, Plans and Programmatic Documents

The first programmatic document aimed at combating desertification and drought was the “National Action Plan to Combat Desertification in the Kyrgyz Republic” developed jointly with UNCCD. The plan was adopted and published in the year 2000. It proposed several projects and activities to combat desertification, many of which are still being implemented (processing of historical hydrometeorological data, digitization of hydrometeorological databases). The document also recommends the use of GIS and Remote Sensing, which were emerging technologies at that time.²³

In 2014, together with the UNCCD and the World Bank, a new National Action Plan for 2015-2020 was developed, postulating the need to create a national system for monitoring and predicting natural disasters, specifically with the use of Remote Sensing and GIT. The document also emphasizes the importance of continuous professional development of government officials and the population through round tables, seminars and educational programs to combat land degradation and promote sustainable land use practices.²⁴ The Plan was valid until 2020, but is regarded as current, as it is expected to be reissued for a new five-year period. The Plan is being updated within the framework of the FAO project titled “Integrated Natural Resources Management in Drought-prone and Salt-affected Production Landscapes in Central Asia and Turkey”.

Preservation of the environment, adaptation to climate change and disaster risk reduction are the areas identified as necessary in the National Development Strategy of the Kyrgyz Republic for 2018-2040.²⁵ Agro-industrial complex development is included as a separate priority. Deployment of a drought information system contributes to several strategic tasks of agriculture at once, in particular, to provide the population of the country with quality food (see also the law “On Food Security of the Kyrgyz Republic”) and to provide information support to small farms.²⁶

The “Digital Kyrgyzstan” concept of the country’s digital transformation sets objectives to

Drought Management and GIS/Remote Sensing as Priorities of Policy Documents

Policy document	Drought/ desertification	Disaster monitoring systems	Disaster monitoring systems
Government Resolution “On the Unified System for Complex Disaster Monitoring and Prediction in the Kyrgyz Republic”	Yes	Yes	–
Kyrgyzhydromet development programme for 2020-2025	Yes	Yes	Yes
National Action Plan (NAP) for implementing UNCCD in the Kyrgyz Republic for 2015-2020	Yes	Yes	Yes
Concept of Comprehensive Protection of the Population and Territory of the Kyrgyz Republic from Emergency Situations for 2018-2030	Yes	Yes	–
Water Code	Yes	–	–
Law “On Hydrometeorological Activity”	–	Yes	–
Law “On Food Security”	–	Yes	–
Classification of Emergencies and their Appraisal Criteria	Yes	–	–
National Development Strategy of Kyrgyzstan for 2018-2040	Yes	–	–
“Digital Kyrgyzstan” Strategy for 2019-2023	–	Yes	–

Table 4.2

introduce information technology in various sectors of the economy, including environmental protection, disaster risk reduction and agriculture. For forestry, the goal is to implement a geospatial tool for displaying forest resource data.²⁷ “Digital Kyrgyzstan” was approved together with an implementation roadmap, which describes specific plans for the creation of processes and services based on digital technologies for various sectors of the national economy, including agriculture. Three policy goals were set, the first one being to adopt the Program for the Development of the Agricultural Industry Using ICT and an action plan for its implementation for 2019-2022. Objectives for disaster risk reduction are also present in the roadmap. Firstly, it is planned to develop an Internet portal for the centralized collection

Summary: Strategies, Plans and Programmatic Documents

Strategic and policy documents adopted in Kyrgyzstan focus on drought, opening the door for further development of laws, standards and lower-level policy documents. The existing legislation regulates some aspects of work with the subject of drought, forming a general organizational structure of responsible state bodies, defining various types of droughts and envisaging the creation of a monitoring system. However, the direction has not been singled out as a priority area. The existing drought classification is not specific enough and does not account for all its possible stages. In addition, no national or regional plans for drought management exist. At the same time, plans for the implementation of a drought monitoring and early warning system were developed by the authorized body at the internal level, but their implementation is lagging behind due to insufficient planning and interdepartmental interaction.

Box 4.1

of information from departmental and international emergency monitoring and forecasting networks by the end of 2022. Secondly, to launch the Center for the Collection, Processing and Transmission of Hydrometeorological Data obtained by the observation network of the Agency for Hydrometeorology under the Ministry of Emergency Situations (Kyrgyzhydromet).²⁸

Kyrgyzhydromet is the national authorized body for hydrometeorological activity. At present three documents determine Kyrgyzhydromet’s direction for the medium and long term. The law “On Hydrometeorological Activities in the Kyrgyz Republic” does not cite drought as such but defines dangerous natural hydrometeorological phenomena and early warning systems for weather forecasting.²⁹

Table 4.2 summarizes the introductory chapter by sorting the normative documents according to how relevant they are to drought monitoring with the use of GIS and satellite monitoring.

4.2. Competent Authorities and their Mandates

4.2.1. Stakeholder Mapping

Global experience in the implementation of technical systems suggests that any system should have a single owner – a permanent team with precisely defined roles. At the same time, given the multidimensional nature of drought, a corresponding monitoring system cannot fully function without active interdepartmental interaction. Table 4.3. presents the prospective participants in the process of creating, maintaining and using the future system, and below is a short summary of the most significant players, one way or another related to the topic of drought. They are divided into three groups – state bodies of Kyrgyzstan, international and foreign organizations, as well as groups of citizens living in the country. The stakeholders’ mandates are described in the following two sections. Section 7.2.1 includes recommendations on their prospective roles in the information system’s development.

Mandates of Prospective Stakeholders of the Process of Developing, Maintaining and Employing a Drought Information System for Kyrgyzstan

Type	Name	Role	Web-site
Government	Agency on Hydrometeorology under The Ministry of Emergency Situations (Kyrgyzhydromet)	Monitoring the hydrometeorological situation, storing hydrometeorological data	↗
	Ministry of Emergency Situations	Civil protection, monitoring and forecasting of emergencies of all types, notification of the public	↗
	Ministry of Agriculture	Policy development for the agro-industrial complex	↗
	Water Resources Service under the Ministry of Agriculture	Integrated water resources management mechanism implementation, interaction with water users, storing hydrological data (including geo-referenced data)	↗
	National Statistical Committee	Formation of detailed agricultural statistics (including those with a high level of geographical detail)	↗
	Land Resources Service under the Ministry of Agriculture	Formation of a geoinformation system for land resources, execution of topographic, geodetic and cartographic works	↗
	Forest Service under the Ministry of Agriculture	Forestry development, maintenance of specially protected natural territories	↗

Government	“Kyrgyzgyprozem” Institute	Cadastral support of the state, storage of land use data (including geo-referenced data)	n/a
	Institute of Biology of the National Academy of Sciences	Environmental research, storage of soil data	↔
	Institute of Water Problems of the National Academy of Sciences	Research in the field of information support systems for water and land resources management	↔
	K.I. Skryabin Kyrgyz National Agrarian University	Training of specialists in agronomy, forestry, hydro-reclamation, ecology, land management	↔
	Basin administrations	Water resources management in the hydrogeographic boundaries of the main basin or area	n/a
International organizations and partner states	ESCAP	Maintaining a wide network of regional initiatives (Regional Drought Mechanism, Regional Space Applications Programme), conducting capacity building activities on the use of geospatial information, policy research	↔
	SRC “Planeta”	One of the main satellite data processing centers in the region, produces thematic products of a wide range – from emergency monitoring to global climate change research	↔
	UNITAR/UNOSAT	Global emergency analysis center with extensive experience in training on the use of geospatial information	↔
	Aerospace Information Research Institute under the Chinese Academy of Sciences	Scientific research center in the field of satellite data applications, producing practical solutions (drought and crop monitoring)	↔
	Mountain Societies Research Institute (MSRI)	A regional research center with technical capabilities for land monitoring and an extensive network of contacts in rural communities	↔
	Central-Asian Institute for Applied Geosciences (CAIAG)	Regional research center specializing in the application of geoinformatics in researching climate-related and environmental problems	↔
Population Groups	Farmers and water users	Use of land and water for agriculture, production	
	Basin councils	Solving issues in the main basin on the use, protection and development of water resources	

Table 4.3

4.2.2. State Organs

The Agency for Hydrometeorology (Kyrgyzhydromet) under the Ministry of Emergency Situations of the Kyrgyz Republic carries out activities in the field of hydrometeorology and monitors the level of environmental pollution. The main tasks of the Agency are a) to monitor the natural environment to protect the population from natural hydrometeorological events, b) to meet the needs of the population and authorities for hydrometeorological information, c) to manage the national fund of hydrometeorological data.

The Ministry of Emergency Situations of the Kyrgyz Republic is the authorized body in the field of civil protection and the head structure of Kyrgyzhydromet. It is tasked with monitoring and forecasting emergency situations. It is also responsible for the development of state policy in the field of disaster risk reduction and has serious organizational and technical capabilities. In

particular, the Ministry operates an established mechanism for alerting the population about impending dangers via SMS and the “112 Kyrgyzstan” mobile app. Moreover, it receives information from the citizens through instant messaging and via a hotline number. MES also has certain GIS competencies, employing relevant specialists, who make use of the ArcGIS Enterprise and ArcGIS Desktop software subscription. The Ministry also uses a DJI Phantom drone for field research.

The Ministry of Agriculture of the Kyrgyz Republic implements state policy for the agro-industrial complex, including animal husbandry, crop production, land reclamation, development of water and land resources. One of the urgent tasks of the Ministry in the context of combating drought is the implementation of state policy in for ensuring effective and rational management and use of lands of the State Fund for Agricultural and Pasture Lands. Due to the importance of the agro-industrial complex for the country’s economy, the Ministry has a large headquarters office and multiple subordinate organizations, including the Water Resources Service, the Land Resources Service and the Forest Service. The Ministry has a wide network of territorial departments at the district level, with 40 representative offices in seven regions.

The Water Resources Service under the Ministry of Agriculture of the Kyrgyz Republic regulates relations in the fields of water management and water consumption. The Service has introduced the Integrated Water Resource Management Mechanism, ensuring sustainable management and rational use of water resources and water infrastructure facilities. The Service is the operator of the Water Information System, the geospatial tool described in paragraph 5.2.3.

Kyrgyzhydromet Development Plans

Kyrgyzhydromet has its own five-year development vision, drawn up in the style of the Concept of Comprehensive Protection: a) an assessment of the current situation in the department is given, b) tasks with certain deadlines are set within four directions, c) risks are mentioned, d) a system of reporting on the implementation of the program is established. Digitization of infrastructure, data and work processes is a cross-cutting theme for Kyrgyzhydromet.³⁰ The introduction of hydrodynamic modeling processes is highlighted as a separate objective for the entire period of the plan (2020-2025). It is expected that by 2025 the Agency would own the following five products:

1. SPI-based atmospheric drought models;
2. A suitable country-tailored soil drought model;
3. Software for extracting satellite information on vegetation cover, soil humidity and temperature;
4. Drought forecasting tools, employing long-term precipitation and temperature forecasting;
5. A suitable country-tailored agricultural crop yield model;

The fact that such detailed action plan has been prepared and published should allow international organizations to provide targeted support to Kyrgyzhydromet as part of a project with an objective to create a drought monitoring system.

Box 4.2

The National Statistical Committee of the Kyrgyz Republic is the government body responsible for the production of official statistics. The Committee conducts purposeful work on the collection and dissemination of agricultural statistics, which are presented in a spatio-temporal context with a high level of detail and are distributed in a machine-readable tabular format.

The State Design Institute “Kyrgyzgiprozem” of the State Service for Land Resources of the Ministry of Agriculture of the Kyrgyz Republic is responsible for cadastral development. The scope of the Institute’s activities includes establishing the availability and soil-reclamation state of agricultural land, as well as making conclusions about the productivity of a particular land plot. The Institute is the main developer of the country’s NSDI, having created the Geoinformation and Climate Data Portal of the Kyrgyz Republic, which integrates geographic data from 14 government agencies.

In the academic environment of Kyrgyzstan, at least two research institutes whose expertise is related to drought, have been identified. They are the Institute of Biology and the Institute of Water Problems and Hydropower of the National Academy of Sciences of the Kyrgyz Republic. In addition, the Kyrgyz National Agrarian University named after K. I. Skryabin is actively preparing specialists and graduate students in the field of agronomy, forestry, hydromelioration, ecology, land management and other related disciplines.

4.2.3. International and Non-governmental Organizations, Population Groups

The United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) is implementing the project “Central Asia Drought Information System” sponsored by the Russian Federation. ESCAP has significant competencies in the field of Information and Communication Technologies and Disaster Risk Reduction, contributing to the implementation of various technical and organizational initiatives in the region.³¹

SRC “Planeta” is the leading organization in Russia for the operation and development of space systems for observing the Earth for hydrometeorological, oceanographic, heliogeophysical purposes and environmental monitoring. The organization is one of the main satellite data processing centers in the region of North and Central Asia, producing thematic products for a wide range of areas – from emergency management to the study of global climate change. The experience of monitoring the vegetation cover produced by “Planeta” for constituent entities, administrative districts and individual farms on the territory of the Russian Federation is relevant for the project considered in this report. The Center’s receiving stations, which are located in the Siberian Center, often receive data not only for the territory of Russia, but also for the countries of Central Asia located to the south, including Kyrgyzstan.

The United Nations Institute for Training and Research (UNITAR) has a wide range of competencies in building the capacity of developing countries to practically apply various technologies. United Nations Satellite Center (UNOSAT), one of the structures of the Institute, specializes in providing states with up-to-date analytical information on the course of emergency situations.

The Aerospace Information Research Institute of the Chinese Academy of Sciences (AIR CAS)

is China’s largest scientific center specializing in geospatial technologies. The Institute develops client and cloud applications for the study of meteorological and agrometeorological information. ESCAP and AIR have gained extensive experience working together under the Asia-Pacific Regional Drought Mechanism by deploying the DroughtWatch system in five ESCAP member countries.

The Mountain Societies Research Institute (MSRI) is an international research center hosted by the University of Central Asia. One of the research areas of the organization is the impact of drought events on the rural population of the countries of the region, including Kyrgyzstan. The center has significant technical capabilities, regularly conducting field studies of vegetation and soils.

The Central Asian Institute of Applied Geosciences (CAIAG) conducts research in three areas: 1) geodynamics and geo-catastrophes, 2) climate, water and geo-ecology, 3) monitoring systems and data management. The two former areas of the institute’s activity appear to be relevant for the purposes of creating the system to which this publication is dedicated.

Rural farmers bear the brunt of drought’s impact in Kyrgyzstan. They often organize themselves into farmer communities and water user associations. At the public level, these associations are represented by basin councils, and at the level of interaction with state bodies – by basin administrations.

There are many governmental, non-governmental and intergovernmental organizations that can benefit from a drought information system. Since resources are limited, not all of them might be involved in the system discussion development, though some of them are included in Tables 4.3 and 7.1 and as a potential user and beneficiary of the system.

Summary: Competent Authorities and their Mandates

Several government agencies in Kyrgyzstan would be interested in using a drought information system. Land and water resources are studied in the academic environment, but they are not often used by government bodies. Various state, scientific and international organizations operating in Kyrgyzstan have extensive relevant experience, methodological apparatus and datasets. National spatial data infrastructure exists and is being supplemented by some geoinformation products. However, the lack of specific focus on drought monitoring, coupled with insufficient staffing in the areas of hydro- and agromonitoring, is a serious drawback.

Box 4.3

5. Existing National, Regional and Global Drought Monitoring Systems with Kyrgyzstan coverage

5.1. Introduction and Technical Reference

Currently, operational monitoring of drought around the world is carried out using platforms employing quantitative indicators referred to as drought indices and indicators. While dozens of different indices and indicators are used, they are based on a single principle – the assessment of moisture inflow and outflow, taking into account the atmospheric, soil and hydrosphere parameters. The most effective approach is the one in which the data of the hydrometeorological network are used together with the data obtained by remote sensing of the Earth.

Remote Sensing Data

The data obtained via Remote Sensing can be divided into vector and raster. Vector data are collections of two-dimensional idealized geometric shapes (points, lines, polygons) denoting certain real-world objects. For example, on a small-scale map, administrative divisions and lakes can be delineated by polygons, rivers and roads – by lines, infrastructure objects – by points. When creating a map of the same objects on a larger scale, it would be advisable to use polygons to mark buildings and wide rivers. Another feature of the vector information is the ability to describe idealized objects, supplementing them with semantic data, through a so called “attribute table”. For example, the number of lanes and speed limits for a road or crop types and crop calendars calendar for an agricultural field. Vector geometry allows its creators to generate complex data enriched by semantic information.

South Shore of the Issyk-Kul Lake, Raster Image of the Sentinel-2 Satellite (left) and Vector Image of the Lake, Villages, Rivers and Croplands (right)



Figure 5.1

Raster data are image files made in the form of a rectangular pixel matrix. The focus of raster analysis are values recorded in each pixel of the file. If a raster comes from a satellite image, this value is a physical quantity, namely the radiance of the Earth's surface in a certain spectral range. Another widespread format are “thematic rasters”, which are generated after processing primary images and dedicated to a specific topic. The pixel values of such rasters can be geographical heights, land cover classes, etc. Such datasets obtained by multispectral, radar or lidar sensors are widely distributed

and form the basis for the analysis of natural phenomena. In the context of droughts, raster data is mainly used to generate vegetation index maps in order to track the state of vegetation cover.

Box 5.1

No single regional system for monitoring drought in Central Asia exists, nor does a national system in Kyrgyzstan. The national drought-related capabilities of Kyrgyzstan are presented in the form of disparate mechanisms and processes, most of which are reviewed in the next section. The countries of the Asia-Pacific region have a significant number of dedicated tools developed for climate science and disaster risk reduction professionals. They were reviewed as part of the ESCAP technical report on geospatial tools for use in the Regional Drought Mechanism, and Section 5.3 summarizes the most relevant of them.³² The use of continental or global systems to support decision-making at the state level appears to be difficult, since the existing global systems do not take into account the peculiarities of national legislation, priorities, approaches, requests and the level of technical equipment of a particular country. However, this Chapter offers insight into global systems that provide up-to-date satellite information analysis and have an acceptable graphic interface for a non-technical end-user. The systems presented in Section 5.4 were created with the participation of specialized UN agencies and make it possible to display information for the Kyrgyzstan's territory, allowing for some national-level analysis.

Ground Data: Hydrometeorological Network

As a starting point for terrestrial meteorological network-based drought monitoring, the WMO recommends calculating the SPI (Standardized Precipitation Index).³³ To calculate this indicator for a specific point, only precipitation data for a certain non-fixed period is required (it is recommended to calculate based on monthly data collected for 30 years or more). SPI values range from -3 to +3, where negative values indicate reduced precipitation compared to the historical norm. Since the calculated result is relative, it allows comparison of drought severity different regions and climate zones. The calculation is based on the probability distribution function (as a rule, the gamma distribution formula is used), the parameters of which are selected separately for each station, considering the period of available observations. This fact causes the complexity of the correct calculation of the index.³⁴

In addition to SPI, the Standardized Precipitation and Evapotranspiration Index (SPEI) has become widespread, the calculation of which is based on the SPI principle but includes air temperature data in addition to precipitation information.³⁵ Other meteorological indicators and indices are also used in existing systems. A detailed overview of such indices in the context of Central Asia is presented in the study of the Center for Emergency Situations and Disaster Risk Reduction,³⁶ and in the global context – in the WMO documents.³⁷

Box 5.2

An extensive network of modern weather stations would be required to monitor meteorological indicators in such a heterogeneous area. Their number dropped sharply due to underfunding in the 1990s and remains insufficient to follow WMO recommendations (and would remain so even if Kyrgyzstan were a flat country). The agrometeorological network has suffered significantly, the equipment of which is becoming obsolete.

5.2. National Drought Monitoring and Early Warning Capacity in Kyrgyzstan

5.2.1. Kyrgyzhydromet's Meteorological Index Calculation System

SPI (left) and SPEI (right) Indices Calculated for a Five-month Period for the Territory of Kyrgyzstan, 2014

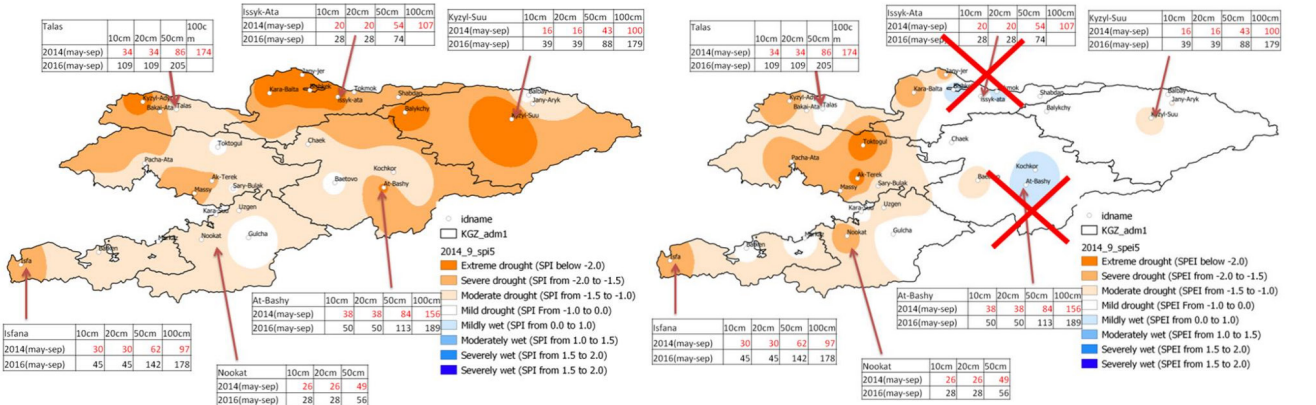


Figure 5.2

At the legislative level, there have been two attempts to launch the development of a national drought monitoring system. Its creation was envisaged in the Water Code and in the Concept of Comprehensive Protection of the Population and Territory of the Kyrgyz Republic from Emergencies for 2018-2030. Technically, there are several disparate applications, but they cannot be called a coherent and functioning system. The work on the creation of these elements was carried out by the Agency for Hydrometeorology (Kyrgyzhydromet) together with the Monitoring Department of the Ministry of Emergency Situations of the Kyrgyz Republic with the support of ESCAP and AIR CAS.

The Agency has digitized and statistically verified a large set of meteorological network data from 31 weather stations. Over the course of three years, from 2018 to 2020, SPI values were calculated monthly based on these data, based on which national maps were compiled. Inverse distance weighting interpolation method was used. These maps have been routinely transferred to the Ministry of Agriculture and were considered when making recommendations, proving

their practical value. However, the need for monthly manual processing of a large amount of data significantly slowed down the process and, as a result, in conditions of high staff turnover, led to the suspension of this activity.

SPI and SPEI indices have proven to be relatively effective in determining meteorological, agricultural and hydrological drought, based on the retrospective analysis of severe droughts in the territory of Kyrgyzstan in 2013-2014. The analysis included not only a visual comparison of maps of meteorological indices from different years, but also a quantitative comparison of additional data on streamflow, productivity of major crops and soil moisture at depths of 10, 20, 50 and 100 cm. SPI demonstrated the best results, indicating stronger drought in those regions, where it was more severe. The highest correlation was found between SPI with grain and legume crop yields, as well as with average streamflows. SPEI came in second in terms of robustness, showing similar dynamics to SPI, but showing inadequate results for some areas. These two indicators are presented in Figure 5.2., which is a map for a particularly dry year 2014. An analysis of the Pied's index, actively used in Russia and Mongolia, showed its unsuitability for the territory of Kyrgyzstan – the index did not reveal drought in any of the regions where it was observed over the years. According to ESCAP studies, this indicator did not register severe drought in the Chui and Naryn regions of the country in 2014. This image also displays soil moisture values measured at a depth of 10, 20, 50 and 100 cm for 2014, the year of severe drought and for 2016, when no drought was observed.³⁸

5.2.2. Satellite-enabled Meteorological Drought Monitoring: DroughtWatch-Kyrgyzstan

DroughtWatch is positioned as a full cycle system, i.e., its functionality includes receiving, processing, storing, analyzing data, as well as disseminating the results of the analysis. The main component of the software is developed in the IDL programming language in the ENVI software environment. The system may be deployed as a desktop application or a server platform with the ability to connect via the Internet using a registered account. Its graphical user interface is functional and provides ample opportunities for analysis, although it requires extensive training for mastering the application. All clients, even if the program is installed on a personal computer, have to request access from the system administrator.

The main purpose of the DroughtWatch model is to allow the automated creation of up-to-date maps of satellite and meteorological indices for use in making informed decisions in the field of regulation and planning in agriculture and related sectors. Raster satellite images are used as initial input data. The source of these data for the current version of the model is the MODIS medium-resolution spectrometers installed on the Aqua and Terra satellites, as well as the MSI instruments installed on the Sentinel-2 series satellites.

Spectrometer raster data at the 1b processing level is subjected to atmospheric, geometric and radiometric correction, stitched and redesigned in the MRT and Sen2Cor software installed jointly with the model. After that the primary vegetation indices NDVI and EVI, as well as the cloudiness mask, are calculated based on them. From this data, the final indices VCI, TCI, VHI, NDDI, NDWI, VSWI are calculated with the possibility of creating an index map for one or five days. The system allows to make maps with plotted values of each index, giving the user the

opportunity to independently generate a map with several plotted indices, which refines the analysis. The suitability of traditional and satellite meteorological indices can be determined by supplementary data. The most appropriate proxy for drought is crop yields measured for major crops on a monthly basis at the regional and sub-regional levels. As part of the ESCAP pilot project, the correlation of satellite indices with soil moisture and yields of major crops was analyzed. A more detailed description of these indicators is given in Section 7.1.

The model also allows downloading meteorological observation data from ground stations of Kyrgyzhydromet. The MySQL database is used to store this data.

Space-based Spectrometer Land Monitoring

An integral part of any modern drought monitoring and early warning system is the periodic calculation of satellite indices based on raster data obtained using multispectral satellite equipment. As a rule, Remote Sensing indices are a relative measure of the vegetation condition. They are derived from the radiometric characteristics of plants in the red and near-infrared spectral ranges. They are calculated using the surface reflectance values of two or more spectral bands. The main advantage of this approach lies in the homogeneity of satellite information – the values of satellite indices can be calculated for each pixel corresponding to a certain area for the country's territory, and the reliability of the data does not depend on the distance from the nearest meteorological observation point. Vegetation indices are convenient to use because they are dimensionless and their equations are designed to minimize the effects of atmosphere, topography, and the sensor viewing angle. However, optical instrument satellite observations have some drawbacks. Observations are dependent on weather conditions, data analysis may be technically complex, and the period of historical observations is relatively short even for the longest-running programmes.

Box 5.3

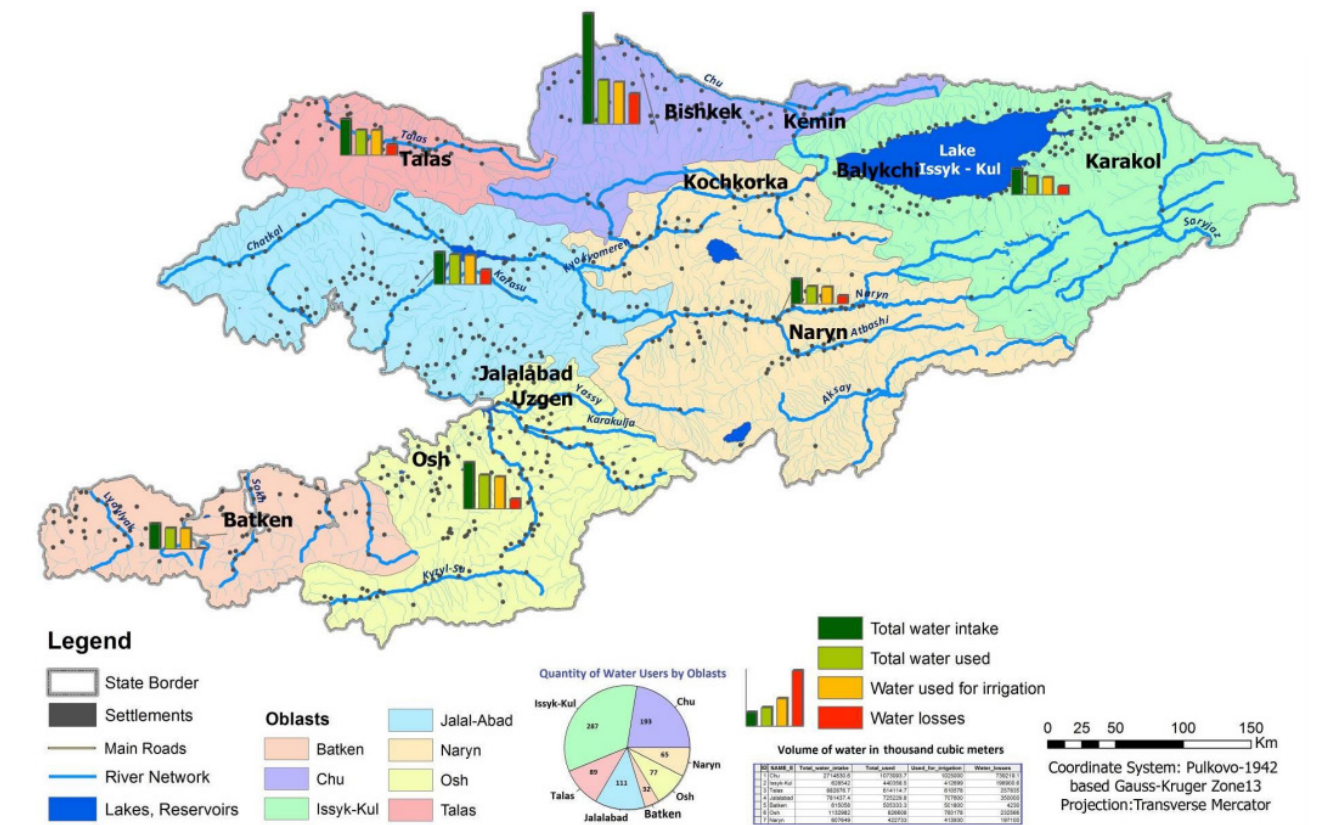
5.2.3. Use of Hydrological Data

The Water Resources Service under the Ministry of Agriculture of the Kyrgyz Republic, which until 2021 has been reporting to the Government, has rich expertise on the country's water resources. The Agency has been implementing the National Water Resources Management project funded by the World Bank for several years. The automated Water Information System (WIS) developed by the project team as the initiative's main result. The purpose of the system is to provide a network of five national basin authorities with up-to-date hydrological data for efficient water management at the basin and district levels. The system uses data from the national hydrometeorological network of 82 hydrological and 47 meteorological posts installed on rivers, lakes, canals and reservoirs. The Water Resources Agency receives Kyrgyzhydromet-collected processed information, such as current and average streamflow, calculated by meteorologists

based on water level values. From the geographical standpoint, the output data divided into water basin administrations. Five administrations exist in the system, but in reality, there are eleven, and plans exist to further subdivide the area covered. WIS is deployed as a distributed database with text data and georeferenced thematic map layers, stored on different servers and combined through a network system.

Technically, the output of the system is presented in the form of regularly updated maps, tables and graphs illustrating inland water body information. The main indicators measured are streamflow, water intake and wastewater discharge. Additionally, the functionality of the WIS includes the analysis the water balance. When digitized meteorological data is available, vegetation period-linked water deficit maps can be generated for third-level administrative

Water Use by Basin Administration, Water Information System, 2014

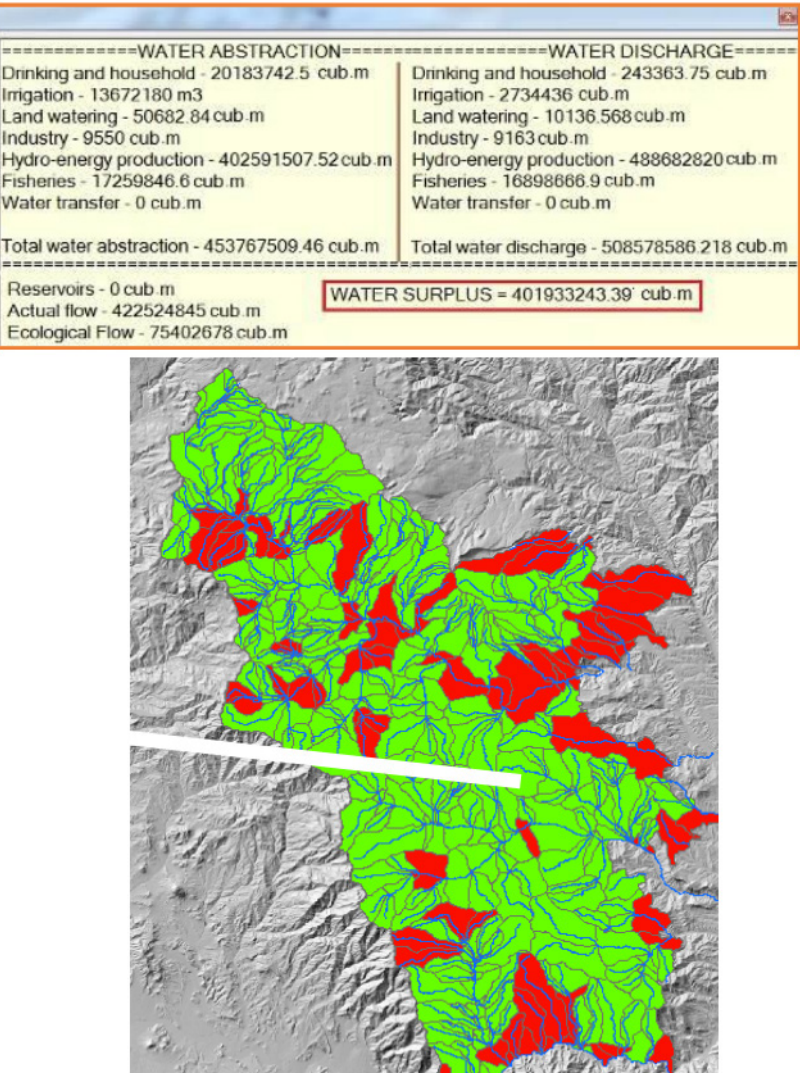


bodies (aiyl aimaks). In addition to the monitoring component, the system makes it possible to make long-term forecasts of natural river flow for a long time using climatic equations.

The WIS data repository is a geospatial database, which stores 124 vector layers and two raster images. It contains data on water bodies and other elements of the irrigation network. The former includes 4,624 river segments over 5 km long, 65 lakes with an area of over 0.5 sq. km, 101 out of 322 most important irrigation canals and 16 reservoirs. The irrigation network information includes 4,560 water intake sites, 1,160 hydrotechnical structures, 194 hydrological posts, 116 hydrological posts of irrigation systems, 48 water quality monitoring posts and 32 meteorological stations. All the above objects have been assigned a unique identifier. This database serves as the source for five tabular thematic web applications providing up-to-date statistics on water quantity, irrigation water use, hydrotechnical structure data, national water consumption and water user associations.³⁹

In addition to web applications, WIS provides mapping services, namely, it maintains the Geoinformation portal on water and provides the vector data underlying this portal on the GeoNode geographic data exchange platform. The geoportal provides an opportunity to view detailed web maps of basin authorities for seven regions, as well as 13 thematic web maps for the entire territory of the country. These maps are based on 59 different vector layers of a high degree of elaboration, related to hydrology, environment, natural disasters, public infrastructure.

Annual River Basin Water Balance: Sample Water Deficit Map, Water Information System



Mountain Societies Research Institute

The Mountain Societies Research Institute of the University of Central Asia also has significant competencies in tracking the hydrological situation through Remote Sensing data. The Center has expertise in various fields, researched through the lens of the problems of rural communities in the Central Asian region. In Kyrgyzstan, the organization has experience working with both the state and the local population, mainly through field research conducted in the country.

Box 5.4

5.2.4. SIBELIUS Portal and the Kyrgyz Data Cube

SIBELIUS is a geo-information portal created by the British NGO eOshpere in collaboration with the Central Asian Institute for Geosciences (CAIAG) and funded by the UK Space Agency.⁴⁰ The portal is a combination of a database (formatted as a “data cube”) and a tool for creating web maps. Server equipment of the data cube is installed in CAIAG and operates upon the principle of open data dissemination. Similar solutions have been implemented in Australia, Mongolia,⁴¹ Colombia and Switzerland.⁴² The resource contains information on several environmental topics, one of which is drought. In particular, the user of the resource can generate maps of satellite indices NDVI, NDDI, NDWI, VCI and VHI based on data from five satellites, namely Sentinel-2A, Sentinel-2B, Landsat 8, Terra and Aqua. The interface allows registered users to select the observation date and download the generated map or obtain additional information in the form of a vegetation state graph for the selected area, a second-level administrative division (rayon). Registration is open to all Internet users, who can sign in automatically with a Google account.

An example of an imported raster image of the VHI satellite index generated for the agriculturally rich central and northern regions of Chui oblast is shown in Figure 5.3.

Map of the SIBELIUS Portal: VHI Satellite Index, derived from MODIS data

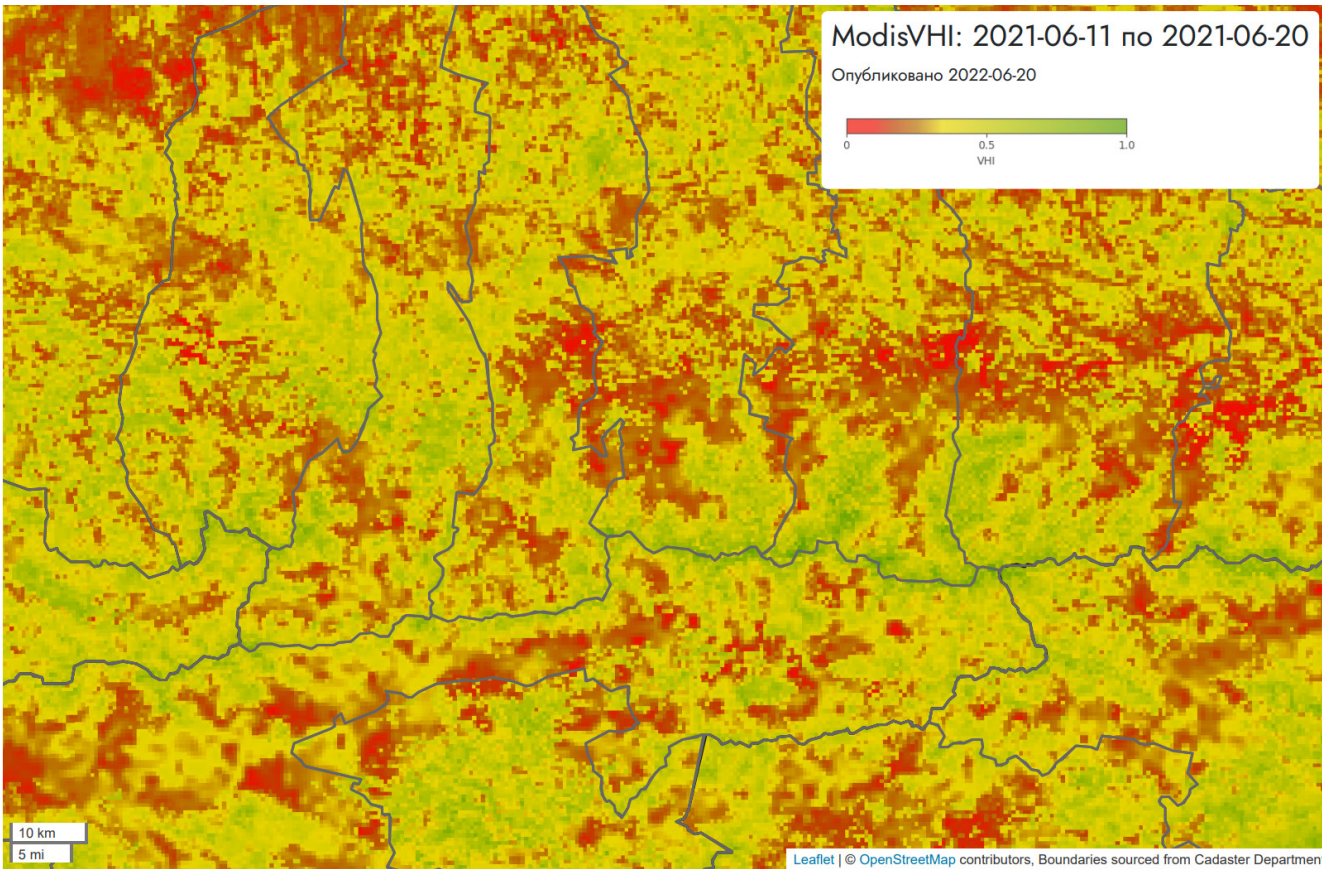


Figure 5.5

The SIBELIUS visualization maps and the Kyrgyz Data Cube behind them allow for a comparative analysis of the vegetation state and are a step in the right direction. However, this product cannot be recognized as a full-fledged drought monitoring system due to the lack of work on

the verification and adaptation of indices, the lack of a methodological apparatus for drought identification, etc. The current version of the portal is not suitable for near-real-time monitoring of the situation, since the data is provided with a delay of four months, and the VCI and VHI satellite indices are available only in 500 m resolution.

5.2.5. Portal of the Unified Disaster Monitoring and Forecasting System

The Ministry of Emergency Situations of the Kyrgyz Republic timely notifies the population in case of rapid-onset emergencies, such as wildfires, mudflows, avalanches, floods, etc. A large set of technological solutions has been deployed in order to notify the population about disasters and receive citizen feedback. The main solutions are the Unified Integrated Monitoring and Forecasting System (further referred to by its Russian acronym ESKMP)⁴³ and the Automated Information and Control System (AIUS).

Web Interface of the ESKMP Public Portal

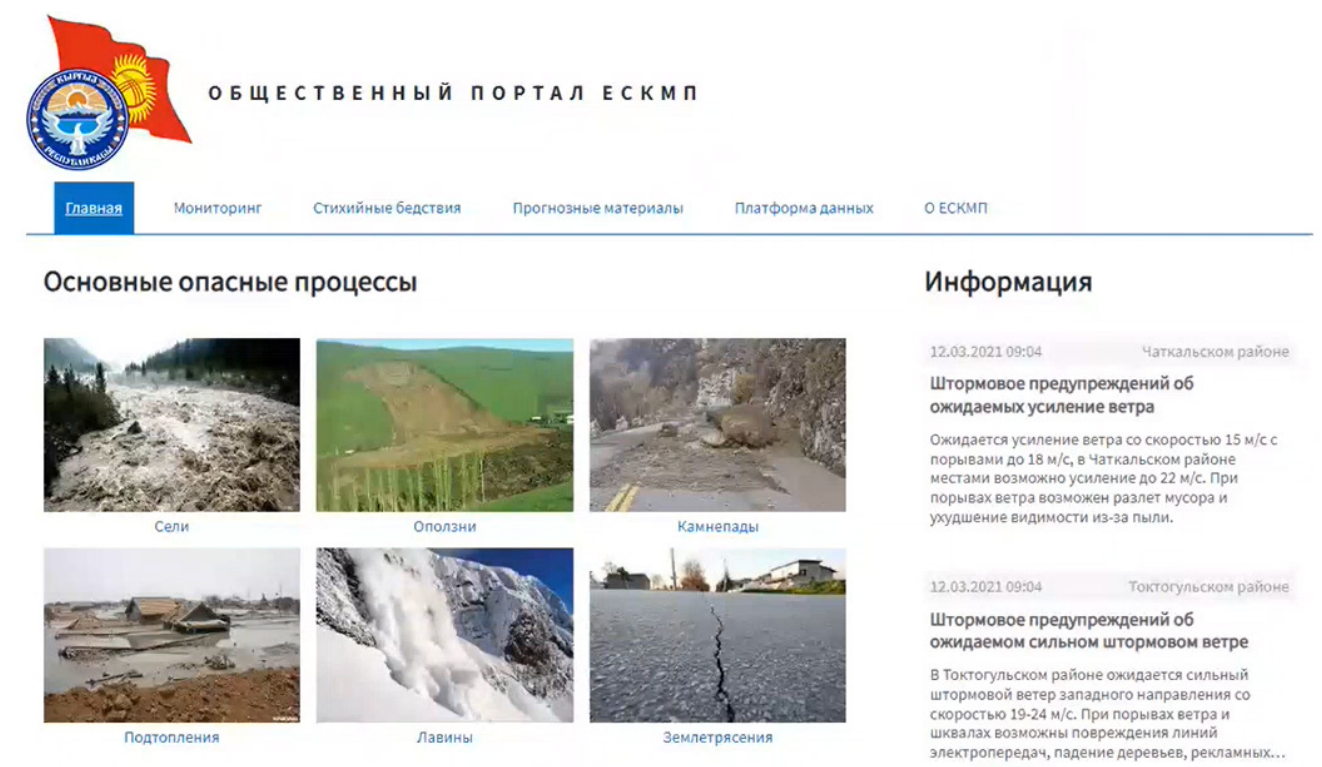


Figure 5.6

ESKMP is designed as a web mapping service with an internal and a public component. The user interface of the latter is attached as Figure 5.6. The service is deployed on top of the database of the Ministry of Emergency Situations and developed with the GeoNode open-source technology, which stems from GeoServer. The portal’s database is constantly updated with Kyrgyzhydromet’s hydrometeorological network measurements and up-to-date geospatial information provided by other stakeholders. Based on this data, the system operator carries out near-real-time monitoring of the situation in disaster-prone areas, monitoring mudflows, landslides, rockfalls, avalanches, floods and earthquakes.

User Interface of the “112 Kyrgyzstan” Mobile Application

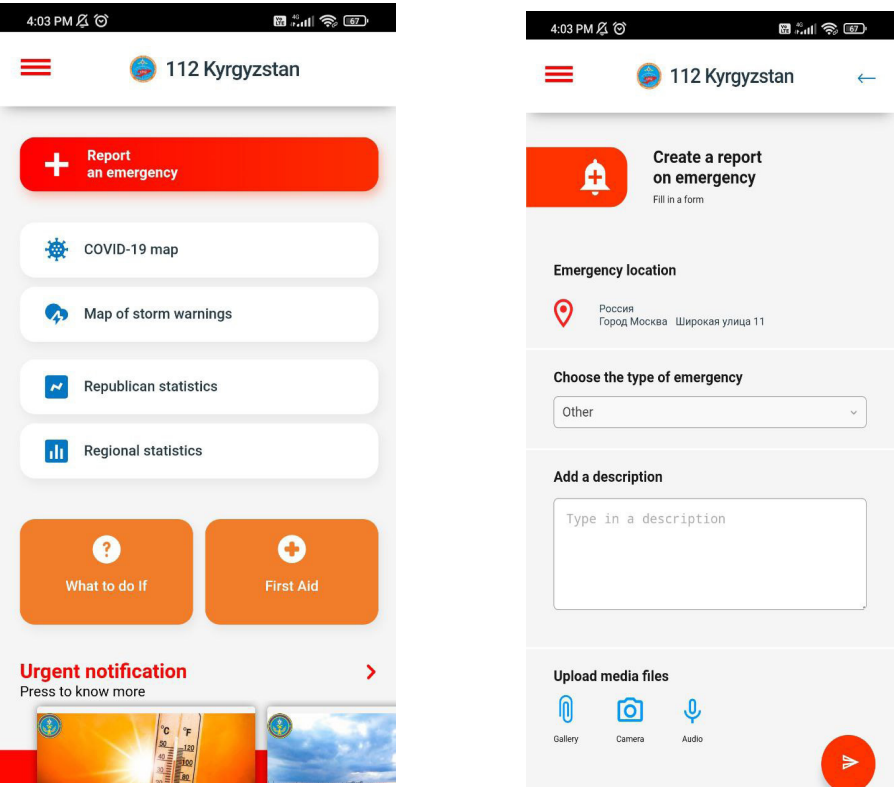


Figure 5.7

The website’s “Forecast” section hosts risk maps for the onset of certain natural disasters, calculated mainly based on geomorphological data. The “Natural Disasters” section includes recommendations on the correct behavior in case of certain emergencies for the general population.

The Issue of Notification

A notification module for its final beneficiaries, namely the general population, should be an obligatory component of any really functioning emergency monitoring system. The experience of other countries in the Asia-Pacific region shows that this component is often very weakly developed or completely absent. Meteorologists, climatologists and GIS analysts process data, create drought vulnerability, risk and impact maps, make weather predictions, forecast crop yields and water levels, but this information remains the property of a narrow circle of people, or is distributed in a form that is incomprehensible to an ordinary citizen and via unknown channels. Thus, all the achievements of scientists and engineers in terms of real impact on the agricultural production cycle are reduced to null. Moreover, the lack of feedback from beneficiaries hinders even the purely technical development of such a system. Thus, the approach where systems are being developed for many years in complete isolation from users, in the expectation that after its launch it will fully satisfy their needs, is fundamentally incorrect.

For the effective operation of such a system, it is necessary to understand at an early stage through which channels and in what format its output information would be distributed.

Box 5.5

The AIUS system, receiving the ESKMP output data, broadcasts disaster notifications directly to the citizens of Kyrgyzstan. This is achieved through all available means – via TV, radio, outdoor voice notification systems, SMS messages and push notifications in the “112 Kyrgyzstan” mobile application.

The latter modality, as well as the “112” hotline number, was designed for receiving population feedback. A citizen can report an emergency by attaching a photo or audio message, as shown in Figure 5.7. The incident report will be tagged with the person’s location and sent from their account linked to their phone number.

5.3. Systems, Tools and Experience from the Asia-Pacific Region

5.3.1. Land-based Atmospheric and Soil Drought Monitoring Approach of the Russian Federation

The Russian Federation has an extensive land observation network, which includes around 14,000 observation points under the jurisdiction of the Federal Service for Hydrometeorology and Environmental Monitoring of Russia (hereinafter – Roshydromet). The agrometeorological network consists of 1073 observation locations, including meteorological, agrometeorological, hydrometeorological, hydrological, aerometeorological stations and posts⁴⁴. Drought monitoring in the Russian Federation is carried out by the Drought Monitoring Center of the Interstate Council for Hydrometeorology of the CIS, founded in 2002. The Council is administered by the National Research Institute of Agricultural Meteorology (hereinafter – NRIAM). Operational monitoring is carried out using ground infrastructure data.

The Russian drought monitoring principles were formed in the Soviet times and precede the comprehensive recommendations of the WMO. Russia uses its own drought classification, which distinguishes between atmospheric and soil drought. NRIAM conducts qualitative drought assessments for a given territory. It is based on the integration of eight agrometeorological indicators originally developed for climate calculations but have been proven effective in meteorology. This approach is based on the postulate that none of the indicators and criteria of arid phenomena separately sufficiently describes arid phenomena, and the best results are obtained through their integrated use. Table 5.1 presents eight parameters of the Russian system and the initial data used for their calculation.

Drought monitoring is performed daily from the terrestrial meteorological network data on precipitation and temperature. Every ten days, indicators are updated based on information received from weather stations on the amount of soil moisture at a depth of 30, 50 and 100 cm.

Drought Index Calculations for the NRIAM Drought Monitoring System

Parameter	Input data	Calculation formula/ designation
Selyaninov Hydrothermal Coefficient (HTC)	daily total precipitation for a dekad with average daily temperatures above 10°C, mm ($P_{>10^{\circ}\text{C}}$) sum of average daily air temperatures for a decade with average daily temperatures above 10°C ($t_{>10^{\circ}\text{C}}$)	$HTC = \frac{\sum P_{>10^{\circ}\text{C}}}{0,1 \sum t_{>10^{\circ}\text{C}}}$
Shashko Atmospheric Humidity Coefficient	dekadal precipitation (P) dekadal sum of average daily air humidity deficits ($E - e$)	$M_d = \frac{\sum P}{\sum (E - e)}$
Soil moisture index	humidity for the previous and current dekad (W_{i-1}, W_i) total precipitation for the current dekad (P) dekadal air humidity deficit ($E - e$)	$V = \frac{W_{i-1} - W_i + P}{0,375 \sum (E - e)}$
Number of days with maximum temperatures above 30 °C	air temperature	$n_{T>30^{\circ}\text{C}}^D$
Number of days with relative air humidity below 30%	relative air humidity	$n_{\varphi<30\%}^D$
Reserves of productive soil moisture at 20 cm	soil samples	$W_{20}, \%$
Reserves of productive soil moisture at 50 cm		$W_{50}, \%$
Reserves of productive soil moisture at 100 cm		$W_{100}, \%$

Table 5.1

Every dekad, the a_{ij} metric is calculated for each of the eight indicators according to the following system:

$$a_{ji} = \begin{cases} 1 - \frac{|x_{ji} - \varphi_j^{xx}|}{\varphi_{a_j}^{xx} - \varphi_{a_j}^x}, & \text{if } x_{ji} > \varphi_j^{xx} \\ 1, & \text{if } \varphi_j^x \leq x_{ji} \leq \varphi_j^{xx} \\ 1 - \frac{|x_{ji} - \varphi_j^x|}{\varphi_{a_j}^{xx} - \varphi_{a_j}^x}, & \text{if } x_{ji} < \varphi_j^x \end{cases} \quad (1)$$

In system (1), index j corresponds to the calculated parameter's index number, and i corresponds to the index number of the dekad. For example, at $j = 2, i = 3$, the Shashko coefficient is calculated for the third dekad of the period. x_{ji} is the actual numerical value of the calculated parameter. The φ_j^x and φ_j^{xx} boundaries are the minimum and maximum of the values of the indicator within the category of drought intensity (absence, presence, severe drought). $\varphi_{a_j}^{xx}$ and $\varphi_{a_j}^x$ represent the absolute range of values for the indicator. Thus, if the Shashko coefficient for the above-mentioned period equals $M_d = 0,25$, then the corresponding metric (estimate) for the three drought classes is calculated as shown in Table 5.3.

Index-based Drought Categorization by Intensity
for the Russian Federation

Parameter	Drought Categories		
	No Drought	Moderate Drought	Severe Drought
HTC	0,71 – 5,00	0,40 – 0,70	0,00 – 0,39
M_d	0,36 – 3,00	0,20 – 0,35	0,00 – 0,19
V	65 – 100	51 – 65	0 – 50
$n_{T>30^{\circ}C}^D$	0	2 – 5	6 – 11
$n_{\varphi<30\%}^D$	0	2 – 5	6 – 11
W_{20}	20 – 70	11 – 19	0 – 10
W_{50}	41 – 100	26 – 40	0 – 25
W_{100}	71 – 280	41 – 70	0 – 40

Table 5.2

Calculating the a_{ij} sample metric for the Shashko Atmospheric Humidification Coefficient $M_d = 0,25$ for the third Dekad of the Vegetation Period

a_{ij} value	Justification	Drought category
$a_{23} = 1 - \frac{ 0,25 - 0,36 }{3,00 - 0} \approx 0,96$	$0,25 < 0,36$	no drought
$a_{23} = 1$	$0,20 < 0,25 < 0,35$	moderate drought
$a_{23} = 1 - \frac{ 0,25 - 0,19 }{3,00 - 0} \approx 0,31$	$0,25 > 0,19$	severe drought

Table 5.3

After calculating the metrics for all eight parameters, the estimates for this decade are combined, in a way which is referred to as their integration. The comprehensive assessment is expressed as the average value of proximity measures in the context of the drought intensity and is calculated using the following formula:

$$\bar{P}_i = \frac{1}{n} \sum_{j=1}^n \delta_j a_{ij}$$

(2)

In expression (2), the divisor n s the number of indicators (in this case $n = 8$), δ_j are the weights of each indicator, a_{ij} is the estimate calculated above for each indicator. The weights of each indicator δ_j can take values up to 1 and ideally vary for different periods and geographical regions, based on how much each indicator correlated with supplementary data.

Subsequently, a dekadal information bulletin is issued in the form of maps, an example of which is shown in Figure 5.8. These maps allow specialists to draw conclusions about the current state of the atmosphere and soil, on the basis of which federal and regional authorities may make informed decisions on notifying the population and organizations of the agricultural sector⁴⁵.

Dekadal Newsletter for the Central Federal District
of the Russian Federation

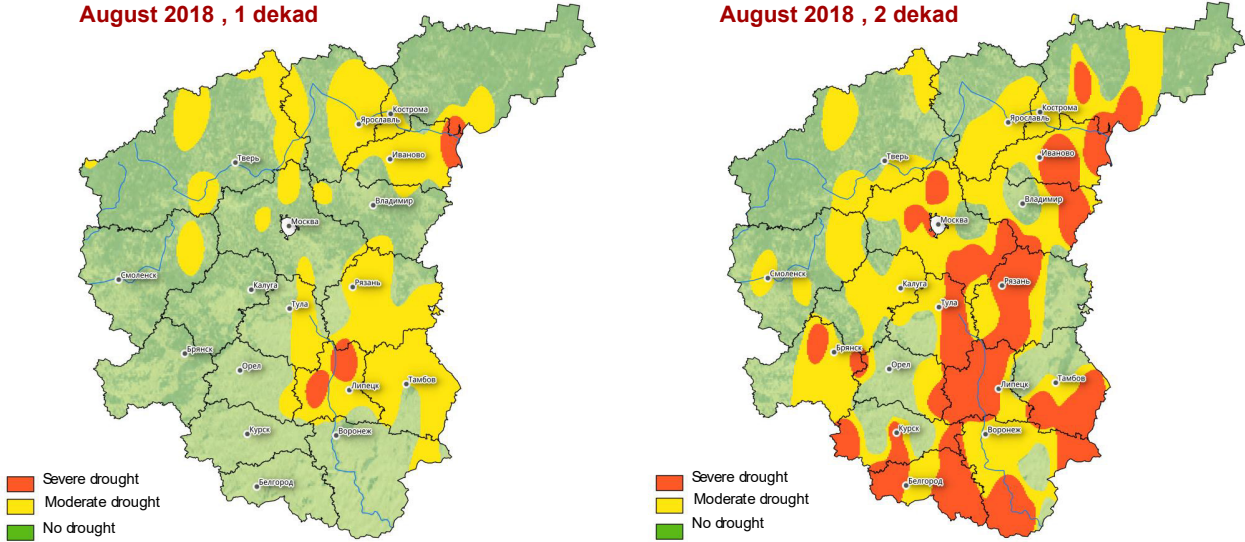


Figure 5.8

5.3.2. SRC “Planeta” Crop Accounting
and Yield Forecasting System

SRC “Planeta” monitors and predicts crop yields using the SDIM software (System of Databases and Imitating Modeling). Monitoring is carried out at regional and local levels. For regional observations, data from MODIS (Terra) and VIIRS (SNPP, NOAA-20) instruments are used, and at the local level from – C-SAR Sentinel-1, MSI (Sentinel-2) and OLI (Landsat-8). This approach stands out because it joint uses spectrometer and synthetic aperture radar data. The obtained multispectral and radar data is employed to compute vegetation indices NDVI, RVI and subsequently aggregate them into the NRVI index. The latter index is determined through an empirical formula, derived by analyzing long-term observations. The formulae for calculating the indices are exhibited below.

$$NDVI = \frac{NIR - RED}{NIR + RED} , \text{ where:}$$

(3)

NIR – reflection coefficient in the near-infrared region of the spectrum

RED – reflection coefficient in the red region of the spectrum

$$RVI_{VV} = \frac{4\sigma_{VH}}{\sigma_{VV} + \sigma_{VH}} , \text{ where:}$$

(4)

σ_{VV}, σ_{VH} – calibrated vertical polarization radar signals

$$NRVI = 0,8 * RVI - 0,04$$

(5)

Regional-level observations allow specialists to draw general conclusions about the vegetation state. At the local level, high-resolution data (10-30 m per pixel) is utilized, enabling the evaluation of individual fields. It is at this level that the yield forecast is made, considering crop genera in a particular field.

In addition to satellite data, the SDIM system uses meteorological parameters – daily and monthly measurements of maximum and minimum air temperature, precipitation, relative humidity, average wind speed, total solar radiation. As additional parameters, the sowing dates, archival data on yield and climatic parameters can be loaded into the system. The yield forecast for a specific area, district, enterprise or field can be subsequently compared with the actual value of the harvested crop. Forecast success rate assessment made according to the below formula:

$$\gamma = 100\% - \left| \frac{u_{\pi} - u_{\phi}}{u_{\phi}} \right| 100\% , \text{ where:} \tag{6}$$

u_{ϕ} – actual yield value

u_{π} – predicted yield value

An example of such a forecast at the regional level is shown in Figure 5.9. Two maps of the districts of the Novosibirsk region of the Russian Federation demonstrate the forecast and actual yield of spring wheat in 2020. As can be seen from the diagram, the system showed a good result.⁴⁶

Actual (left) and forecasted (right) Yield of Spring Wheat in the Novosibirsk Region of the Russian Federation, 2020

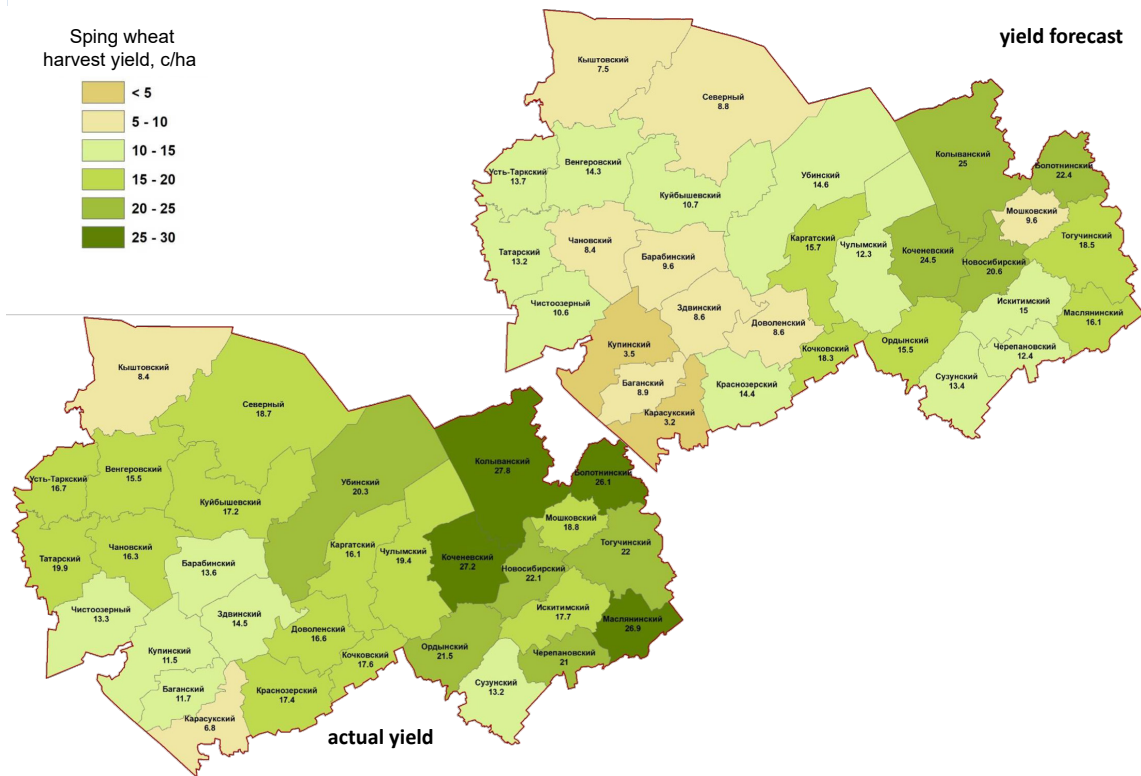


Figure 5.9

5.3.3. Plant Monitoring with CropWatch

The CropWatch system, developed by the Aerospace Information Research Institute of the Chinese Academy of Sciences, is a cloud-based system for storing, processing and analyzing agricultural information in a spatial context. This global system identifies the six largest agricultural zones worldwide with further subdivision into key countries and their regions. Each level of the geographic hierarchy has its own input and output data presented in Table 5.4.

Global CropWatch System: Inputs and Outputs

Level	Input Data	Output Data
Global	Precipitation Air temperature Photosynthetically active radiation Potential biomass volume	Main agricultural zones Climate indices
Six core arable farming zones	VHI Uncultivated arable land Planting density Maximum VCI	Field profiles Intensity of farming activity Biomass Graph
Key countries	NDVI Spare the arable land Reading Schedule	Intensity of arable land use The state of crops Yield and productivity
Country regions	Share of arable land Hierarchy of crops Information about pests and diseases	Intensity of arable land use The state of crops Yield and productivity Phytosanitary state of crops (PRC)

Table 5.4

The platform provides a variety of opportunities for user interaction, from viewing regularly published ready-made CropWatch newsletters to uploading their own data and connecting with the expert community. The ability to collaborate and upload user-owned high-resolution data is still in its infancy. AIR CAS is constantly improving the portal, replenishing its functionality based on its own scientific exploration. If a country wishes to use the CropWatch system, its additional benefit is the willingness of AIR CAS to provide pro bono support by organizing training and field missions.⁴⁷

5.4. Global and Regional Systems with Kyrgyzstan Coverage

5.4.1. FAO Global Information and Early Warning System (GIEWS)

The mission of the FAO Global Information and Early Warning System (GIEWS) is to monitor the food situation globally and in a multifaceted manner. Data, including analytical reports, is provided openly and is intended for a wide range of users, from government officials and GIEWS User Interface

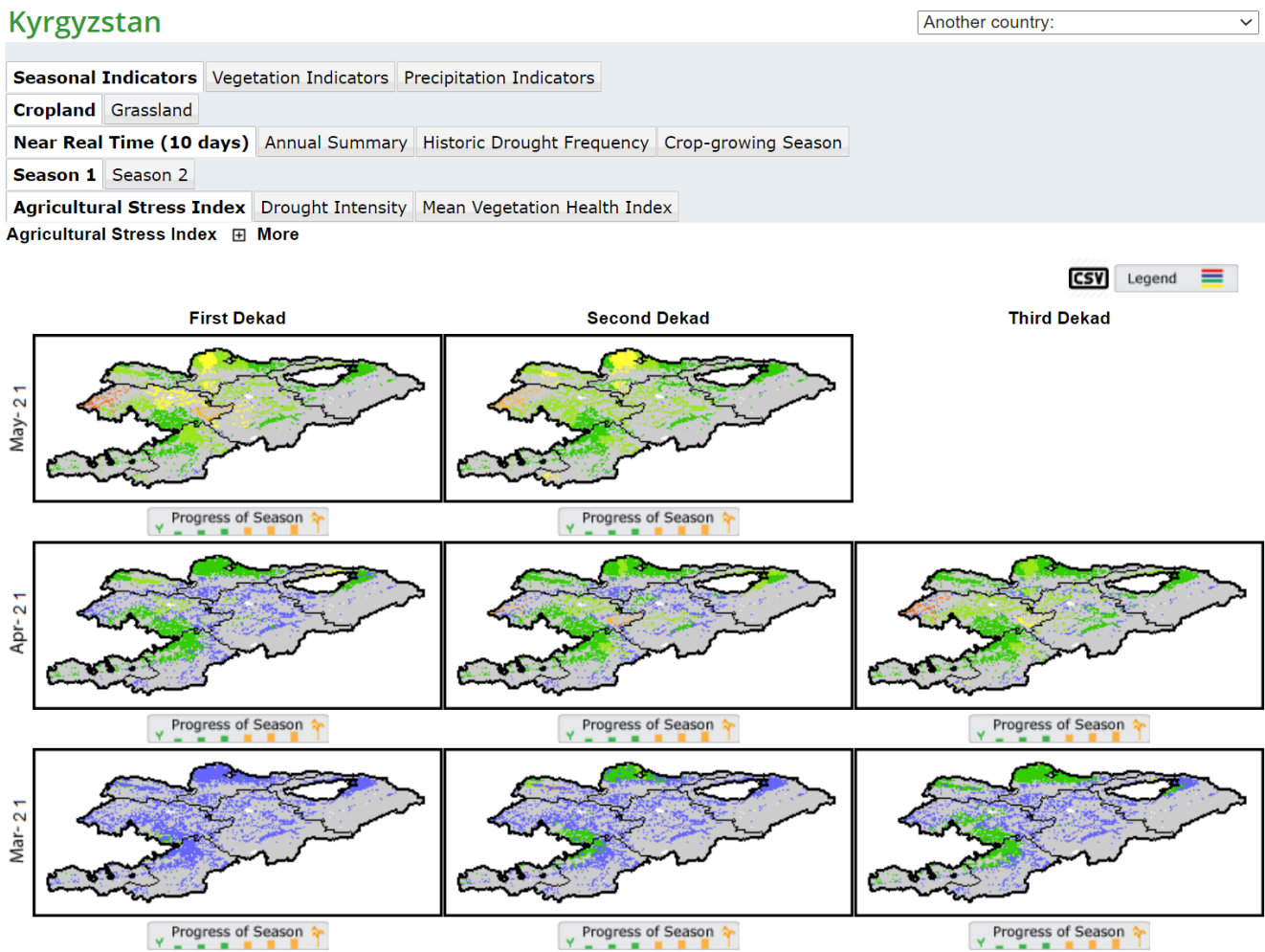


Figure 5.10

economists to farmers. Services provided by the GIEWS team include drought monitoring since dry phenomena directly affect food security.

As part of the programme, Earth observations are carried out to control the quality of crops by monitoring the meteorological and hydrological situation. At the global level, NDVI anomaly, VCI and VHI vegetation indices are calculated every 10 days based on AVHRR-METOP satellite data, as well as FAO's own Agricultural Stress Index (ASI). The latter indicator is based on the analysis of the VHI index and is a quick look indicator for early identification of arable land with a high probability of moisture deficiency. ASI's distinct feature is that the index takes into account the drought event's duration. The spatial resolution of the AVHRR satellite radiometer is 1 km per pixel, which is significantly higher than in many other global systems. Access to the portal is open and carried out via the Internet.⁴⁸ Figure 5.10 depicts the user interface of the web-service.

For countries with heterogeneous terrain and complex geography, such as Kyrgyzstan, the GIEWS model may not be sufficient for decision-making at the national level, but rather serve as an indicator for identifying long-term trends. In this regard, the FAO team is developing additional software products to be provided at the national level, namely, NIEWS.⁴⁹ Its geospatial aspect will be embodied in the Agricultural Stress Index System, which would allow assessing the crop condition, having loaded additional datasets. Such information can be designed as land cover maps, crop calendars, crop coefficients, data from agrometeorological stations and posts. The most important task for the adaptation of the system is the refinement of land cover data and the transition from the global GLC-SHARE database to thematic rasters provided by various government agencies.

Recently it has become possible to download data from the FAO "Hand in Hand" portal using the WMS protocol for GIS professionals who would like to use ASI rasters in their work. Index rasters have also been made available for download, which, however, are not georeferenced.⁵⁰

5.4.2. Flood and Drought Portal

The United Nations Environment Programme (UNEP) and the DHI Group have developed a monitoring and early warning portal for droughts, which is also part of the UNCCD’s Drought Toolbox. The portal is a cloud service, access to which is available to anyone after registration.⁵¹

The portal allows the user to quickly analyze the values of several low-resolution meteorological and satellite indices linked to a map. Table 5.5 lists the available indices (SPI, NDVI, VCI, SWI) and the water level indicator for large lakes (JASON). Figure 5.11 presents the service’s graphic user interface.

Flood and Drought Portal User Interface

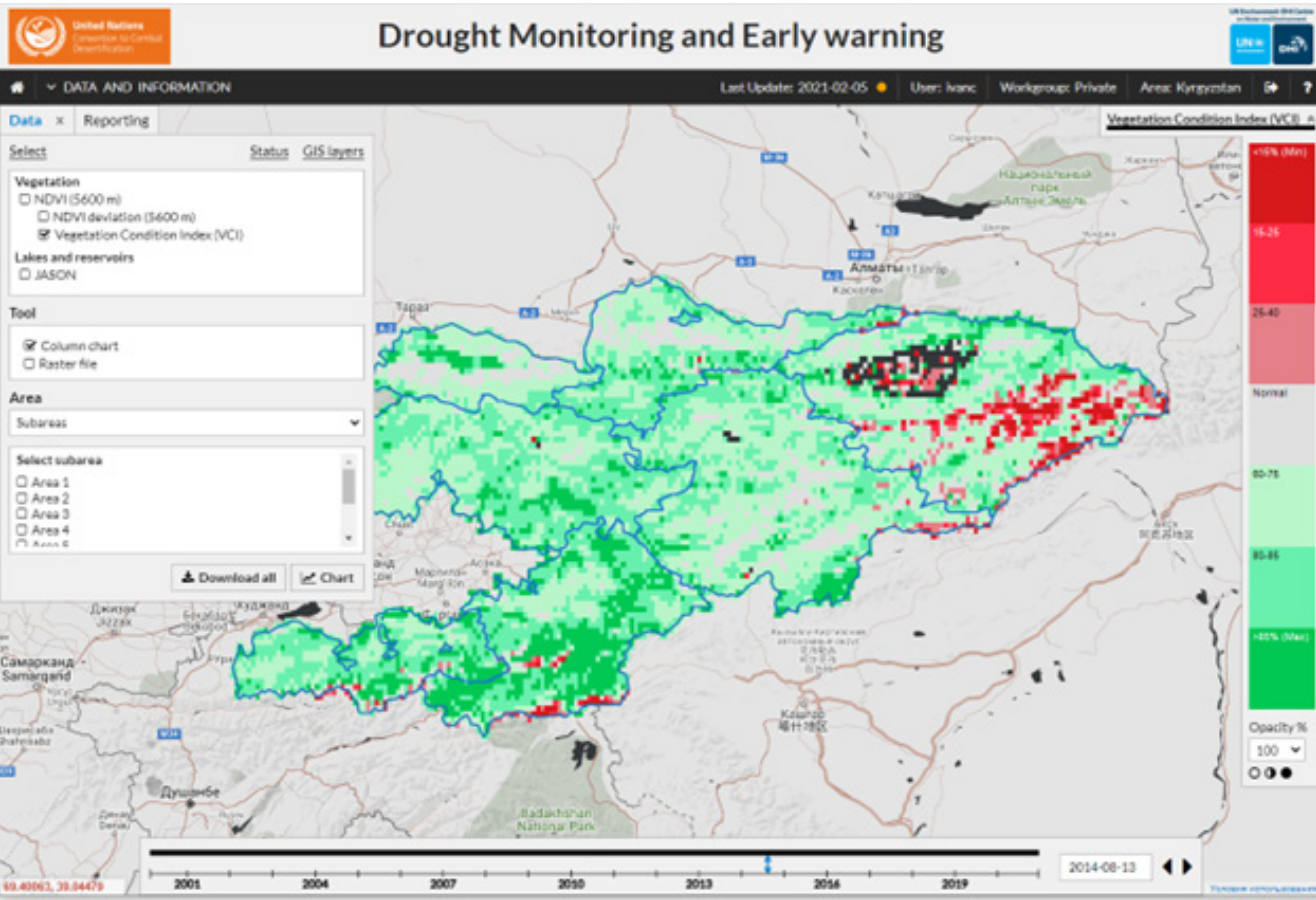


Figure 5.11

The graphic user interface is intuitive. It involves of fast time scrolling option, allows for adjusting the transparency of layers and data downloading, all of which speaks to the service’s strengths. In addition to raw data, the portal can generate drought reports from templates for the area of interest. The report provides a summary of precipitation, as well as SPI, SWI and NDVI schematic maps. Later, these data are aggregated, and based on them, a conclusion is made about the drought presence and severity, accompanied by a corresponding map. The U.S. Drought Monitor Classification Scheme is used as reference.

The Flood and Drought Portal has an exemplary user-friendly graphical interface and offers well-thought-out user experience. However, the quality of underlying information is insufficient for decision-making at the national level in Kyrgyzstan. The spatial resolution of the datasets is insufficient, and the datasets themselves have not been verified for specific territories.

Satellite Data available on the Flood and Drought Portal

Name	Spatial resolution, km	Revisit time, days	Functioning since, year	Instrument/ Mission title	Space agency
Precipitation	12,5	1	2000	GPM	NASA, JAXA
Precipitation anomaly		30			
SPI 1, 3, 6 months		1			
NDVI	5,6	16	2000	MODIS-Terra	NASA
NDVI anomaly					
VCI					
SWI	12,5	10	2007	ASCAT-METOP	ESA
JASON	water bodies > 100 sq. km	10	1992	TOPEX/Poseidon/ Jason	NASA, CNES

Table 5.5

5.5. Other Data Sources

5.5.1. Geoportals

Geoinformation portals, commonly referred to as “geoportals”, allow the user to select, view and download vector and raster data via a web interface. Geoportals are undergoing development, and provision of specific datasets is increasingly being replaced by the creation of geographical services aimed at the end-user without any specialized knowledge. This chapter provides some examples of such web interface-based services. At the same time, traditional geoportals remain a reliable source of geospatial data, on the basis of which weather monitoring and forecasting systems can be built, as well as tools for the assessment of vegetation conditions, water levels and other drought-related indicators. Following best global practice, it is recommended to automate data downloading and processing procedures. To achieve this, special solutions can be employed, such as Application Programming Interfaces (APIs) and the Open Geospatial Consortium standards.

API, WMS, WFS

An Application Programming Interface is a set of mechanisms which allow one program can interact with others. Many geoportals have their own API and allow developers of other GIS projects to connect and upload raster and vector data as files or through OGC standards.

The most used OGC standards are Web Mapping Service (WMS) and Web Feature Service (WFS). WMS are essentially readily available base maps. These maps can be designed in any form and represent any subject. Most often they are used to supplement the project with general information about the location of settlements, infrastructure, mountains and water bodies. Using WMS, the system’s user or operator can understand where exactly the part of the thematic layer that he is viewing is located, which simplifies the formation of output information for the end-user.

The WFS standard can also be useful for drought monitoring purposes. Through WFS, vector cartographic layers are loaded into a GIS application. This allows independent spatial analysis, which is not possible with WMS. This can be of particular value if the development of the downloadable layer is not the responsibility of the system operator, but of another department. Examples of such layers are thematic maps of soils, surface and groundwater, fields and pastures posted on the Geoinformation and Climate Data Portal of the Kyrgyz Republic.

Box 5.6

Table 5.6 highlights several popular Internet geoportals for downloading raster and vector data employable for drought analysis.

Popular Geoportals and Data Sources applicable to Drought Analysis

Name and web-site	Owner	Типы файлов	Raster data description
ArcGIS Open Data ↗	ESRI	vector, raster	thematic rasters: environment, geography; DEM
GEOSS Portal ↗	GEO, ESA	vector, raster	collection of international and national thematic rasters; ground data
EarthExplorer ↗	USGS	raster	AVHRR; IKONOS-2; OrbView-3; EO-1; HCMM; ISERV, ECOSTRESS (MKC); Landsat 1-5,7,8; ASTER; MODIS; VIIRS; Sentinel-2; Resourcesat-1,2; SPOT 1986-1998 archive; several DEMs; multiple thematic land cover and vegetation products
Copernicus Open Access Hub ↗	ESA	raster	Sentinel-1, 2, 3, 5P;
EO Browser ↗	ESA	raster	Sentinel-1, 2, 3, 5P; Landsat 1-9; MERIS; MODIS; Proba-V; GIBS; Planet NICFI; DEMs
FENGYN Satellite Data Center ↗	National Satellite Meteorological Center, PRC	raster	raw data and thematic products for FY-1 (D), FY-2 (C, D, E, F, G, H), FY-3 (A, B, C, D, E), FY-4 (A, B), TANSAT; NOAA (15, 16, 17, 18); MTSAT; MODIS
Roscosmos geoportal ↗	Roscosmos	raster	Kanopus-V №1, 3, 4, 5, 6, IK; Resurs-DK № 1; Resurs-P №1, 2, 3;
Humanitarian Data Exchange ↗	UN OCHA	vector, raster, table	thematic products: demography, economy, healthcare, humanitarian situation, infrastructure
UNEP GRID ↗	UNEP	vector, raster	thematic rasters: demography, urban areas, forests, surface water, land cover; DEMs
Hand in Hand ↗	FAO	vector, raster	thematic rasters: food security, agriculture, land and water resources, socio-economic and demographic aggregates
ESA Worldcover ↗	ESA	raster	high-resolution land cover raster updated monthly

Table 5.6

5.5.2. Smart Field Data Collection

Data collection through field research can serve both to determine the suitability of drought indices and indicators for a specific area, and to collect general information about the condition of land, vegetation and reservoirs. Thanks to the development of smartphones, almost anyone can collect field data using the built-in cameras and location functionality. This feature has reduced the expenses of many organizations, removing the need to purchase expensive professional GNSS devices. Currently, field data can be collected using forms through geographically linked pictures, as well as video and audio files, reports, with virtually no additional equipment costs.

Epicollect5 Web Interface

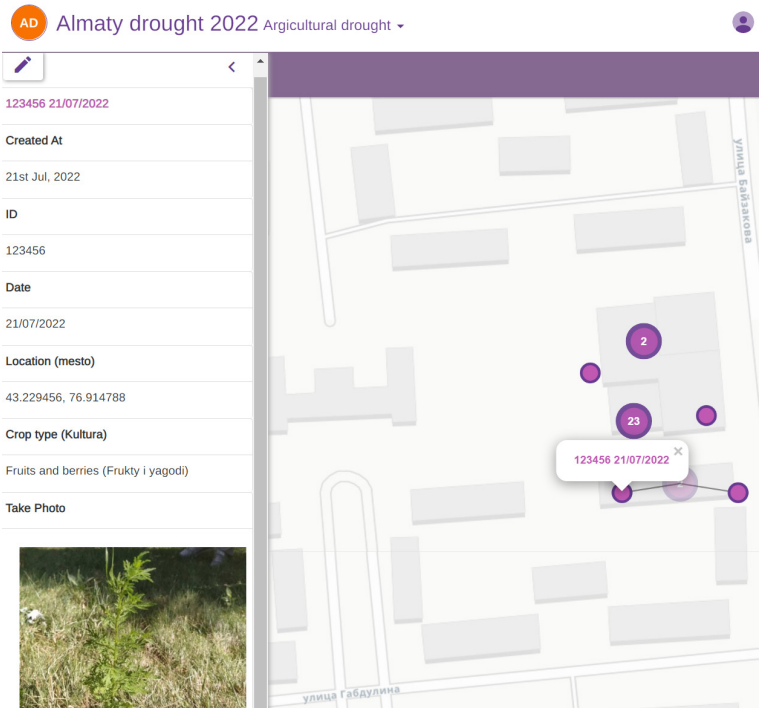


Figure 5.12

UN-ASIGN Mobile Application Interface

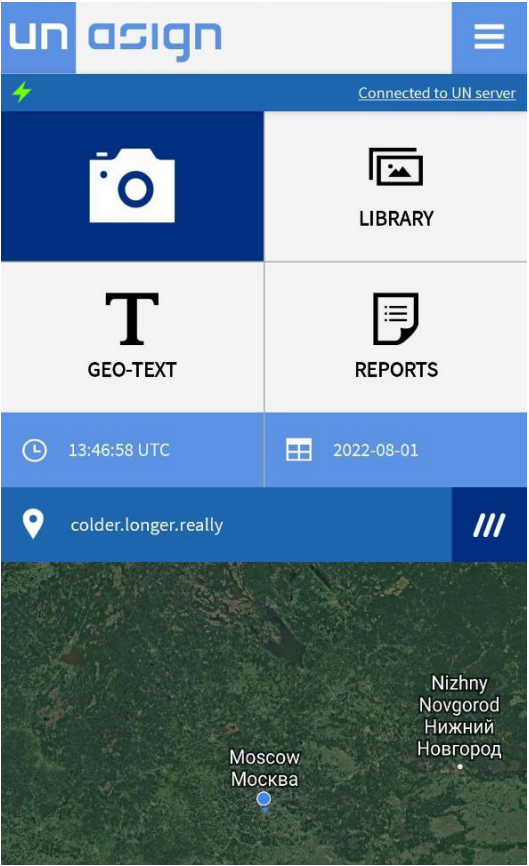


Figure 5.13

EpiCollect5 and UN-ASIGN are two examples of smartphone applications used for field data collection. Epicollect5 is distributed as a mobile application for both iOS and Android, as well as a web application for PC. The service allows its user to create structurally complex and voluminous questionnaires and surveys. All data collected from multiple collectors is synchronized for further viewing or filtering on the project's website. The survey results can be visualized on a web map or downloaded in table format. EpiCollect5 belongs to the Centre for Genomic Pathogen Surveillance.

UN-ASIGN is a free crowdsourcing application made available by the United Nations Satellite Center UNOSAT. It is a tool for taking and sharing photos and videos with location tags, specifically designed to work with low Internet bandwidth. Photos are automatically plotted on the analyst's map, which helps to increase general awareness of the situation. Individual survey participants can view their own photos using the built-in Google Maps base map, while UNOSAT has access to all materials, while being able to share them with relevant coordinating and thematic organizations. Data is transferred in real time if the data collector has an internet connection. Otherwise, it is stored on the device until the network connection is restored, after which it is uploaded to the server. Examples of system interfaces are shown in Figures 5.12 and 5.13.

6. Developing the Central Asia Drought Information System: Pilot Project

6.1. Capacity Building Activities

Considerable results were achieved in Kyrgyzstan during the preparatory work under the ESCAP pilot project in 2019-2022. Project objectives have been assigned and a plan for its implementation has been drawn up. The project's purpose is to enhance the capacity of all involved stakeholders to effectively employ geospatial data and analysis for drought monitoring and early warning. Core national stakeholders were identified at an early stage. They are Kyrgyzhydromet and the Ministry of Emergency Situations of the Kyrgyz Republic, namely the Department of Monitoring and Forecasting of Emergency Situations.

In March 2019, the project inception meeting was held at the ESCAP headquarters in Bangkok, Thailand. The meeting participants were specialists from Kyrgyzstan (Ministry of Emergency Situations, Ministry of Agriculture), People's Republic of China (AIR CAS), Republic of Korea (Korean University, KRIHS), the Russian Federation (Agrophysical Research Institute, Ministry of Foreign Affairs), Uzbekistan (Academy of Sciences), Mongolia (NCDC IIMGOS), as well as representatives of international organizations (ESCAP, AIT). Representatives of all states stated that they were ready to support Kyrgyzstan in creating a national drought monitoring system. As one of the core outcomes, AIR CAS staff agreed to become the main technical partner for operationalizing the pilot system.⁵²

Draft Conceptual Composition of the Drought Information System for Kyrgyzstan

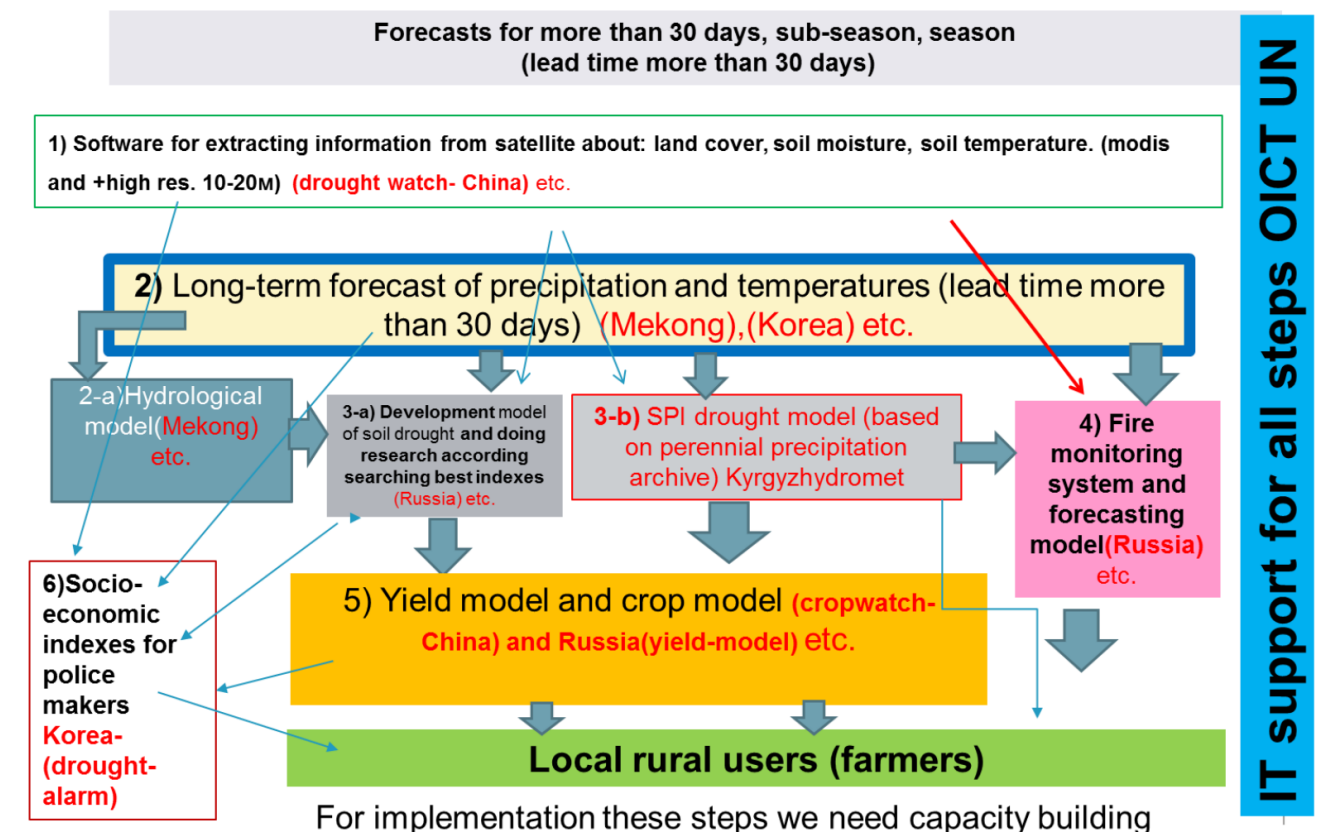


Figure 6.1

In July 2019, the first project Expert Group Meeting was organized in Cholpon-Ata, Kyrgyzstan. The meeting was attended by representatives of Kyrgyzstan (MES, Ministry of Agriculture, KRSU, KNU), China (AIR), the Russian Federation (Agrophysical Research Institute, SIC "Planeta", NRIAM, University of Twente), Uzbekistan (Academy of Sciences, State Forestry Committee), Korea (Korean University, KRIHS, KPEA), Singapore (SFA), Mongolia (NRSC IRIMHE) and staff of international organizations (ESCAP, UN Secretariat, ADPC, AIT, CESDRR, FAO). At the meeting, a conceptual scheme of the future drought information system was drawn up, which is presented in Figure 6.1. The system formed as a set of technological solutions, access to which is necessary for the system operator to effectively monitor drought events. Also at the meeting, representatives of China agreed to adapt its own national DroughtWatch monitoring system for Kyrgyzstan for the subsequent transfer of the system to the state meteorological agency Kyrgyzhydromet.⁵³ The adaptable model has the working name DroughtWatch Kyrgyzstan. Thus, Kyrgyzstan became the fifth country in which work is underway to adapt DroughtWatch,

along with Mongolia, Cambodia, Myanmar and Sri Lanka.

Further activities carried out within the framework of the project can be characterized as technical trainings dedicated to one or another conceptual component of the envisaged system. The first of these events was a workshop held in October 2019 in Bishkek, Kyrgyzstan. Specialists of the Asian Disaster Preparedness Center demonstrated the capabilities of the RHEAS model. RHEAS is a software environment for hydrological modeling, which includes the functionality of determining the current situation and forecasting. The software is based on a spatial database of satellite data describing various elements of the hydrological cycle.⁵⁴

A month-long training on the DroughtWatch system was held in Beijing in November-December 2019. The training was organized for two Kyrgyz specialists of the Ministry of Emergency Situations in the headquarters office of the Research Institute of Aerospace Information of the Chinese Academy of Sciences. During the training, meteorological station data and satellite images were collected and consolidated. Drought indices and the search for correlations between their values with data on precipitation, temperature, soil moisture and yields of major crops. The MODIS (Terra, Aqua) and MSI (Sentinel-2) satellite data were also downloaded to calculate and study the suitability of five satellite vegetation indices. The analysis was carried out both at the national level and for most regions of the country. The results of the work carried out are described in more detail in the Section 5.2.2.

The next educational event was organized by ESCAP and the Korean University in January 2020 in Bishkek, Kyrgyzstan. At the event, Korean methods of drought forecasting were described, and relevant practices were presented. Lectures were held on calibrating the values of satellite indices and diagnosing the degree of drought hazard based on them.

In March 2021, with the support of ESCAP, an online seminar was held, at which the Russian drought monitoring methodology of NRIAM, discussed in more detail in Section 5.3.1, was demonstrated to the MES staff. The Kyrgyz side was also briefed on the possibilities of wildfire monitoring through by SRC “Planeta”. The wildfire theme has received great interest due to the operational nature of the satellite data employed. As a result of further interaction, the relevant agencies of Kyrgyzstan received trial access to the “Meteo-Siberia” portal, which makes it possible to register fire hotspots almost in real time. More detailed information on this area, as well as a historical analysis of the fire situation, are presented in the ESCAP publication “Satellite Monitoring of the Wildfire Situation in Kyrgyzstan, 2001–2021”.

In July 2022, ESCAP conducted a training in Almaty, Kazakhstan, where various aspects of creating a drought information system were discussed yet again. At the event, Chinese experts presented a new version of the DroughtWatch system, and SRC “Planeta” demonstrated its capabilities in the field of agricultural monitoring. The United Nations Satellite Center UNOSAT, during a training session, conducted a mock field mission, where MES representatives learned how to use smartphone crowdsourcing apps for field research.

In September-October 2022, UNOSAT staff organized a series of online calls with MES Kyrgyzstan. During these calls the Ministry’s specialists were instructed on the ArcGIS Enterprise installation process. Two installation modalities were demonstrated – batch and separate installation of ArcGIS Data Store, ArcGIS Server, Portal for ArcGIS and ArcGIS Web Adaptor.

6.2. Meteorological Drought Monitoring with DroughtWatch-Kyrgyzstan

The introduction of the DroughtWatch system to support the operational activities of Kyrgyzhydromet is at an early stage. It is also important that the software transfer from China to Kyrgyzstan is free of charge, and all related events are sponsored by ESCAP and the AIR CAS within the framework of the Regional Drought Mechanism.

A joint ESCAP-AIR CAS study concluded that the VCI, TCI and VHI satellite indices are useful in identifying droughts in all regions of the country. In addition to the above indicators, the NDDI and NDWI indices performed well in Naryn and Issyk-Kul oblasts.

Currently, all work with the system is carried out on the AIR CAS hardware, because Kyrgyzhydromet does not own a server with sufficient capacity to install and maintain the software. In this regard, it is planned to procure a server that meets the system requirements listed in Table 6.1.

Minimum and Recommended Hardware Specifications for the DroughtWatch System, version 5.0

Parameter	Minimum specs	Recommended specs
Operating system	Windows 10 or Windows Server 2016 and above	
Database software	Access or MySQL (included in DroughtWatch)	
Software environment	ENVI4.7 or above (included in DroughtWatch)	
CPU	4 cores, frequency 2.0 GHz or above, 64-bit	8 cores, frequency 3.0 GHz or above, 64-bit
RAM	4 Gb, DDR3 1600	High-speed, 16 Gb or above, DDR4 3200
Storage	1 Tb	High-speed, 10 Tb or above
GPU	1 Gb	High-performance, 4 Gb or above
Monitor diagonal	19 inches	24 inches and above

Table 6.1

7. Operationalization of the Central Asia Drought Information System: Recommendations

2019 can be considered the year when the operationalization of the Central Asia Drought Information System was started as a pilot initiative, with the advent of the DroughtWatch system being adapted for the territory of Kyrgyzstan. However, to consider the system full-fledged and launched, its various elements that ensure regular and prompt monitoring of the hydrometeorological situation, must be in use. A sufficient condition for its launch will be the achievement of a certain level of integration of the elements of the system into a single whole. It is also important to achieve a certain level of redundancy of datasets and system components to ensure its stable operation. However, redundancy should not be excessive. Chapters 5 and 6 present a gamut of solutions, the use of each of which would enrich the experience of experts in Kyrgyzstan, however, the integration of all those elements into a single system is impossible due to their heterogeneity, both technical and conceptual. The system must have a single core and use a specific analysis algorithm. The output of all supplementary tools should be included in the system for joint viewing of output information.

Due to the fact that the Ministry of Emergency Situations of the Kyrgyz Republic owns a perpetual license for ArcGIS Enterprise software, it is recommended to take advantage of the opportunities provided by ArcGIS Data Store, ArcGIS Server and ArcGIS Portal by building the core branch of CADIS-Kyrgyzstan on this platform. It is proposed to receive input data from several sources, including from AIR CAS. The output information is proposed to be analyzed together with a wide range of scientific and socio-economic data.

After the system is put into operation, it will be possible to talk about the transition to the next phase of the work programme, which will consist in maintaining and finalizing the solution. The working title of the proposed system is Central Asia Drought Information System for Kyrgyzstan or CADIS-Kyrgyzstan.

7.1. Technical Composition of the System

In this section, a system that includes the minimum necessary elements is presented as the “Basic Option”, while the “Advanced Option” describes a more complex and versatile architecture. The second proposed option can be considered both independent or as a logical continuation of the first one. The presentation of two possible compositions of the CADIS-Kyrgyzstan is followed by a detailed description of each of its elements. Many elements are included in both the Basic and the Advanced options, have the same names and do not fundamentally differ from each other. The descriptions of these components are merged, and their differences, if any, are highlighted in the text itself.

7.1.1. System Structure: Basic Option

The Basic version of the system is a set of necessary modules set to perform two main tasks – providing recommendations to the general population and expert analysis for government-level decision-making. If it is necessary to receive operational or proprietary data, individual software products can be amended by third-party sources, through partner organizations. With this configuration, the system consists of a Data Node, a Preprocessing module, a Geoprocessing module, a Decision Matrix, Front-end, and an Overlay module.

CADIS-Kyrgyzstan Proposed Conceptual Diagram: Basic Option

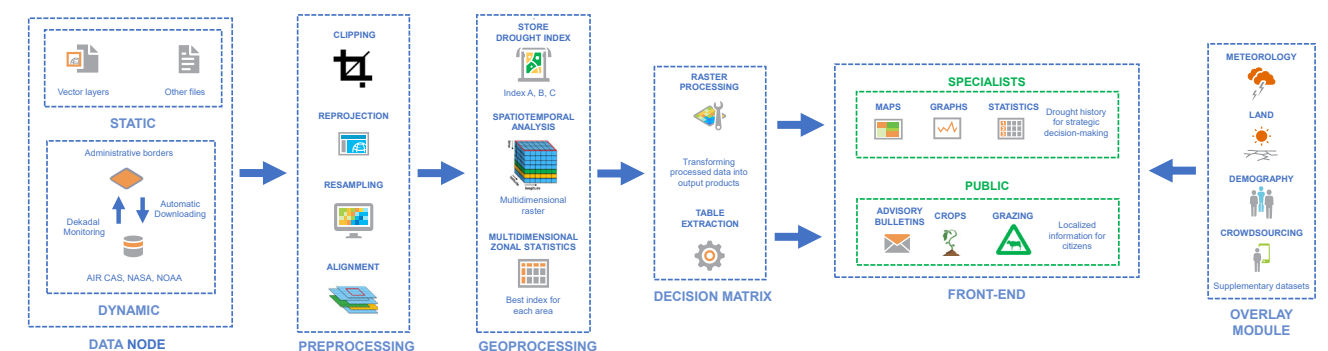


Figure 7.1

The main data on the basis of which the conclusion about the presence and extent of drought is made are downloadable analysis-ready drought and vegetation Remote Sensing indices.

7.1.2. System Structure: Advanced Option

The Advanced version of the system is not only a logical continuation of the Basic one, but it has some fundamental differences that bring it to the next level in terms of complexity and versatility. Firstly, instead of pre-calculated drought indices it uses multiband satellite images, which will allow improving the system based on studies of the suitability of a particular index. Secondly, this option suggests the possibility of a more serious drought analysis, including forecasting. Thirdly, integrates CADIS into the existing system of mass notification for the population of Kyrgyzstan. The above functions correspond to the following modules: Satellite Ingestion, Advanced Analytics and Smart Notification.

CADIS-Kyrgyzstan Proposed Block Diagram: Advanced Option

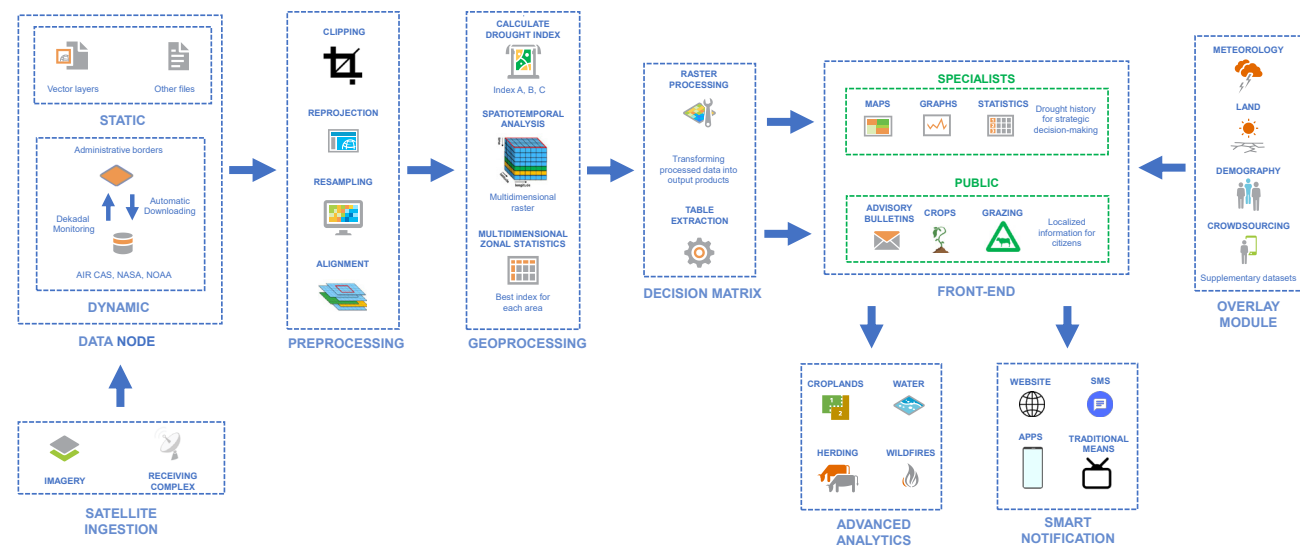


Figure 7.2

7.1.3. Data Node

The recommended structure of the software package of the system is such that its various components can use the same datasets stored in a multi-user database. Most of its volume will be occupied by multispectral satellite images downloaded for the entire territory of the country with a given frequency. They will be used for spatio-temporal analysis in the Geoprocessing module. Administrative division files and other vector data will be required for both geoprocessing and visualization. Thus, it seems appropriate to have all data stored centrally and organized according to the concept of a multi-user geographic database or “data cube”. This approach guarantees minimal conflicts between data, contributing to the unification of the algorithms for new modules. The Data Node consists of static and dynamic components.

Static Component

The Static Component is responsible for loading data that remains unchanged during the sys-

tem's period of observation, i.e., throughout a given vegetation period. This includes data updated annually or less frequently. For example, the boundaries of regions and districts are updated only if these boundaries change, and the tables of agricultural productivity are provided by the National Statistical Committee annually, in the second dekad of January.

Dynamic Component

The drought analysis relies on the Dynamic Component, which loads Remote Sensing data updated several times over the period of observation. The end of this period should coincide with the end of the period of active vegetation, and the beginning of observations should be set somewhat earlier than the beginning of the agricultural season. In the interval between the beginning of April and the middle or end of October, there are approximately 20 dekads or 12-13 sixteen-day periods. Based on this, dynamic data should be downloaded 12-20 times a year for the entire territory of the country.

7.1.4. Satellite Ingestion

The system's Advanced Option provides for autonomous drought index calculation instead of a simple download, through multispectral image processing of data, which is raw or preprocessed to a certain degree. Self-loading images may require the system operator to pre-process data by performing geometric and atmospheric correction, calculating a cloud mask. Under the Basic Option this task falls entirely on the data providers, but under the configuration with the Satellite Ingestion Module, the system would become more versatile, benefitting from a possibility to increase the range of drought indicators. The choice of their spatial and temporal resolution (i.e, the time interval for which the index is calculated) will be widened, as well.

In the long term, Kyrgyzhydromet can revitalize and upgrade its own satellite data receiving capacity in order to reach a higher degree of the system's autonomy and decrease latency. However, this task is not seen as an immediate priority.

7.1.5. Preprocessing

Preprocessing of dynamic data includes cropping its extent by the country's borders, reprojecting it into a single projected coordinate system, bringing all rasters to a single spatial resolution, and ensuring accurate overlay of pixels from different rasters (known as “resampling”). For vector data from all of the above procedures, a reprojection to the target coordinate reference system is carried out.

For better geographic reference, it is preferable to use the national projected coordinate system. It is advisable to use two projections – the 3rd zone of the national projection Kyrg-06 or UTM 43N.

7.1.6. Geoprocessing

The Geoprocessing module is central to CADIS-Kyrgyzstan. As its output, this module is set to form a multidimensional raster of drought indices for the entire territory of the country.

First, drought indices are uploaded or calculated, depending on the selected system configuration option. For data storage, it is advisable to use a file geodatabase. Observations for different periods of time are superimposed on each other, forming a “data cube”, the temporal dimension serving as its depth.

The depth of the “cube” increases at each iteration of observations, that is, once a week, a dekad, an eight-day, sixteen-day or one-month period. The resulting multidimensional raster undergoes zonal statistical processing along selected vector boundaries – regions, districts, river basins, etc.

First, it is proposed to use drought indices and indicators that have proven their effectiveness in preliminary studies conducted under the ESCAP project, namely VCI, TCI and VHI. Here, VCI is the Vegetation Health Index, TCI is the Thermal Condition Index, and VHI is the Vegetation Health Index. The last parameter gives a comprehensive assessment of the state of vegetation, based on its physical condition and the land surface temperature. VHI is calculated as the sum of VCI and TCI with a weighting factor α , which is selected depending on the significance of the former or latter component. In most studies, the weighting factor is chosen to be 0.5. VCI is calculated from the historical values of the Normalized Difference Vegetation Index NDVI, based on its maximum and minimum values for a given area during the observation period. The calculation of TCI follows the same principle, but instead of the vegetation index, the formula uses land surface temperature. The scheme for calculating these indices is shown in Figure 7.3.

VCI, TCI and VHI Drought Index Calculation Formulae

$$VCI = \frac{NDVI_i - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \quad (7)$$

$$TCI = \frac{T_{max} - T_i}{T_{max} - T_{min}} \quad (8)$$

$$VHI = \alpha * VCI + (1 - \alpha) * TCI \quad (9)$$

Figure 7.3

7.1.7. Decision Matrix

The resulting statistical data obtained during geoinformation processing must be converted into a format accessible to the end user. Each of the two main groups of users of the system will receive information in a format most suitable to them. Farmers – in the form of a newsletter,

and specialists – in the form of maps, tables and graphs of both all drought indices and the Resulting Complex Indicator.

Resulting Complex Indicator

Best global practices dictate to select one resulting quantitative drought indicator, graduated according to its drought severity. There are two options for calculating such indicator – by arithmetic summation of various weighted or normalized indices or by assigning a given territory the value of the most appropriate index for it. Some systems rely on a qualitative, rather than quantitative, conditional outcome indicator, as shown in Table 5.2.

7.1.8. Front-end

Public Element

The website interface should be based on a newsletter aimed at farmers and water users, the beneficiaries of the system. The bulletin may include a weather forecast for the coming days, a conclusion regarding the presence or absence of drought, and practical advice on farming. Information should be presented in a spatial aspect, that is, creating separate sections for each territorial unit, preferably to of 2nd degree (rayon). In the initial period, though, it is advisable to provide bulletins at the regional level (oblast). A good example of such a document is the Bangladesh District Agriculture Meteorological Advisory Service Bulletin.

Excerpts from the Bangladesh District Agriculture Meteorological Advisory Service Bulletin

Key weather conditions and forecasts

According to the Bangladesh meteorological department forecast, the weather in the district may remain dry in the coming days. Light fog is possible in some places from dawn. Night and day temperatures can remain virtually unchanged. Daytime and nighttime temperatures may drop in the next 72 hours.

Maize:

- Do the first watering 15-20 days after sowing, the second watering after 30-35 days, the third watering after 60-70 days and the fourth watering after 85-89 days.
- It is necessary to ensure that water does not accumulate on the ground during the flowering and ripening of the grain.

Potatoes:

- Provide watering as needed.
- In addition, chlorpyrifos 20 EC insecticide should be mixed at a rate of 5 ml per liter of water and sprayed on the roots and soil. 30-40 days after planting, the potatoes must be sprayed.

Vegetables:

- Provide light watering.
- Use hexaconazole or menconazole at approved doses when pumpkin powdery mildew occurs.

Cattle:

- Cattle should be fed raw grass and homemade grain feed along with hay. For the time being, properly store the rice straw.
- Hay should be supplemented with raw grass and homemade pellets.

Box 7.1

Specialist Element

A static or an interactive map with a legend-classification of droughts according to various drought indicators, including the resulting complex indicator, can become the core of the Specialist Element. The base map should highlight medium and large settlements, regions and districts of the country. It is desirable to have the ability to change dates both backward, to view historical information, and forward, to view the forecast.

7.1.9. Overlay module

Temperature and Precipitation Forecast

Kyrgyzhydromet predicts temperature and precipitation based on hydrometeorological network data using the international COSMO model. Satellite information is also used in combination with this approach, but to a lesser extent.

In the context of CADIS, weather forecast data will be used to generate forecasts for some of the system's outputs: drought indices and crop yields. When making such a forecast, the simple approach of replacing actual meteorological indicators with forecast ones should be taken.

Socioeconomic Analysis

The Socioeconomic Analysis module is necessary to assess the impact of drought on the country's population, correlating with the drought condition in a particular area with socio-economic indicators.

It is recommended that demographic data rasters be loaded in the system as an initial step. The most elementary operation would be to identify high population zones, where drought occurs, as well as calculating the number of affected citizens. In addition, the age and

gender composition of drought-prone areas should be analyzed, and its dynamics monitored. Particular attention should be paid to settlements with a significant proportion of children and adolescents, since those age groups, who have not yet become economically active, may be especially affected by drought consequences. It is also recommended to monitor the process of urbanization and unemployment in drylands. Accelerating population outflow from rural areas will indicate a greater degree of internal migration, the reasons for which can be assessed by correlating its peaks with the degree of aridity around the settlement.

Meteorological Data

The SPI meteorological index will be calculated for the entire territory of the country by Kyrgyzhydromet. This process should be integrated into the overall CADIS structure, making this index, which has shown very good results in its verification, an additional indicator for assessing drought from ground data. It is believed that one-month and three-month SPI is most suitable for drought forecasting. The three-month index has the highest correlation with the state of vegetation, while monthly SPI aides to register sharp changes, the so-called "flash droughts".⁵⁵

Soil and Land Cover Data

Calculations regarding the state of land should be based on agricultural field data. The latter can be presented both in the form of a regularly updated land cover raster and in vector form. A great example of the former is the ESA WorldCover dataset, while the latter requires field vectorization and attribute collection, which is serious work. Similar disquisition was carried out by the Kyrgyzgiprozem Institute with pastures, soils and sown lands of the state agricultural assets. Access to these files is best established through the Portal of Geoinformation and Climate Data of the Kyrgyz Republic.

As the output of the component, maps of drought indices compiled within agricultural lands should be generated for transfer to the yield calculation component and further modification by combining the output data from other CADIS elements.

7.1.10. Advanced Analytics

MES Kyrgyzstan has access to the ArcGIS Enterprise software, inclusive of the following components: Network Analyst, 3D Analyst, Spatial Analyst, Geostatistical Analyst, Schematics, as well as access to other tools described in Chapters 5 and 6. In the future the Ministry can develop in-depth analytics on drought and drought-adjacent topics. The Advanced Analytics Module hosts some themes that will require additional technical work to be implemented in CADIS-Kyrgyzstan, which leads to their inclusion in the Advanced Option of the system configuration.

Crop Yield Data

Calculating crop yield is a challenging to develop yet sought for functionality. To calculate crop yield, it is recommended to use satellite vegetation indices already calculated at the stage of modeling agricultural drought, as well as meteorological parameters. The latter are collected at weather stations and may include solar radiation, air temperature and humidity, total precipitation, and average wind speed. To the above main parameters, one should also add the archive data available to the National Statistical Committee on the actual yield at the level of aiyl aimaks with the dates of sowing. Further, based on the adopted methodology, yield forecasts at the regional and local levels should be calculated, based on low and medium resolution data, respectively. A working embodiment of such a methodology is the SDIM software package developed by the “Planeta” Research Center.

Wildfire Monitoring

Near-real-time wildfire monitoring requires a receiving station complex, which Kyrgyzstan currently does not possess. Therefore, to solve this problem at this stage, it is advisable to cooperate with a state that has such capabilities. SRC “Planeta”, which receives satellite data for the entire territory of Central Asia, is seen as a viable partner.

Software-wise, it is recommended to supplement the existing GIS portal “Wildfires in the Kyrgyz Republic” with the functionality of downloading layers of possible fire hotspots for statistical and historical analysis, enabling the assessment of mutual influence of wildfires and droughts. Another option for solving this problem can be the development of a programming interface (API) between CADIS and the Portal.

Hydrological Data

The Water Resources Service has strong water monitoring capabilities and can provide some hydrological data by uploading it directly to the CADIS database. Water balance maps can be combined with meteorological and agricultural information to provide a more detailed basis for early detection of long-term, hydrological drought. In addition, the use of the Service’s data adds an additional dimension – analysis of the situation within the boundaries of a given river basin, which may be more reasonable than relying on the administrative division of the country, from the scientific standpoint.

7.1.11. Smart Notification

The Smart Notification component should be able to inform the country’s population about an impending or deteriorating drought by providing specific recommendations. Notification should be carried out both massively, on a national scale, and targeted, that is, on a territorial basis or personally. The CADIS website and relevant traditional channels should be employed for mass announcements, while SMS and mobile apps should be used for targeted informing.

System Website

The yet-to-be-developed CADIS-Kyrgyzstan website or webpage should serve as the main method for publication and dissemination of information. The Ministry of Emergency Situations operates a website of the Portal of the Unified Integrated Monitoring and Forecasting System (ESKMP – see Section 5.2.5). Using this existing solution is reasonable, provided that a dedicated CADIS-Kyrgyzstan webpage is developed within the site.

Notification through Traditional Channels

Traditional emergency communication channels include radio, television, newspapers and other media. In addition to mass information, it is necessary to organize targeted work with the population at the level of districts and aiyl aimaks (third- and fourth-level administrative units, respectively), through state and public mechanisms.

SMS and Mobile Applications

SMS notification has proven to be an effective means of disseminating information in rapid-onset emergency context. Using the same channels, it is recommended to establish targeted notification of the population on drought. Due to the technical nature of the SMS message format, such mailing cannot be detailed, so as an additional source of information in SMS, a link to the system’s website should be attached.

Newsletters are also recommended to be published in the “112 Kyrgyzstan” mobile app, described in Section 5.2.5.

Information collected from the end-users of the system can act as its feedback component. Those can be field research reports, photo and video materials collected using the tools described in Section 5.5.2.

7.2. Recommendations on the System Implementation Process

7.2.1. Stakeholders and their Roles

Kyrgyzhydromet's Agrometeorology Department, as well as the Department of Monitoring and Forecasting of the Ministry of Emergency Situations can become principal operators of CADIS. It is desirable that the interested state bodies also have access to the system, and the analytical reports, maps and forecasts created by the system are interpreted in such a way that their outputs become available to the general population. Many government agencies, as well as partner state and international organizations, could make a significant contribution to the development of the system, at least by providing valuable statistical, geographical and other data. The ultimate beneficiaries of the system are seen as broad sections of the population, represented mainly by farmers, agricultural communities and water users. The list of stakeholders that seem to be the most suitable for the process of creating and operating the system is given in Table 7.1, where stakeholders are assigned potential roles.

Kyrgyzhydromet can become the main operator of a promising drought monitoring and early warning system, as the body has the competencies necessary to use it and has clear goals for acquiring it. MES is seen as the main developer and owner of the system, along with Kyrgyzhydromet. The principle of project management, according to which the system should have a single responsible operator, is not maintained due to the fact that the Agency for Hydrometeorology is part of the structure of the Ministry of Emergency Situations of the Kyrgyz Republic.

The Ministry of Agriculture is seen at least one of the main consumers of the data of the future system due to the serious population notification potential albeit a wide network of territorial departments. The headquarters and subordinate organizations could participate in CADIS development, in particular, its agricultural components.

The activities of the Water Resources Service under the Ministry of Agriculture, not being directly related to the monitoring of drought events, however, can be closely related to the future drought information system if its hydrological component under the Advanced Analytics module is developed. The Service can become the project's beneficiary and make a significant contribution to CADIS deployment, too. The latter can be achieved by providing the system developers with the opportunity to connect to their own geospatial resources, namely the Water Information System Geoinformation Portal.⁵⁶

The National Statistical Committee stores its agricultural data with geographically referenced

harvest information, providing detail up to regions and districts (administrative units of the first and second order, respectively). Such granularity will allow CADIS operators to conduct spatial statistical analysis, comparing yield data with drought indices at a low scale, up to six times for one vegetation season. In addition to information on agriculture, the demographic statistics compiled by the Committee are of interest. Those datasets are also very detailed and include population of regions, districts, cities, urban-type settlements, aiyl aimaks and aiyls (villages) of Kyrgyzstan. Availability of up-to-date georeferenced information on the size, gender and age structure of the population will allow to draw valuable conclusions regarding drought-affected groups. In this light, the National Statistical Committee is seen as one of the primary data providers for the future system.

The Mountain Societies Research Institute can become a provider of high-resolution data for pilot areas, as well as contribute to the development of the hydrological component of the system.

The State Design Institute "Kyrgyzgiprozem" can become both a provider of information and a beneficiary of the future system. Following CADIS implementation, the Institute may avail itself of the opportunity to plan its soil assessment activities based on drought data. The academic staff are able to assist system developers by providing detailed land use information derived from corresponding research. In the future, the Institute will be able to use the system to draw conclusions about the productivity of a particular land plot, based on its agricultural components.

The Institute of Biology, as well as the Institute of Water Problems and Hydropower of the National Academy of Sciences can become a source of detailed soil and water maps. The K. I. Skryabin Kyrgyz National Agrarian University alumni can become personnel for operating the system.

ESCAP's extensive experience in coordinating technical support programmes, including through the Regional Drought Mechanism, should help to achieve the project's overall goals to the full extent.

The experience of vegetation cover monitoring carried out by SRC "Planeta" regions, districts and individual farms on the territory of the Russian Federation is of relevance. Of particular value is the fact that the receiving stations located in the organization's Siberian Center often work to receive data not only for the territory of Russia, but also for the countries of Central Asia located to the south, including Kyrgyzstan.

The United Nations Institute for Training and Research (UNITAR), as well as its United Nations Satellite Center (UNOSAT), can become partners with the system operator in conducting additional research and educational activities. UNOSAT has a wealth of experience both in creating GIS in national and regional contexts and in developing relevant educational programs and materials, which can be helpful for cooperation with Kyrgyzstan in the field of capacity development.

The Aerospace Information Research Institute of the Chinese Academy of Sciences (AIR CAS) can act as one of the main suppliers of up-to-date scientific data for the CADIS-Kyrgyzstan system. Work to improve the DroughtWatch system and its adaptation for the territory of Kyrgyzstan should also be continued.

With a geospatial data platform and 11 own automatic hydrometeorological stations, the Central Asian Institute of Applied Geosciences can become a primary data provider for more complete information on the hydrological cycle. The studies of river flow and groundwater conducted by the Institute with the corresponding long-term databases can become an additional source of information introduced into the future system.

The ultimate goal of creating a drought information system is to boost the preparedness for drought not only and not so much of state bodies, but of the general population of Kyrgyzstan, namely, farmers, farmer communities and water user associations. The beneficiaries of the system should be both such local organizations and independent farmers.

Roles of Prospective Stakeholders in the Process of Developing, Maintaining and Using CADIS-Kyrgyzstan

Type	Name	Web-site	Development or data provision	Ownership and maintenance	Use
Government	Agency on Hydrometeorology under The Ministry of Emergency Situations (Kyrgyzhydromet)		+	+	+
	Ministry Of Emergency Situations		+	+	+
	Ministry of Agriculture		+		+
	Water Resources Service under the Ministry of Agriculture		+		+
	National Statistical Committee		+		+
	Land Resources Service under the Ministry of Agriculture		+		
	Forest Service under the Ministry of Agriculture		+		+
	“Kyrgyzgyprozem” Institute	n/a	+		+
	Institute of Biology of the National Academy of Sciences		+		+
	Institute of Water Problems of the National Academy of Sciences		+		+
	K.I. Skryabin Kyrgyz National Agrarian University		+		+
	Basin administrations	n/a			+
International organizations and partner states	ESCAP		+	+	
	SRC "Planeta"		+	+	
	UNITAR/UNOSAT			+	
	Aerospace Information Research Institute under the Chinese Academy of Sciences		+	+	
	Mountain Societies Research Institute (MSRI)		+		+
	Central-Asian Institute for Applied Geosciences (CAIAG)		+		+
Population groups	Farmers and water users	n/a			+
	Basin councils	n/a			+

Table 7.1

7.2.2. System Improvement

Drought index calculation functionality should not be equated to full, immediate and widespread drought monitoring capacity. In addition to the correct index calculation, it is necessary to assess the suitability of each of them both at the national level and at the level of various climatic zones. To achieve this, it is necessary to compare the obtained values with the values of physical variables obtained during field research or through statistical surveys. Based on these accomplishments, it is necessary to make an assessment of the suitability of each index for different climatic zones, regions and river basins.

7.3. Strategic Recommendations

7.3.1. Legislative Base

Drought is rarely mentioned in the programmatic and legal documents of Kyrgyzstan, at best highlighted as a secondary topic. Since drought events are persistent and worsening in the country, this state of affairs does not correspond to the actual level of disaster risk.

Lower Mekong River Basin Drought Forecast Map

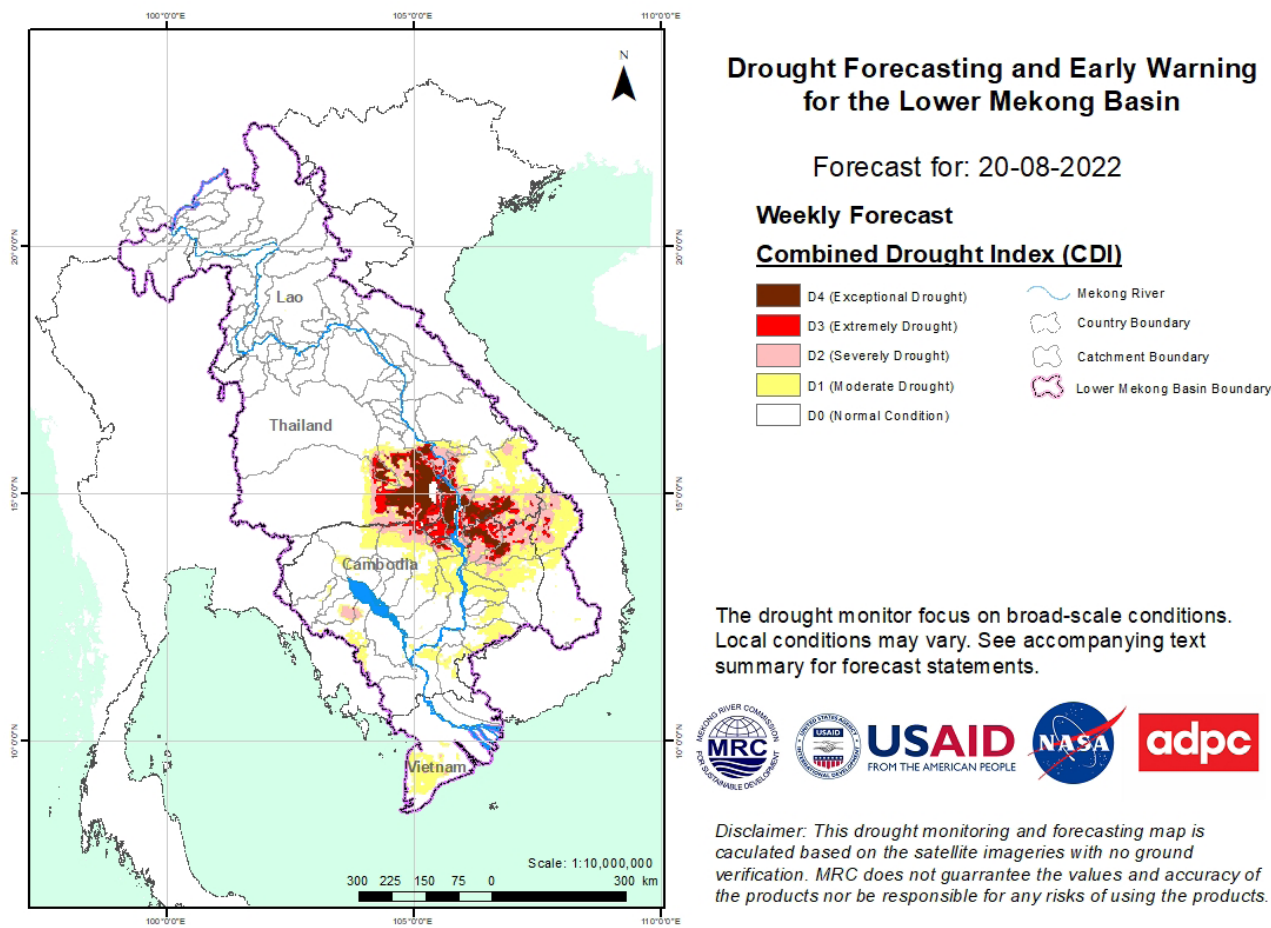


Figure 7.4

Proper, disaster management standard-dictated drought management includes eight stages (planning, prevention or mitigation, monitoring and forecasting, active phase, damage

assessment, response, relief, system modernization). In this regard, it seems reasonable to improve the structuring of national legislation and organizational and technical regulations based on existing examples and highlight drought as a separate legislative and organizational topic.

A starting point can be the development of drought preparedness plans based on the recommendations contained in WMO’s “National Drought Management Policy Guidelines: A Template for Action”.⁵⁷ The WMO Guidelines offer ten concrete steps for government authorities, starting with the establishment of a national drafting committee for the development of official documents to combat drought and aimed at improving the effectiveness of drought management through clear planning and the active multi-stakeholder involvement. At present, only 27 UN Member States have developed their own drought management plans, and none of them are in the North and Central Asian region, but the experience of these countries can still be useful for Kyrgyzstan.⁵⁸ As a first step, the country can also follow a simplified scheme, focusing on the implementation of the eight steps recommended by the UNCCD in the prescribed “Model National Drought Plan”.⁵⁹

Where such advisory bodies have been established, the following situation is observed. The systems provide monitoring and forecast information on drought, notifying in specific regions of danger. Although this information has been made public, its main consumers mostly belong to the government, mainly being regional authorities. The information is presented in the form of maps, often with an intuitive legend that classifies regions according to the level of danger (Figure 7.4).

However, such maps are still not sufficient to make very specific decisions at the level of farmers and agricultural communities. It is at this stage that pre-designed drought mitigation plans come into play. Afghanistan is an illustrative example, where a yearly two-month-long process of drought counteraction measure planning takes place in accordance with the well-developed

Drought Declaration and Response Planning Process in Afghanistan

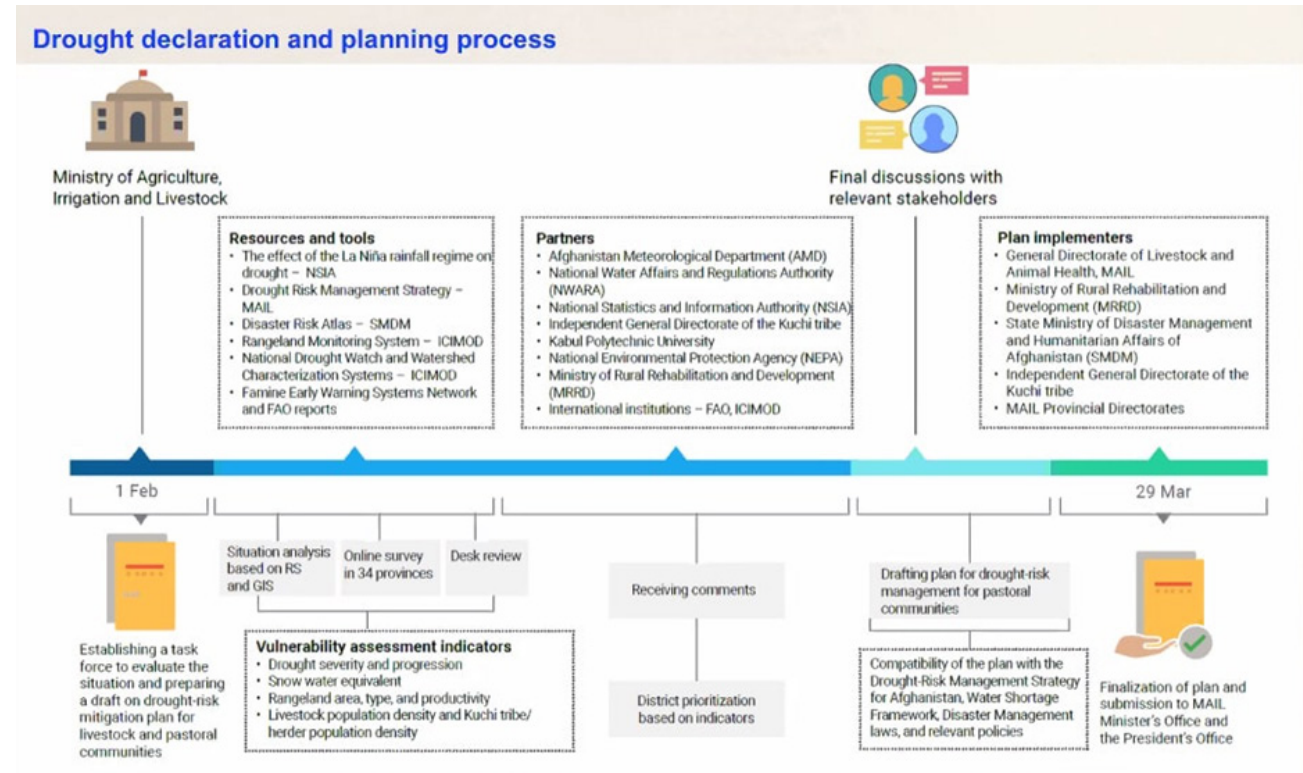


Figure 7.5

methodology presented in Figure 7.5. This country has a National Drought Committee, which consists of 19 ministries and agencies.

7.3.2. Interagency Coordination

It is advisable to draw up a new national action plan for the implementation of the UNCCD in Kyrgyzstan, using the best practices in the application of information technologies and proposing concrete steps for their implementation in order to combat the consequences of drought events. In addition to the establishment of a monitoring and early warning system for droughts, it is advisable to touch on the following topics:

1. Integration of the developed system with systems for monitoring land and water resources in order to clarify and improve the quality of the data provided;
2. Mapping the quality and productivity of land and soils for the purpose of sowing and planting suitable crops;
3. Mapping of food, water and agriculture infrastructure for demand forecasting and supply planning;
4. Knowledge sharing on the use of space technologies to support climate change mitigation and adaptation programs in agriculture, water and forestry;
5. Participation in the discussion of seasonal forecasting issues and the exchange of information related to common crops in existing intergovernmental forums, such as the Global Agricultural Monitoring initiative of the Earth Observation Group (Kyrgyzstan is not represented in the Group of Earth Observations, unlike neighboring Kazakhstan and Tajikistan).⁶⁰

Of great importance is representation in international organizations dealing with GIS, remote sensing and the introduction of innovative technologies in the field of environmental protection, agriculture and disaster risk reduction. It is advisable to consider cooperation or entry of the relevant state structures of Kyrgyzstan into the following organizations:

1. Group on Earth Observations;
2. APEC Climate Center;
3. Global Facility for Disaster Risk Reduction and Recovery of the World Bank;
4. International Hydrographic Organization;
5. International Cartographic Association;
6. International Society for Photogrammetry and Remote Sensing of the International Scientific Council;
7. International Federation of Surveyors;
8. International Center for Integrated Mountain Development.

7.3.3. Building Overall Technical Capacity

Due to the lack of computing power at the Ministry of Emergency Situations of the Kyrgyz Republic for the deployment of a new full-scale system, the task of acquiring the necessary server capacities is seen as a priority. It seems expedient to use the CADIS-Kyrgyzstan system proposed in this Chapter and the DroughtWatch system. Therefore, purchased hardware should be slightly larger than the minimum ROM requirements stated in Table 6.1 to provide redundancy.

The proposed CADIS-Kyrgyzstan system operates on a file-based geographic database and, according to preliminary estimates, its rasters should not take up large amounts of memory, especially in the basic configuration. However, in the future, the situation may change due to plans to accumulate the nomenclature of drought indices and create a spatial raster archive. Therefore, the most competent decision seems to be the purchase of equipment that meets the recommended requirements.

The results of field studies can also be improved by increasing the technical range – UAVs, devices for taking soil samples, measuring soil moisture and analyzing their composition.

To improve the quality of meteorological observations from the ground, it is recommended to increase the number of meteorological stations and posts. This can be done both by traditional methods, that is, by acquiring equipment by the state, and by popularizing the principle of public weather observations among the population. An ordinary citizen interested in meteorology or climatology can purchase a personal weather station and become part of a scientific network.

8. List of Sources

- 1 State Water Resources Agency under the Government of the Kyrgyz Republic, Water resources and water management infrastructure of Kyrgyzstan, https://water.gov.kg/index.php?option=com_content&view=article&id=365:water-resources-and-water-management-infrastructure-of-kyrgyzstan&catid=127&lang=en&Itemid=1470
- 2 Monitoring of the Sustainable Development Goal Indicators in the Kyrgyz Republic 2014-2018, UNICEF, 2020, <https://www.unicef.org/kyrgyzstan/reports/monitoring-sustainable-development-goal-indicators-kyrgyz-republic-2014-2018>
- 3 Official Statistics: Agriculture, National Statistical Committee of the Kyrgyz Republic (aggregates were compared for 1991-1993 and 2018-2020), <http://www.stat.kg/en/statistics/selskoe-hozyajstvo/>
- 4 How can Kyrgyzstan sustain on its own food production (Kyrgyz and Russian), Sputnik Kyrgyzstan, 2018, <https://sptnkne.ws/yfDn>
- 5 Would we starve without Kazakhstan's wheat. Expert opinions, Sputnik Kyrgyzstan (Kyrgyz and Russian), 2020, <https://sptnkne.ws/GtB7>
- 6 World Bank, World Bank Open Data, accessed from <https://data.worldbank.org/indicator/SP.RUR.TOTL.ZS?locations=KG>
- 7 Farm Mechanization and Agricultural Productivity, FAO, 2009, <http://www.fao.org/3/i3340e/i3340e.pdf>
- 8 Crop growing season, FAO GIEWS, <https://www.fao.org/giews/earthobservation/country/index.jsp?type=21&code=KGZ>
- 9 Official statistics: Agriculture, National Statistical Committee of the Kyrgyz Republic (aggregates were compared for 1991-1993 and 2018-2020), <http://www.stat.kg/en/statistics/selskoe-hozyajstvo/>
- 10 Rehabilitating the Irrigation Canals in Southern Kyrgyzstan: An Impact Evaluation Study, MSRI, <https://ucentralasia.org/publications/2022/march/rehabilitating-the-irrigation-canals-in-southern-kyrgyzstan-an-impact-evaluation-study>
- 11 Agriculture, Food Industry and Agrofood Item Export in Kyrgyzstan, R. Mogilevskii (Russian), https://ecfs.msu.ru/images/documents/stranovie%20issledovaniya/Paper%20on%20KGZ%20vs.%202%20clean_cor.pdf
- 12 World Bank, Climate Change Knowledge Portal: Kyrgyzstan, <https://climateknowledgeportal.worldbank.org/country/kyrgyzstan>
- 13 Drought frequency maps for Kyrgyzstan, FAO GIEWS, <https://www.fao.org/giews/earthobservation/country/index.jsp?type=21&code=KGZ>
- 14 Resolution of the Government of the Kyrgyz Republic №569 “On the Unified System for Complex Disaster Monitoring and Prediction in the Kyrgyz Republic”, <http://cbd.minjust.gov.kg/act/view/ru-ru/157217/10?cl=ky-k&mode=tekst>
- 15 Resolution of the Government of the Kyrgyz Republic №58 “On the Concept of comprehensive Protection of the Population and Territory of the Kyrgyz Republic from emergency situations for 2018-2030”(Kyrgyz and Russian), 2018, <http://cbd.minjust.gov.kg/act/view/ru-ru/11990/20?cl=ky-k&mode=tekst>
- 16 Resolution of the Government of the Kyrgyz Republic №550, On the approval of the Classification for emergency situations and criteria for their evaluation in the Kyrgyz Republic (Kyrgyz, Russian), 2018, <http://cbd.minjust.gov.kg/act/view/ru-ru/12747/10?cl=ky-k&mode=tekst>
- 17 Background Paper on Drought - an Assessment of Asian and Pacific Progress, ESCAP, https://sustainabledevelopment.un.org/content/documents/escap_drought.pdf
- 18 GAR Special Report on Drought, UNDRR, <https://www.undrr.org/publication/gar-special-report-drought-2021>
- 19 Law of the Kyrgyz Republic “On Food Security of the Kyrgyz Republic” (Kyrgyz and Russian), 2008, <http://cbd.minjust.gov.kg/act/view/ru-ru/202397/30?cl=ky-k&mode=tekst>
- 20 State of the Kyrgyz Agriculture, Knowledge Portal for Water Resources and Ecology of Central Asia CAWATER (Russian), http://www.cawater-info.net/review/agri_kyrg.htm
- 21 Water Code of the Kyrgyz Republic, 2005, http://www.cawater-info.net/bk/water_law/pdf/water_code_kyrgyz_en.pdf
- 22 Law of the Kyrgyz Republic “On the Development of Agriculture in the Kyrgyz Republic” (Kyrgyz, Russian), 2009, <http://cbd.minjust.gov.kg/act/view/ru-ru/202555/40?cl=ky-k&mode=tekst>
- 23 National Action Plan on Combatting Drought in Kyrgyzstan, UNCCD, 2000 (Russian), <https://www.unccd.int/sites/default/files/naps/kyrgyzstan-rus2000.pdf>
- 24 National Action Plan (NAP) and Activity Frameworks for Implementing the UNCCD in the Kyrgyz Republic for 2015-2020, <https://knowledge.unccd.int/sites/default/files/naps/Kyrgyzstan-2014.pdf>
- 25 National Development Strategy of Kyrgyzstan for 2018-2040 (Kyrgyz and Russian), 2018, <https://mfa.gov.kg/ru/osnovnoe-menyu/vneshnyaya-politika/gosudarstvennye-programmy/nacionalnaya-strategiya-razvitiya-kyrgyzskoy-respubliki-na-2018-2040-gody>
- 26 Law of the Kyrgyz Republic “On Food Security of the Kyrgyz Republic” (Kyrgyz and Russian), 2008, <http://cbd.minjust.gov.kg/act/view/ru-ru/202397/30?cl=ky-k&mode=tekst>
- 27 National Digital Transformation Framework “Digital Kyrgyzstan” (Kyrgyz and Russian), 2018, <https://digital.gov.kg/kg/>
- 28 Executive Order of the Government of the Kyrgyz Republic № 20-r (Kyrgyz and Russian), 2019, <http://cbd.minjust.gov.kg/act/view/ru-ru/216896/20?cl=ky-k&mode=tekst>
- 29 Law of the Kyrgyz Republic “On Hydrometeorological Activities in the Kyrgyz Republic” (Kyrgyz and Russian), 2006, <http://cbd.minjust.gov.kg/act/view/ru-ru/1950/20?cl=ky-k&mode=tekst>
- 30 Development Programme of the Agency for Hydrometeorology under the Ministry of Emergency Situations of the Kyrgyz Republic for 2020-2025 (Kyrgyz and Russian), http://upload.meteo.kg/attachment/62_53_fcc6233b6d558e7d4277055cc6d90aa1.pdf
- 31 Webpage of the ICT and Disaster Risk Reduction Division, ESCAP, <https://www.escap.org/>

- 32 Geospatial Tools to Support the Implementation of the Sustainable Development Goals in Asia and the Pacific: the Drought Riskscape and the Regional Drought Mechanism, ESCAP, 2019, <https://www.unescap.org/resources/geospatial-tools-support-implementation-sustainable-development-goals-asia-and-pacific>
- 33 Handbook of Drought Indicators and Indices, WMO, 2016, <https://public.wmo.int/en/resources/library/handbook-of-drought-indicators-and-indices>
- 34 The Standardized Precipitation Index – An Overview, S. Cheval, https://www.researchgate.net/publication/291747885_The_Standardized_Precipitation_Index_-_an_overview
- 35 A Multiscalar Drought Index Sensitive to Global Warming: The Standardized Precipitation Evapotranspiration Index, Vicente-Serrano, Beguería, López-Moreno, Journal of Climate, 2010, <https://journals.ametsoc.org/view/journals/clim/23/7/2009jcli2909.1.xml>
- 36 Assessment of Drought Challenges and Drought Monitoring Models in the Central Asian Region (Russian), CESDRR, 2020, <https://ces-drr.org/uploads/projects/2.10.%20%D0%98%D1%81%D1%81%D0%B-%D0%B5%D0%B4%D0%BE%D0%B2%D0%B0%D0%BD%D0%B8%D0%B5%20%D0%BF%D0%BE%20%D0%BF%D1%80%D0%BE%D0%B1%D0%BB%D0%B5%D-0%BC%D0%B0%D0%BC%20%D0%B7%D0%B0%D1%81%D1%83%D1%85%20%D0%B2%20%D0%A6%D0%90.pdf>
- 37 25+1. Standardized Precipitation Index User Guide, WMO, 2012, <https://public.wmo.int/en/resources/library/standardized-precipitation-index-user-guide>
- 38 ESCAP Expert Research Materials
- 39 Water Information System (WIS) of the Water Resources Service of the Kyrgyz Republic, https://www.water.gov.kg/index.php?option=com_content&view=article&id=422&Itemid=1522&lang=en
- 40 User-facing Map of the SIBELIUS Project, <https://kyrgyzstan.sibelius-datacube.org:8443/map/EN>
- 41 SIBELIUS project in Mongolia, <https://sibelius-mongolia.org/>
- 42 CEOS Open Data Cube Initiative, <https://www.opendatacube.org/ceos#:~:text=As%20of%20July%202017%2C%20there,other%20countries%20with%20expressed%20interest.>
- 43 Portal of the Unified System for Complex Emergency Monitoring and Forecasting, <https://ucmfs.mes.kg/>
- 44 Automatic Meteorological Observation Site Tracking System of Roshydromet (Russian), <http://asunp.meteo.ru/portal/asunp/?portal:componentId=UILanguageSelector&portal:action=Save&language=en>
- 45 Expert Team Discussion on Agricultural Drought Monitoring in Kyrgyzstan, meeting materials (Russian), <https://www.unescap.org/events/2021/expert-team-discussion-agricultural-drought-monitoring-kyrgyzstan>
- 46 Use of Remote Sensing Data for Drought Monitoring and Agrometeorology, I. Rublev, SRC “Planeta” (Russian), [https://www.unescap.org/sites/default/d8files/event-](https://www.unescap.org/sites/default/d8files/event-documents/1.%20Use%20of%20remote%20sensing%20data%20for%20drought%20monitoring%20and%20agrometeorology_by%20Mr.%20Igor%20Rublev_SRC%20Planeta%20ROSHYDROMET%20%28RUS%29.pdf)

documents/1.%20Use%20of%20remote%20sensing%20data%20for%20drought%20monitoring%20and%20agrometeorology_by%20Mr.%20Igor%20Rublev_SRC%20Planeta%20ROSHYDROMET%20%28RUS%29.pdf

- 47 Building Resilient Agricultural Practices by Integrating Geospatial Information for Agricultural Monitoring, Miao Zhang, AIR CAS, https://www.unescap.org/sites/default/d8files/event-documents/5.%20Building%20resilient%20agricultural%20practices%20by%20integrating%20geospatial%20information%20for%20agricultural%20monitoring_by%20Mr.%20Miao%20Zhang_AIRCAS_China%20%28ENG%29_0.pdf
- 48 Global Information and Early Warning System, FAO (GIEWS), <http://www.fao.org/giews/earthobservation/country/index.jsp?code=KGZ&lang=en>
- 49 National Information and Early Warning System, the Case of Timor-Leste, https://www.fao.org/giews/countrybrief/country/TLS/pdf_archive/TLS_Archive.pdf
- 50 Hand-in-Hand Geospatial Platform: About, FAO, <http://www.fao.org/hih-geospatial-platform/en/about/index>
- 51 Flood and Drought Portal, <https://www.flooddroughtmonitor.com/home?ugredirect=true&ug=unccd>
- 52 Team Building Meeting on Effective Use of Space Applications for Drought monitoring in Central Asia, <https://www.unescap.org/events/team-building-meeting-effective-use-space-applications-drought-monitoring-central-asia>
- 53 The First Expert Group Meeting on Development of Decision-making Tools for Geo-drought Monitoring and Early Warning in Central Asia, <https://www.unescap.org/events/1st-expert-group-meeting-development-decision-making-tools-geo-drought-monitoring-and-early>
- 54 The Regional Hydrologic Extremes Assessment System: A software framework for hydrologic modeling and data assimilation, <https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0176506>
- 55 Assessing vegetation response to drought in the northern Great Plains using vegetation and drought indices, <https://www.sciencedirect.com/science/article/abs/pii/S0034425703001743>
- 56 Water Information System Geoinformation Portal of the Kyrgyz Republic, <https://gis.water.gov.kg/portal/home/>
- 57 National Drought Management Policy Guidelines: A Template for Action, WMO, 2014, <https://public.wmo.int/en/resources/library/national-drought-management-policy-guidelines-template-action>
- 58 Drought Policies and Plans, WMO Integrated Drought Management Programme, <https://www.droughtmanagement.info/drought-policies-and-plans/>
- 59 Model National Drought Plan, UNCCD, 2014, <https://www.unccd.int/resources/publications/model-national-drought-plan>
- 60 State of the Space Industry in Central Asia: Policy Brief, Achievements, Challenges and Perspectives, ESCAP, 2020, <https://www.unescap.org/sites/default/d8files/knowledge-products/State%20of%20the%20Space%20Industry%20in%20Central%20Asia%20policy%20brief%2C%20achievements%2C%20challenges%20and%20perspectives.pdf>