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R.K. Chettykbayev[1], N.F. Denissova[2]
D. Serikbayev East Kazakhstan Technical University, Ust-Kamenogorsk, Kazakhstan
[1]*E-mail: RChettykbayev@edu.ektu.kz**
[2]*E-mail: NDenisova@edu.ektu.kz*

INFORMATION-ANALYTICAL SYSTEM FOR FORECASTING THE FLOODING OF TERRITORIES DURING SEASONAL FLOOD

МАУСЫМДЫҚ СУ ТАСҚЫНЫ КЕЗІНДЕ АУМАҚТАРДЫ СУ БАСУЫН БОЛЖАУДЫҢ АҚПАРАТТЫҚ-ТАЛДАУ ЖҮЙЕСІ

ИНФОРМАЦИОННО-АНАЛИТИЧЕСКАЯ СИСТЕМА ПРОГНОЗИРОВАНИЯ ЗАТОПЛЕНИЯ ТЕРРИТОРИЙ ПРИ СЕЗОННЫХ ПАВОДКАХ

Abstract. *The article considers the main approaches to the design of an information-analytical system for forecasting the flooding of territories during seasonal floods. Flood monitoring technologies and methods for forecasting flooding of territories are described. A description of the possibility of assessing the potential development of the dynamics of flooded areas during flood activity of waters and floods based on the analysis of long-term monitoring data is also given. The basics of mathematical modeling, forecasting and assessment of the situation during floods are shown. The obtained results are shown.*
Keywords: *information and analytical system, modeling, flooding, databases, geoinformation systems, hydrological information, space images, digital map.*

Аңдатпа. *Мақалада маусымдық су тасқыны кезінде аумақтардың су басуын болжаудың ақпараттық-аналитикалық жүйесін жобалаудың негізгі тәсілдері қарастырылған. Су тасқынын бақылау технологиялары, аумақтардың су басуын болжау әдістемесі сипатталған. Сондай-ақ мониторингтің көпжылдық деректерін талдау негізінде су тасқыны мен су тасқыны кезінде су басу аумақтарының әлеуетті дамуын бағалау мүмкіндігінің сипаттамасы келтіріледі. Математикалық модельдеу негіздері, су тасқыны жағдайын болжау және бағалау көрсетілген. Алынған нәтижелер көрсетілді.*
Түйін сөздер: *ақпараттық-аналитикалық жүйе, модельдеу, су басу, мәліметтер базасы, геоақпараттық жүйелер, гидрологиялық ақпарат, ғарыштық суреттер, сандық карта.*

Аннотация. *В статье рассмотрены основные подходы к проектированию информационно-аналитической системы прогнозирования затопления территорий при сезонных паводках. Описаны технологии мониторинга наводнений, методика прогнозирования затопления территорий. Также приводится описание возможности оценки потенциального развития динамики территорий затопления при паводковой активности вод и наводнений на основе анализа многолетних данных мониторинга. Показаны основы математического моделирования, прогнозирование и оценка обстановки при наводнениях. Продемонстрированы полученные результаты.*
Ключевые слова: *информационно-аналитическая система, моделирование, затопление, базы данных, геоинформационные системы, гидрологическая информация, космические снимки, цифровая карта.*

Introduction. Floods to a greater or lesser extent are periodically observed on most rivers of the East Kazakhstan region. In terms of repeatability, area of distribution and total average annual material damage throughout the country, flooding ranks first in a number of natural disasters. And in the East Kazakhstan region, where more than 40% of all water reserves of the Republic of Kazakhstan are concentrated, this natural disaster is one of the most destructive.

In East Kazakhstan, the area of flood-prone territories is about 200 thousand square km^2 and about 20 thousand km2 of such territories are flooded annually. According to the statistics of the Department of Emergency Situations in the East Kazakhstan region, 108 potentially flood-prone settlements were identified in the spring of 2022, where 7682 residential buildings are located, in which 23576 people live [1]. At this time, floods, as a natural disaster, cannot be completely prevented, and therefore the information and analytical system being created will help to reduce damage from seasonal floods.

Literature Review. The works of many Kazakhstani and foreign scientists and specialists are devoted to the study and solution of problems related to flood modeling: A.G. Terekhov, I.T. Pack, S.A. Dolgikh, L.F. Spivak, O.P. Arkhipkin, V.S. Pankratov, L.V. Shagarov, G.N. Sagatdinov, V.H. Bagmanov, S.E. Bednaruk, V.I. Vasiliev, B.I. Gartsman, V.A. Akimov, V.E. Gvozdev, L.A. Grinevich, V.I. Danilov-Danilyan, V.A. Connelly, V.G. Krymsky, L.K. Levit-Gurevich, V.G. Pryazhinskaya, A.H. Sultanov, R.Z. Khamitov, M.A. Shakhramanyan, I.U. Yamalov, D.M. Yaroshevsky, S. Lind, S. Haggett, D. Egenhofer and others.

Materials and methods of research. According to V.A. Akimov, floods can be divided into four groups according to the size and the total damage caused [2]

Group 1 – low (small) floods. They are observed mainly on flat rivers and have a repeatability of about once every 5-10 years. Flooding with less than 10% of agricultural land located in low places. These floods cause minor material damage and almost do not disrupt the pace of life of the population.

Group 2 – high floods. They are accompanied by significant flooding, cover relatively large areas of river valleys and sometimes significantly disrupt the economic and household way of life of the population.

Group 3 – outstanding floods. Such floods cover entire river basins. They paralyze economic activity and sharply disrupt the way of life of the population, cause great material and moral damage. Outstanding floods recur approximately once every 50-100 years. At the same time, 50-70% of agricultural land is flooded – the main hay-pasture lands and half of the arable land of the floodplain. Flooding of settlements begins.

Group 4 – catastrophic floods. They cause flooding of vast territories within one or more river systems. Such floods lead to huge material losses and loss of life and occur no more than once every 100-200 years or even less often. More than 70% of agricultural lands, settlements, industrial enterprises and engineering communications are flooded.

Over the next 30 years of observations, floods of groups 1 and 2 prevail annually in the East Kazakhstan region, but in 2018 a natural disaster caused serious material damage. Due to the maximum runoff from the spring snowmelt, intense rains, due to a sharp warming (see Figure 1), the great resistance that the water flow encountered in the river (ice congestion), the impact of the elements was unexpected for the response services and especially for residents of areas that were prone to flooding.

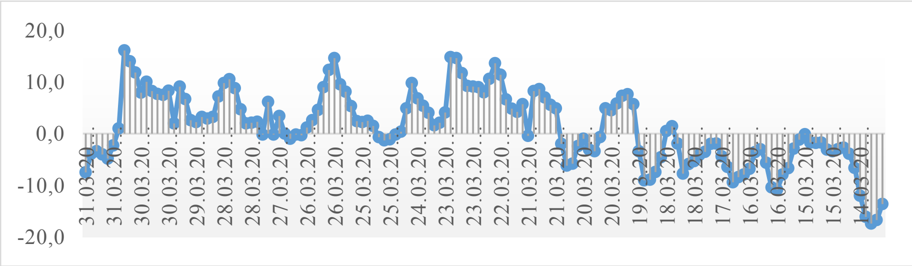

Figure 1. Detailed graph of daily temperature growth in March 2018

Taking into account this experience, the information and analytical system being developed should be a complex information system that consists of different modules (subsystems) that can accumulate, process, model, predict and visualize big data. The block diagram is shown in Figure 2.

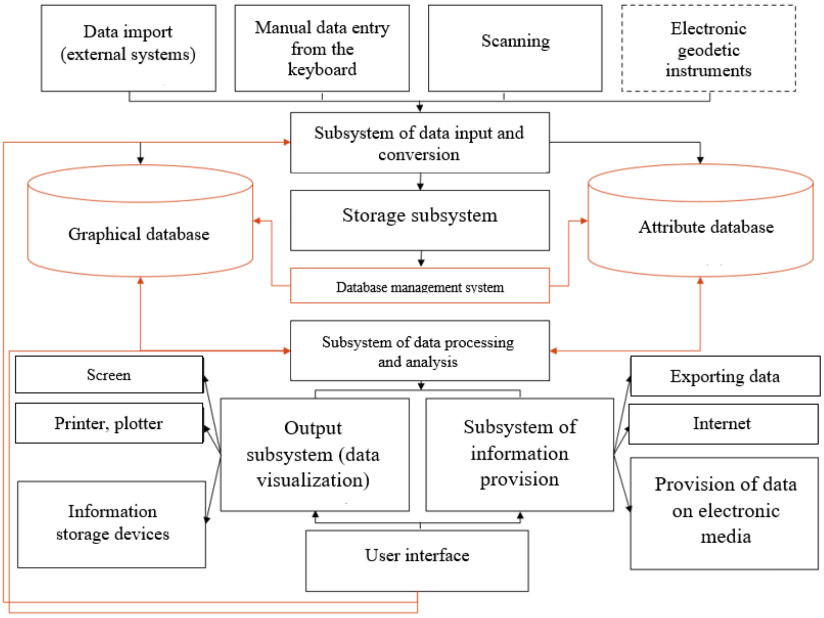

Figure 2. Structure of the information and analytical system

The graphical database is being updated by obtaining information about the current state of the flood zones and the dynamics of their development when using space monitoring systems. Such an operational space monitoring system has been developing in Kazakhstan since 2001, and since 2002 the practical use of this system in the interests of emergency authorities of various levels has begun [3].

To promptly monitor the situation during the passage of flood waters and floods, monitoring technology based on EOS-AM TERRA MODIS daytime images (resolution 250 m) is used. The main purpose of solving this problem is to map flood zones during the passage of flood waters and floods. Flood zones are defined as the difference between water surfaces under normal conditions and during a flood. In the thematic processing of satellite images, five classes of objects are distinguished: territories covered with snow and ice cover, territories free of snow, territories covered with water with the allocation of flood zones, territories covered with cloud cover.

To assess the potential threat of floods and floods in the system being developed, layers are used that contain information about settlements, road and railway networks, forests, especially important objects, etc. By superimposing flood zones on these layers, including in the dynamics of their development, it is possible to determine which objects are in real danger.

The subsystem of data processing and analysis is a complex subsystem for flow modeling, which has a modular structure. This subsystem includes the following modules – hydrodynamics module, forecast module, water quality module, impurity transfer and propagation module, snow cover module [4].

In the hydrodynamics module, when calculating the prediction of flood consequences, usually the cross-section of the riverbed is schematically represented either by a triangular cross-section (Figure 3) or by a trapezoidal cross-section (Figure 4).

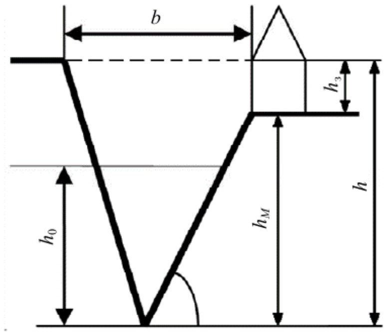

Figure 3. Design diagram of the triangular section of the river

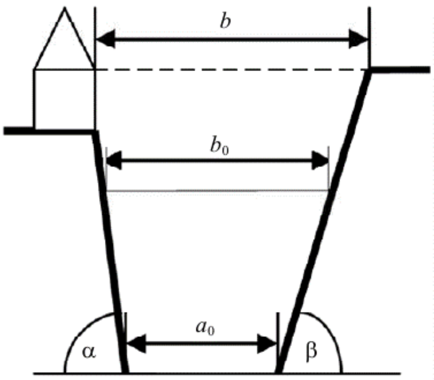

Figure 4. Design diagram of the trapezoidal section of the river

In this figure: a0 is the width of the river bottom; b0, b is the width of the river before and during the flood; h0, h is the depth of the river before and during the flood; hз is the depth of flooding; hм is the height of the place [5].

The flow rate of water in the river before the onset of a flood (flood) Q0, m3/ s, is equal to:

$$Q0 = V0 * S0 \quad (1)$$

where *V0* is the water velocity in the river before the flood, m/s; *S0* is the cross-sectional area of the riverbed before the flood, m2, equal to:

$$S0 = 0,5 * b0 * h0 \text{ – for triangular section;} \quad (2)$$

$$S0 = 0,5 * (a0 + b0) * h0 \text{ – for trapezoidal section} \quad (3)$$

Water consumption after precipitation (snowmelt) and the onset of high water (flood) *Qmax*, m^3/ s, is equal to

$$Qmax = Q0 + JF / 3,6 \quad (4)$$

where J is the intensity of precipitation (snowmelt), mm/h; F is the area of precipitation (snowmelt), km2.

The height of the rise of water in the river during the passage of the flood h, m, regardless of the shape of the profile of the riverbed is determined by the formula:

$$h = (2Qmaxh05/3 / b0V0)3/8 – h0 \quad (5)$$

The maximum speed of water flow during flood *Vmax*, m/s, is equal to

$$Vmax = Qmax / Smax \quad (6)$$

where *Smax* is the cross-sectional area of the flow during the passage of the flood, m2, determined by the formula:

$$Smax = (S0 + 0.5h(b0 – a0))*(1+h/h0) \quad (7)$$

In the case of a triangular profile of the riverbed, *a0* = 0 should be considered.

The damaging effect of the flood is determined by the depth of flooding *hз*, m:

$$hз = h – hм \quad (8)$$

and the maximum flow rate of flooding *Vз* m/s:

$$Vз = Vmaxf \quad (9)$$

The parameter of the object's distance from the riverbed *f* is determined according to Table 1.

The damaging effect of the flood wave can be estimated according to Table 2.

Table 1. Value of parameter f

hз / h	Section of the riverbed		
	Rectangular	Trapezoidal	Triangular
0,1	0,2	0,23	0,3
0,2	0,38	0,43	0,5
0,4	0,60	0,64	0,72
0,6	0,76	0,84	0,96
0,8	0,92	1,05	1,18
1,0	1,12	1,2	1,32

Table 2. The values of the parameters of the flooding wave, leading to the destruction of objects

Name of the object	Degree of destruction					
	Strong		Medium		Weak	
	V, м/s	*h,* м	*V*, м/s	*h,* м	*V*, м/s	*h,* m
Port buildings and structures						
Prefabricated wooden residential buildings	3,0	2,0	2,5	1,5	1,0	1,0
Wooden houses (1... 2 floors)	3,5	2,0	2,5	1,5	1,0	1,0
Brick low-rise buildings (1... 3 floors)	4,0	2,4	3,0	2,0	2,0	1,0
Industrial buildings with a light metal frame and frameless buildings	5,0	2,5	3,5	2,0	2,0	1,0
Brick houses of medium height (4 floors)	6,0	3,0	4,0	2,5	2,5	1,5

Name of the object	Degree of destruction					
	Strong		Medium		Weak	
	V, м/s	*h*, м	*V*, м/s	*h*, м	*V*, м/s	*h*, m
Industrial buildings with heavy metal or w/w frame (walls made of expanded clay panels)	7,5	4,0	6,0	3,0	3,0	1,5
Concrete and reinforced concrete buildings, buildings of antiseismic construction	12,0	4,0	9,0	3,0	4,0	1,5
Wooden bridges (traffic flow)	1,0	2,0	1,0	1,5	0,0	0,5
Reinforced concrete bridges	2,0	3,0	1,0	2,0	0,0	0,5
Metal bridges and overpasses with a span (30... 100 m)	2,0	3,0	1,0	2,0	0,0	0,5
Metal bridges and overpasses with a span of more than 100 m	2,0	2,5	1,0	2,0	0,0	0,5
Railway tracks	2,0	2,0	1,0	1,0	0,5	0,5
Roads with gravel (crushed stone) pavement	2,5	2,0	1,0	1,5	0,5	0,5
Highways with asphalt and concrete pavement	4,0	3,0	2,0	1,5	1,0	1,0

Flooding has a lasting effect, exacerbating the initial destructive effect of the flood wave (Table 3).

Table 3. The proportion of damaged objects (%) in flooded areas during major floods (*Vз* = 3-4 m/s) [6]

Object	Time of flooding, h					
	1	2	3	4	24	48
Flooding of basements	10	15	40	60	85	90
Traffic violation	15	30	60	75	95	100
Destruction of street pavements	-	-	3	6	30	5
Washing out of wooden houses	-	7	70	90	100	100
Destruction of brick buildings	-	-	10	40	50	60
Termination of power supply	75	90	90	100	100	100
Termination of telephone communication	75	85	100	100	100	100
Damage to gas and heat supply systems	-	-	7	10	30	70
Harvest failure	-	-	-	-	3	8

Results and discussion. These calculations can be performed by the subsystem core, which is based on the MIKE 11 software package. Using the Application Programming Interface (API) created for data access, the information is available for processing. The created API provides a convenient way to get data for third-party systems using GraphQL technology. The solution is designed using a database-independent architecture approach, which in turn makes it possible to easily scale the API using subsystems. Subsystems do not depend on each other's work, and this makes this solution adaptive and flexible. The platform was used in the development of this solution .NET 5 and the C# programming language (see Figure 5).

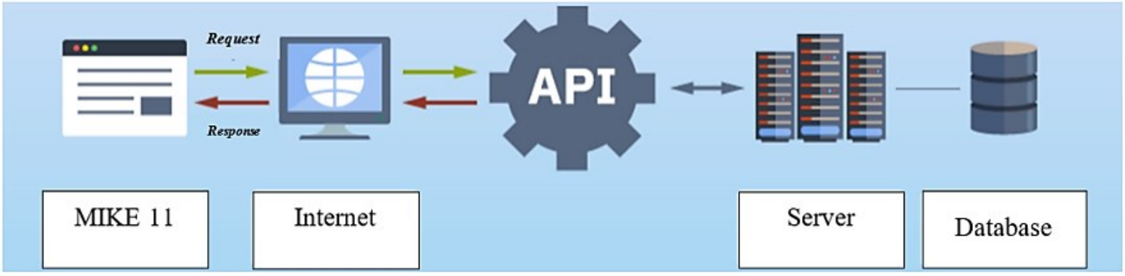

Figure 5. API operation diagram

To simulate the flooding of territories during seasonal floods, the following data are required: topographic, hydrological and hydrotechnical.

Topographic data provide a description of the geometry of the simulated river system, i.e. width, cross-sectional areas, volumes of flooded floodplains, etc., also called morphometric data. Based on these data, the topology of the model is developed:

– floodplain fragments are highlighted;
– bends, branches of the riverbed, old trees are installed;
– characteristic cross-sections along the riverbed where the design points should be located;
– the boundaries between the main channels and floodplains, etc.;
– the location of hydraulic structures is determined.

Hydrological data (sometimes called hydraulic data):

– water-measuring charts and hydrographs;
– records tidal characteristics;
– measurement of levels, costs and speeds;
– maximum flood marks;
– expense curves;
– boundaries and depths of flooding;
– other.

Hydrotechnical data – information about hydraulic structures, their purpose, about the marks of reservoirs, about the composition of hydraulic structures, about the type and characteristics of spillways, about the schedules of hydroelectric power plants [7].

Figure 6 shows a hydraulic model in the MIKE program, in this project the site of the confluence of the Kurchum and Maralikha rivers of the East Kazakhstan region is modeled.

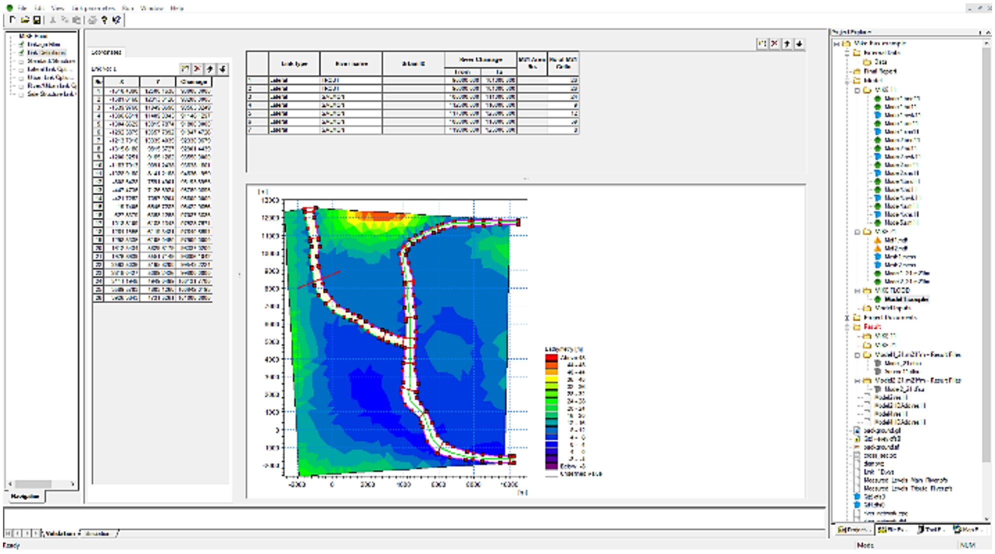

Figure 6. Model of the Kurchum river section

Basic topographic data of rivers were added from the graphical database for processing, profiles of the Kurchum River and the Maralikha River were also built. At the confluence of these rivers is the city of Maraldy (Maralikha) (Figure 7), which suffers from seasonal floods every year [8].

Figure 7, Geographical location of the city of Maralikha

When modeling the same conditions as in March 2018, the following result was obtained, which is shown in Figure 8. As can be seen, almost 50% of the city's territory is in the zone of potential flooding, which is fraught with serious consequences and material losses [9].

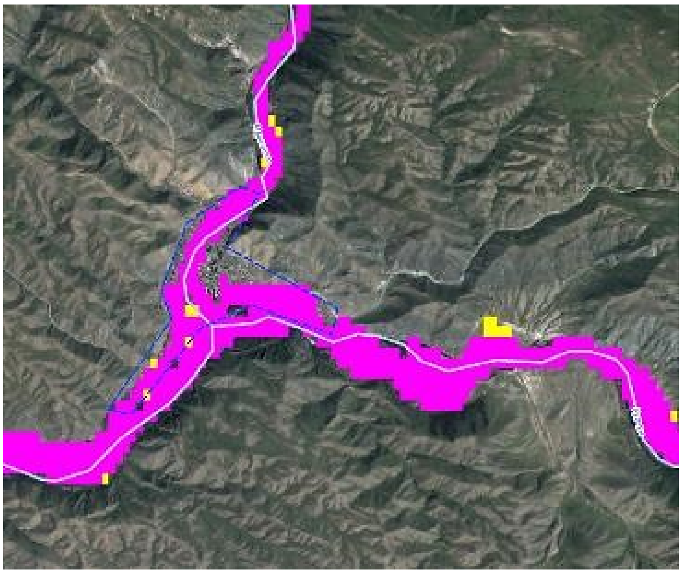

Figure 8. The area of potential flooding during a flood

Analyzing historical data and weather conditions, such a paradox was revealed that not always with a large amount of snow cover and warm air temperature, there is a critical increase in the water level in rivers. The reason for this is the presence of groundwater. If the soil is full of groundwater, then the water from the surface has nowhere to go, and it replenishes the rivers, and if the groundwater level is low, then in general the water from the surface goes into the soil and a very small amount of water gets into the rivers [10].

GRACE Follow-On (GRACE-FO) is a continuation of the GRACE project to track the movement of water on Earth across the planet. Monitoring changes in ice cover and glaciers, groundwater reserves, the amount of water in large lakes and rivers, as well as changes in sea level provides a unique insight into the Earth's climate and has far-reaching benefits for people (Figure 9).

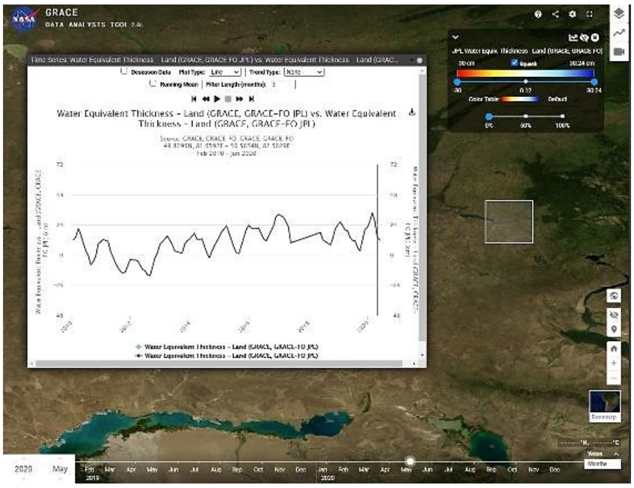

Figure 9. Analysis of underwater waters according to GRACE-FO data

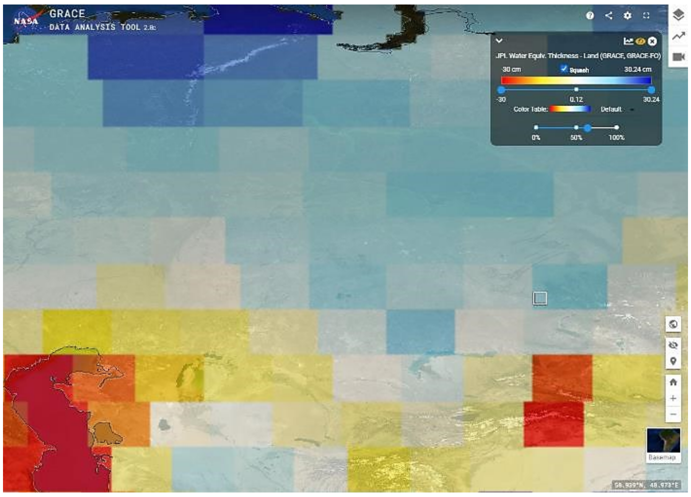

Figure 10. Groundwater level

As can be seen from Figure 10, the level (as of March 2022) of groundwater saturation in the territory of Ust-Kamenogorsk is at a fairly low level, which in the future it can be argued that water will leave the surface, which in turn, under other favorable conditions, can guarantee a calm flood situation [11].

Based on the initial data, a test version of the analytical system for predicting flooding zones was designed. The operation of this service is shown below (Figure 11).

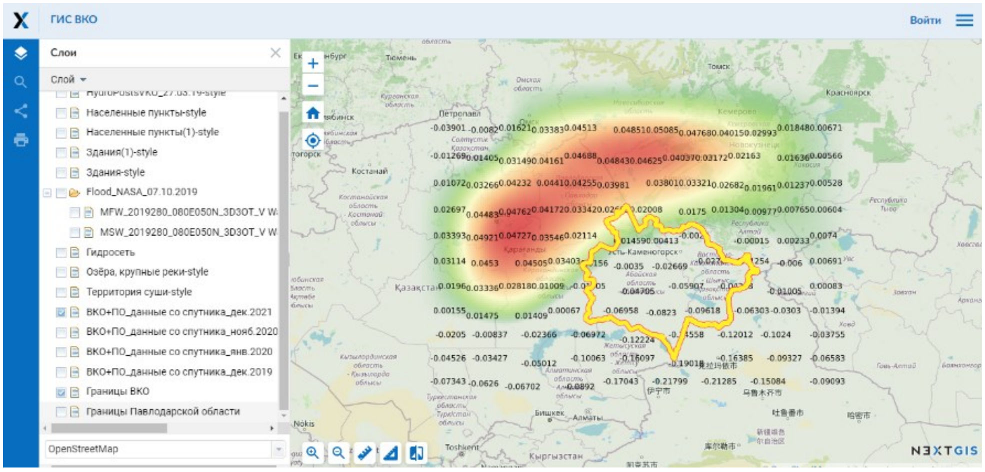

Figure 11. Test version of GIS flood monitoring system in East Kazakhstan region

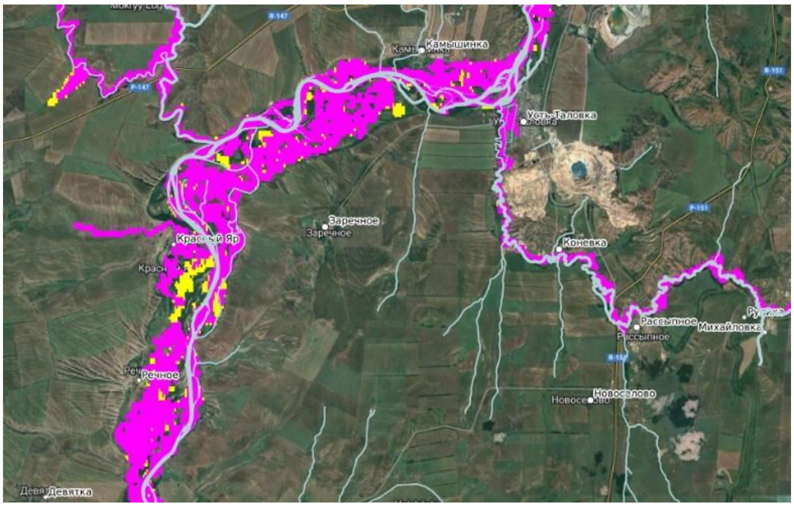

Figure 12. Potentially flood-prone area on the Uba river, spring 2022

The main advantage of GIS is a detailed digital, coordinate and cartographic binding of dangerous objects, infrastructure facilities, institutions, residential buildings and so on to the terrain, the ability to take into account the relief and weather conditions, which allows to improve the quality of emergency forecasting and increase the efficiency of managing forces and means of eliminating their consequences.

Conclusions. Work on the study continues, in particular, at the moment, the mathematical model of modeling and forecasting of flooding of territories during a flood is being refined.

In the process of studying the research topic, the following results were achieved:

1. A GIS test portal of East Kazakhstan region has been developed. The necessary layers have been created and the ability to import data layers from GIS systems, in particular QGIS.
2. Digital maps of the East Kazakhstan region have been created (a map of the territory of the East Kazakhstan Region, a vegetation map, a map of the hydraulic system, a map of large lakes, a map of settlements, a map of buildings of the cities of the East Kazakhstan Region, a map of specially protected natural territories of the East Kazakhstan Region).
3. The mathematical model of flood forecasting is being refined.
4. Work is underway to create digital models of river systems of East Kazakhstan region.
5. At the beginning of March 2019, an analysis of data on the flood situation in the region was carried out and a preliminary forecast was made about the high probability of flooding in the Beskaragai district. This forecast was confirmed on 28.03.2019, the groundwater was raised and the settlements of this area were flooded [12].
6. Taking into account the data for 2019 and 2020, a forecast was given for the spring of 2020 that there is no serious threat of flooding in the East Kazakhstan region, and this threat persists for the Pavlodar region of the Republic of Kazakhstan [13] and the city of Omsk of the Russian Federation [14].
7. Based on data from space satellites, the level of snow cover and the water table for December 2021, a forecast was given that there was no serious threat of flooding in the East Kazakhstan Region, only the area along the Uba River, the cities Shemonaiha, Ust-Talovka, Krasny Yar, Rechnoye in the middle of April caused concern (Figure 12). This forecast was also confirmed [15]

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