

Implementation of a New Paradigm for Hydrometeorological Support for Enterprise Leaders and the Public for Adaptation Purposes

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Abstract: - The aim of the article is to increase the efficiency of hydrometeorological support users for the population and enterprises leaders by implementing a new paradigm. The failure of enterprises to account for all climate and change-related risks, combined with the absence of systematized and formalized impact forecasts and recommendations for preventive actions, leads to increased losses. To establish a modern hydrometeorological support system, the paper proposes an implementation integrated approach of an end-to-end data processing scheme – spanning from observation to decision support. New tools are employed to raise awareness among the public and enterprise leaders regarding the consequences of natural hazards, alongside the personalized delivery of information. The article presents methods and services for an implementing new hydrometeorological support paradigm. These methods include the autonomous detection of natural hazards, using "Local threshold values" knowledge base of natural hazard indicators, forecasting the impact of natural hazards on the population and enterprises, and issuing recommendations for actions to mitigate or avert such impacts. Indicators hydrometeorological support system for the user are presented. A demonstration version of the decision support system has been developed (<http://portal.itu.esimo.ru>). For the first time, an integrated approach. "Impacts and recommendations" database has been created. The proposed methods enhance the capacity of enterprises and the public to adapt to natural hazards.

Key-Words: - hydrometeorological support, natural hazards, new paradigm, impact forecasting, recommendation issue, adaptation, DSS.

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1 Introduction

Climate change has increased the frequency and intensity of hazardous and extreme climate events, affecting the vulnerability of enterprises and individuals, as well as water and food security. The impacts of climate change, such as rising air temperatures, melting glaciers, rising sea level, and others, are global problems that must be addressed [11]. Failure to consider climate change risks and the lack of systematic and formalized impact forecasts and recommendations for preventive action at each enterprise leads to increased damage [1].

The UN's initiative "Early warning for all" [8, 10], aimed at protecting every person on Earth, includes the implementation of a new paradigm for the development of a hydrometeorological support system (HMS). The World Meteorological Organization (WMO) proposed a new paradigm in 2014 [9]. The main idea of this paradigm is to increase awareness of decision makers and the public about current hydrometeorological, social, economic and other conditions that help them make the right decisions. Awareness is achieved through

timely receipt of natural hazards forecasts, forecasts of the potential impact of natural hazards on the activities of the population and enterprises, and the issuance of recommendations for actions. The decision support system uses forecasts from the Hydrometcentr of Russia and territorial organizations of Roshydromet.

Research [2] has shown that the development of hydrometeorological support lags significantly behind the emergence of new IT capabilities. Modern information technologies have provided consumers with broad access to information and transformed decision-making processes. Enterprise leaders receive not only ready-made analytics but also information on hazardous phenomena detected in data streams. Enterprise leaders can work from anywhere, on any device, including a personal computer, laptop, or smartphone. New data processing methods based on generative AI have emerged. These include improved information search in databases and the use of generative chat-bots to collect and formalize potential recommendations. The creation of decision support systems (DSS) combines the delivery of data to

enterprise leaders and machines, as well as the formalization of impacts and recommendations in the form of knowledge bases to increase enterprise leader's awareness. Modern IT architectures utilize cloud technologies; containers and micro services; new data management methods, including data delivery through open APIs; augmented reality (AR) and digital twins.

Underestimating complexity is one from the problem in HMS development. The parameter that determines the complexity of a HMS system is not the volume of accumulated data, but the number of data sources. This problem is addressed by data integration using the Unified State System of Information on the Situation in the World Ocean (ESIMO) [7].

Roshydromet is currently undergoing a digital transformation of its HMS system [2]. Self-service data delivery is being implemented through email subscriptions and API services. Data can be remotely entered into a computer, making it available to users online. Data exchange opens up new opportunities for decision-making. For example, data is not only delivered to users but also used in various impact assessment models for enterprise operations.

Roshydromet early warning systems deliver storm warnings to government agencies and enterprise leaders in a variety of ways—via radio, television, websites, fax, and phone messages. These warnings are not formalized and structured enough to be included in the message catalog. The natural disaster name, date and time of the storm, the area of occurrence and manifestation, and the hazardous level indicators must cull from the messages.

To format official threat alerts, including warnings about natural hazards, Google proposed using the Common Alerting Protocol (CAP) [16] standard for delivering and publishing warnings about natural hazards. A CAP message can additionally include a list of possible consequences, the probability of occurrence of a natural hazard, and recommendations for making decisions. By defining a polygon or circle to denote a threat area, a computer can notify everyone within this area. Mobile phones, the Google online service, and the Red Cross or Mobile Rescuer (Russia) smartphone applications are used for this purpose [6]. The WMO has created an international registry of alerting authorities designated by national governments. The US National Oceanic and Atmospheric Administration publishes a CAP news feed for each "forecast zone." CAP feeds (<https://www.alert-hub.org/>) have become aggregators of news feeds for 2,000 major cities around the world. Each city can have a CAP storm warning feed for various government agencies, such as police, fire, health,

transportation, and others. The Hydrometcentr Russia collects storm warnings from Roshydromet's regional offices, creates a national feed in English and Russian for key regions of the Russian Federation, and transmits it to the WMO Global Warning Center.

To improve the efficiency of hydrometeorological monitoring, Roshydromet is developing AI methods and tools across all areas of its activities, from data collection to decision-making. AI tools can be used for:

- decoding of satellite images;
- converting digital forecasts into readable text;
- development of DSS "Natural Hazards";
- training neural networks and further forecasting of the natural hazards;
- creation of various tools to automate monitoring of the work of the HMS system.

The use of augmented reality technology in the case of natural hazards will allow seeing:

- a real picture of the weather conditions obtained using meteorological video cameras, meteorological radars, unmanned aerial vehicles, mini-satellites, etc.;
- additional effects in the form of animation and demonstration of the impacts of heavy rain, heavy snowfall, blizzards, floods and other natural hazards in the area where the facility is located.

Augmented reality can generate video prompts for those taking preventative actions and improve occupational safety by highlighting hazardous areas at sites, such as potential fallen trees, downed electrical wires, and so on. Recommendations are then provided to enterprise leader to prevent or mitigate the consequences of a hazardous situation. This tool facilitates coordination among those implementing actions plan, as they are more aware of the situation. During a hazardous situation, any assistance to affected people is essential.

It is important to ensure that the virtual world accurately reflects the physical world in real time. This can be achieved using a digital twin of processes related to the impact of natural hazards on the population and enterprises. Technologies for integrating and visualizing environmental conditions in real time already exist, for example, in ESIMO [7], <http://esimo.ru>.

To eliminate the identified barriers and difficulties, the following tasks must be addressed:

- ensure the resilience of enterprises to natural hazards by applying the DSS [3, 12, 14, 15, 17];
- implement a comprehensive data processing scheme;
- develop "Impacts and recommendations" database and the "Local thresholds" knowledge base;

- autonomously detect natural hazards based on the “Local threshold values” knowledge base;
- use an interactive map to raise public and enterprise leaders' awareness of hazardous areas, their hazardous levels, and the current hydrometeorological situation in the region, with observation data, forecasts, and climate generalizations presented on a one screen.

The aim of the article is to increase the efficiency of hydrometeorological support for the population and enterprises leaders by implementing a new paradigm.

2 Methods for implementing the new paradigm

The study utilized methods for creating "Local threshold values" knowledge base, generative chat-bots to collect information on the potential impacts of natural hazards on the population, enterprises, and formalizing the impact and recommendations for actions. New methods for implementing the HMS paradigm of the population and enterprise leaders include:

- integrated approaches to the implementation of the HMS system, including an end-to-end scheme for processing hydrometeorological data;
- autonomous detection of natural hazards;
- raising awareness among the population and enterprises leaders about the consequences of hazardous weather conditions for the population and enterprise through the creation of an information panel and interactive map "MeteoMonitor";
- autonomous delivery of information about natural hazards to the population and enterprise leaders.

2.1 Integrated approaches

A comprehensive approach to HMS development, based on the creation of an end-to-end data processing system, is supported by a unified model of integrated data from various fields and a unified structure for describing all types of hazardous conditions in the atmosphere, hydrosphere, lithosphere, and cryosphere. The digital twin includes hydrometeorological, social, technological, economic, and other indicators, reflecting the entire current situation within the enterprise's area of responsibility. Digital twin objects are maximally independent, allowing for the input of new data and its processing as it arrives. The digital twin's data model allows for its storage in separate information resources, and links between these resources enable

rapid retrieval and enrichment of the information provided to leaders.

2.2 Raising awareness of the population and enterprises leaders about natural hazards

Equally important is the ability of enterprise leaders to develop a preventive actions plan based on an analysis of the potential impacts of natural hazards and recommendations received from the DSS. To assess the consequences, it is necessary to determine potential damage, the significance of the consequences in terms of the scale of damage, probability of impacts.

The recommendations specify the facility's management level and priority, based on the timeframe and cost of actions. This allows for the optimization of these actions. Increasing public and enterprise management awareness of natural hazards and their hazardous levels is achieved through [2]:

- autonomous notification of hazardous situations identified based on the “Local threshold values” knowledge base;
- an information panel visualizing key hydrometeorological indicators indicating the level of hazardous;
- interactive map "MeteoMonitor", which displays information about the current hydrometeorological situation in the region, showing observed, forecast and climate data on one screen.

The HMS system should include additional data in the form of economic information to calculate damage and losses; demographic information to estimate the required number of buses to evacuate children and the elderly; and social data on the need to evacuate people with disabilities.

Enterprises, dependent from hydrometeorological conditions, must integrate climate and weather risks into their business processes to adapt to prevailing hydrometeorological conditions.

2.3 Decision support system

The use of hydrometeorological information and the consideration of the impact of current conditions on human activity require identifying not only hydrometeorological factors but also information on the macroeconomic indicators of enterprises, the condition of equipment, transport, roads, the demographic status of settlements, and more. This allows us to predict potential impacts on enterprise operations and demonstrate the potential consequences of their influence. The information obtained will help us take actions.

For example, the value of an Arctic ice forecast lies in its ability to enable early actions and minimize

damage. A favorable wind increases vessel speed, reducing travel time and fuel consumption, while an ultra-long-term Arctic ice forecast allows for the launch of northern cruises from Russia's eastern or western seaports, enabling the transportation of more cargo.

Enterprise leaders should consider the impact of climate change on their operations. The values of climate change indicators can be used to determine potential consequences and necessary actions. Roshydromet organizations should help enterprise leaders and local authorities assess climate risks, their associated consequences, and the impacts of climate change, potential damage, and calculate the cost of preventive actions. The decision support system contains [2]:

- means for autonomous detection of hazardous phenomena and extreme events based on local threshold values of hazard indicators in streams of operational and predictive data;
- short-term weather forecasts and climate change forecasts received from the Hydrometcentr of Russia;
- formalized information on the possible impacts of natural hazards on the activities of the population and enterprises, collected from existing publications and the existing experience accumulated by enterprise leaders;
- assessment of potential damage and calculation of the cost of preventive actions, which allows for the optimization of adaptation solutions;
- information needed by enterprise leaders to implement actions to adapt to climate change [4];
- analytical data on potential damage from climate risks for making more effective decisions on investment planning and increasing the resilience of enterprises and populations to climate change [5, 13].

The key elements of the DSS, taking into account the possible impact of natural hazards on the population and various sectors of the economy, are presented in Figure 1.

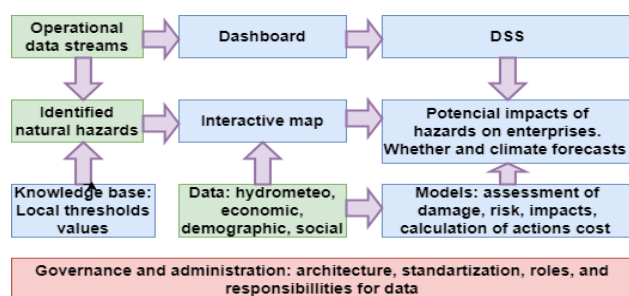


Fig. 1: Key elements of the DSS for taking into account the possible impact of extreme events and natural hazards on the population and various sectors of the economy

The new method for organizing HMS involves moving from self-service to a personalized service that provides leaders with only the information they need for a given hydrometeorological situation. Leaders also pre-define local thresholds for hazard indicators. Storm warnings are issued when the system is activated after a natural hazard is detected. In the future, it will be possible to upload data to corporate information systems. This will require not only digital data but also impact forecasts, damage assessments, decision-making recommendations, and cost estimates for actions.

It is essential to learn to adapt [4] and build resilience to climate change. All enterprise leaders receive storm warnings, but some refuse to take advantage of them due to a lack of understanding of the potential consequences and a lack of guidance for decision-making in specific situations. It is virtually impossible for the average person to collect and process data and determine all the possible impacts of climate change on people, the environment, and business-operations across various industries. Manual and even partially automated processes for identifying natural hazards do not allow for a full assessment of the consequences and mitigation of their impact. Without prompt delivery of information on natural hazards and a focus on those that have the greatest impact on business-operations, it is very difficult to minimize losses.

3 Results

The article presents the following new results:

- demo version of the DSS has been created;
- comprehensive data processing scheme has been implemented – from data integration to its delivery to applications;
- “Impact and recommendations” database was developed;
- interactive map has been developed that allows to see observed, forecast and climate parameters on one screen;
- subscription data delivery has been organized.

To enhance the resilience of enterprises exposed to hazardous natural phenomena, it is essential to provide them with information regarding these events, specifying the location, time, name of natural hazards, and hazardous level. Key hydrometeorological indicators should also be displayed so that leaders can better understand the hydrometeorological situation, refine the forecast of impacts on the population and enterprise operations, and provide recommendations for decision-making.

After determining the hazardous level, the dashboard displays key indicators of current hydrometeorological conditions, showing the hazardous level and a graph of parameter changes over the past seven days, as well as a forecast for the next five days. For a more detailed overview of the hydrometeorological situation in the region, use the interactive map "MeteoMonitor", which provides observation data, forecasts, and climate summaries for any point on the map in the form of thematic layers with contours or polygons of key meteorological parameters.

Next, a decision is made on the use of the DSS. Based on the hazardous level indicator values, a forecast of the potential impacts of natural hazards on the enterprise and its operations is generated. After analyzing the impacts and recommendations for completeness, decisions are optimized based on an economic model: "The ratio of the cost of actions to the estimated potential damage should be less than 0.3". If this ratio is greater than 0.3, the impacts are refined or the scope of actions is reduced. This approach is used for risk management in the areas of insurance, occupational safety, emergencies, ecology, IT security, and others. For example, in insurance, experts recommend using a ratio of 0.2 or less.

An example description of one of the activities related to the impact of liquid precipitation on electronic equipment is described below. One morning, the enterprise leader of a large enterprise that uses or produces large volumes of electronic equipment enters their office, opens the HMS system, and begins analyzing key hydrometeorological indicators on the dashboard, displaying both observed and forecasted values. The leader notices that the forecasted precipitation exceeds 20 mm. This poses a risk to moisture-sensitive electronic equipment delivered the previous evening. The leader launches the interactive map "MeteoMonitor" to check the hydrometeorological situation. The map shows a powerful cyclone approaching the enterprise's location. In this case, the DSS recommendations should be checked. After selecting the "Heavy Precipitation" situation with the "Orange" hazardous level, the DSS generates a forecast of the consequences (potential damage to electronic equipment due to moisture) and recommendations (temporarily cover the equipment with a waterproof

tarp or unload vehicles and move the equipment to production facilities) based on the forecast data for the "Electronic equipment" object. Screenshots of the operation of DSS services are shown in Figure 2.

The interactive map displays the locations of hydrometeorological stations. Each station's hazardous level is continuously assessed based on live data from the WMO Global Telecommunication Network. Hovering the cursor over a station displays a pop-up window with the station's coordinates, hazardous level, hazard indicator value, and links to the information panel and the DSS. By selecting the information panel, the user receives the status of the main hydrometeorological parameters, indicating the hazardous level for each parameter and graphs of their changes over the past week. A link to the DSS provides a forecast of the potential impacts of natural hazards on enterprises and activities, as well as recommendations for actions.

ESIMO, which integrates heterogeneous and distributed data, is used to store the large number of datasets required for DSS. The data is standardized, using common classifiers and codes. Subscription-based datasets are autonomously delivered to various applications after each data update. JSON and CSV data exchange formats are used. Data obtained from ESIMO is used to determine risk levels based on local thresholds set by the facility leader.

To organize such work the following were created:

- knowledge base "Local threshold values", the example presented in Table 1;

- database "Impacts and recommendations" includes more than 150 situations related to hazards.

The main indicators of the HMS system are:

- time required to notify about natural hazards after its detection is up to 30 minutes;

- 24/7 service availability (365x7x24) at 98%;

- data relevance – 93 %;

- completeness of provision of information on consequences and recommendations – 90%;

- time for preparing an information product is no more than 15 minutes from the moment the initial data is received;

- average user interface response time is no more than two seconds;

- average time to restore system functionality is no more than two hours.

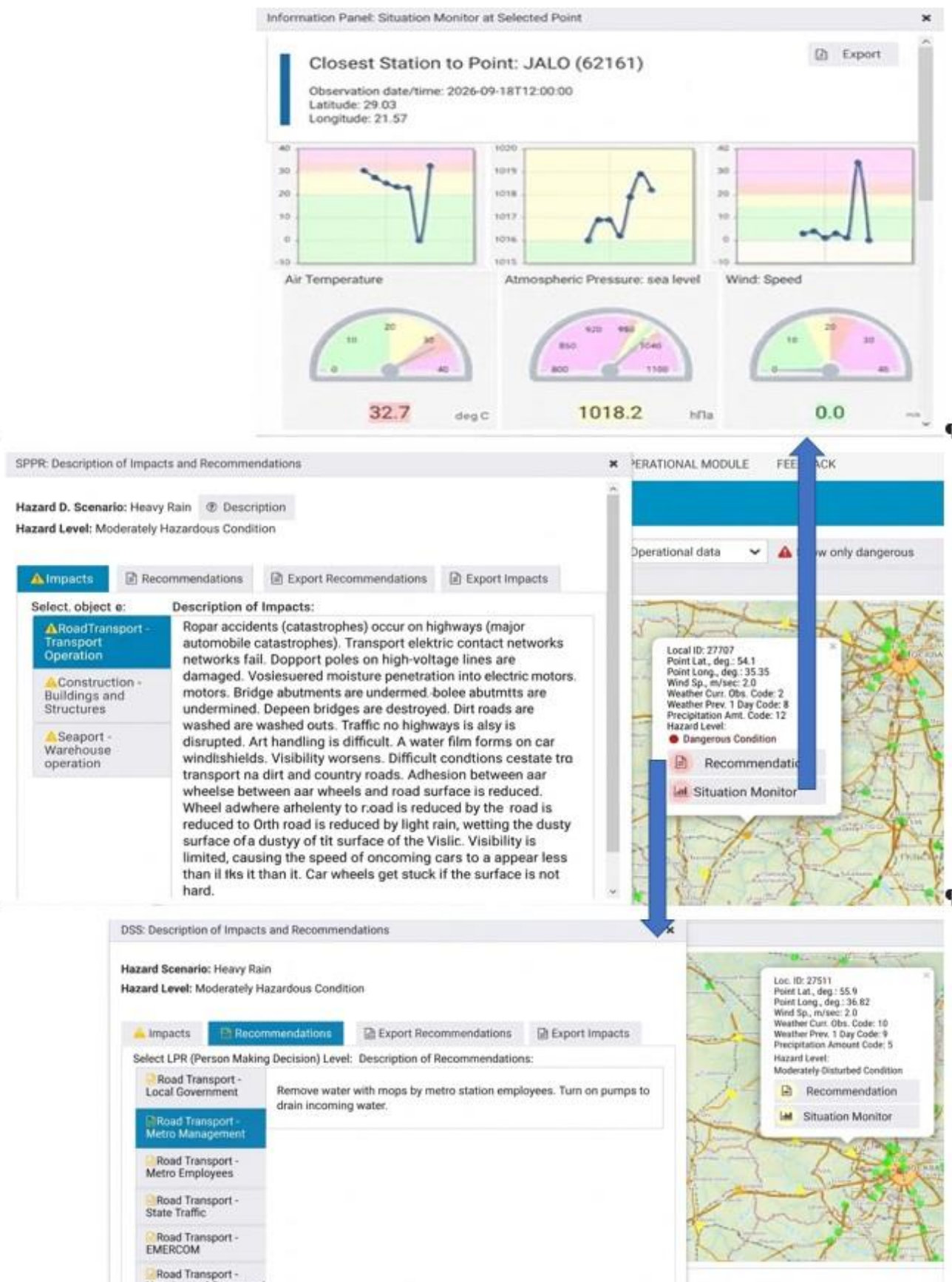


Fig. 2: Screenshots of the HMS system services

- a) Interactive map "MeteoMonitor" with hazardous levels for each observation point or grid node.
b) Information panel. c) DSS.

Table 1. Threshold values of the hazardous level based on water levels in Russian river

ID	Synop index	Object type	GeoDistrict	Latitude	Longitude	Parameter code	Hazardous level	From, cm	Up to, cm
1	76482	Settlement	Dyusyanovo	32, 09	32, 51	P0069_00	1	163	420
2	76482	Settlement	Dyusyanovo	32, 09	32, 51	P0069_00	2	421	560
3	76482	Settlement	Dyusyanovo	32, 09	32, 51	P0069_00	3	561	663
4	76482	Settlement	Dyusyanovo	32, 09	32, 51	P0069_00	4	>663	

Note. Hazardous levels: 1 - minimum level – no flooding; 2 - level above zero on the flooding graph, upon reaching which flooding begins (yellow); 3 - level above zero on the flooding graph, upon reaching which a catastrophic flood begins; 4 - catastrophic flood level – greater than the maximum possible flooding level.

Planned performance indicators for the DSS are based on over 10 years of continuous operation of ESIMO. This system includes resource and service monitoring tools. These indicators have been developed by using results of monitoring availability, relevance, and completeness.

The study's findings are highly significant for the field of hydrometeorological information application. Testing the hypothesis regarding the adoption of a new paradigm for hydrometeorological support for enterprise managers confirmed the need to accelerate efforts in this area. The hypothesis concerning the use of generative AI methods and tools to transform numerical forecasts into text requires further research, specifically to fine-tune Large Language Models using the collected data on impacts and recommendations.

4 Discussion

During implementation, the HMS system was expanded with other ideas, including:

- use of integrated ESIMO data [7] as a single source of heterogeneous and distributed hydrometeorological, social, economic and other categories of data necessary for making decisions;
- providing information on natural hazards response to enterprises leaders and the public, with links to access the interactive map “MeteoMonitor” and DSS, which allows the head of the enterprise to quickly become familiar with the current situation at the enterprise, and the public to reduce the vulnerability of their movable and immovable property [5];
- the use of models to refine impact assessments allows for a more accurate assessment of the influence of various factors on individual activities or elements of an enterprise's infrastructure;
- obtaining estimates of potential damage and calculating the cost of preventive actions allows us to clarify risks and optimize the composition of actions;

– optimization of decisions using economic models allows us to reduce the damage caused by natural hazards.

These studies confirm the need for DSS implementation and complement existing information on the use of knowledge bases and other AI tools. The barriers to the large-scale implementation of DSS at enterprises are not methodological, but rather organizational and legal in nature, related to the use of hydrometeorological information. For example, who is responsible for making or not making decisions? Furthermore, what regulations will govern the transfer of additional data into the system?

Key fields for future research:

- improving the completeness and quality of descriptions of situations related to the preparation of impact forecasts and recommendations;
- development of models for assessing the impact and consequences of natural hazards;
- creation of models for obtaining optimal solutions using the probability of forecasts of natural hazards and the probability of their impact on the activities of enterprises;
- description of various indicators of the natural hazards for which it is necessary to compile impact descriptions and a list of recommendations;
- development of AI methods and tools to collect information about possible consequences and generate recommendations for decision-making.

The created services can be integrated into existing automated business-processes dependent on hydrometeorological conditions. This will improve the efficiency of hydrometeorological monitoring and the use of hydrometeorological information.

The results obtained significantly advance previous research by the author and other scientists working in the field of DSS development. The new GMO paradigm is gaining wider adoption in the creation of DSSs for various management levels across many countries.

5 Conclusion

Because of the study, the following tasks were solved:

- demo version of the DSS has been developed, which allows for the prediction of possible impacts and the provision of recommendations for the implementation of actions;
- tools for identifying natural hazards have been created based on the “Local threshold values” knowledge base;
- “Impact and recommendations” database was developed;
- interactive map has been developed to raise awareness among the public and enterprise leaders.

For the first time, an integrated approach to developing an HMS of the population and enterprise leaders has been implemented. This integrated approach is supported by a unified model of integrated data from various subject areas and a unified structure for describing situations involving any type of natural hazards in the atmosphere, hydrosphere, lithosphere, and cryosphere. An equally important approach is the inclusion in the HMS system of tools for tracking composition of users, information on enterprises, and the number of information products provided to users.

The use of the services will significantly improve the efficiency of HMS at enterprises of various economic sectors. The proposed personalized HMS method has significant potential for cost-effectiveness, reduced damage, and improved decision-making.

The main obstacles to further research and large-scale implementation of DSS are unresolved legal issues related to the use of recommendation for decision making in enterprises management systems.

During the first phase of implementation, the impact assessment and recommendation service will be launched as a standalone product. During the second phase, other services will be integrated, including autonomous natural hazards detection and interactive map “MeteoMonitor”. Subsequently, as they become available, damage assessment models, actions cost calculations, and decision optimization will be integrated.

The scalability of the developed system assumes the expansion of the composition of the natural hazards, new objects and types of activities, for which descriptions of new situations will be prepared without changing the software.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

The authors wrote, reviewed and edited the content as needed and they have not utilised artificial intelligence (AI) tools. The authors take full responsibility for the content of the publication.

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