



## Integration of satellite monitoring for flood risks forecasting on the example of the Dniester's Flood Surveying Site

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✔ **Abstract.** The relevance of the study lies in the development, improvement and practical implementation of a geoinformation approach to flood risk forecasting within the Dniester flood control area by integrating satellite monitoring, spatial analysis and interpolation methods. The study was aimed at creating an effective system for identifying potentially dangerous areas, analysing floodwater pollution and assessing the impact of climate change on hydrometeorological processes in order to increase environmental safety and ensure sustainable risk management at the level of territorial communities. Mapping of Quaternary deposits, geomorphological levels and landscape structure was carried out, and a forecast map of flooding of territories with water rising by 1, 3, 5 and 10-12 meters was constructed. The final result was a 3D map, which is presented as an interpolated surface, created using the inverse weighted distance method. The optimal intervals of the value and size of the cells were selected: the obtained result allows not only to analyse the risks of flooding, but also to draw up reports with visualisation of data stored in the form of graphic images. For the first time, a map of the ecological risk of flooding of the Dniester flood control site by catastrophic floods was created for the Dniester Valley and adjacent territories of Podillia and Prykarpattia. The study showed that the process of flooding of the Dniester Valley occurs sequentially: first, the low floodplain is flooded (water rise +1 m), then the middle (+3 m), high (+5 m) floodplains and, finally, the first suprafloodplain terrace (+10-12 m). Based on the identified patterns, a system for predicting the rise of water during floods was developed. In addition to forecasting, this system performs the function of notifying the population about catastrophic manifestations of water elements

✔ **Keywords:** interpolation; modeling; remote sensing; geographic information systems; water resources management

### ✔ Introduction

The relevance of the research topic is explained by the increasing frequency of severe floods in the Dniester regions due to climate change, suboptimal water use and disruption of natural hydrological systems. Such floods pose a threat to human life and health, destroy valuable natural and social resources and negatively affect ecosystems. The Dniester Valley is one of the most urbanised and valuable areas of Ukrainian Podillia, characterised by a high level of flood

risk. Protecting the population from catastrophic floods and assessing the risks associated with them is a priority area of environmental and social research in this region.

Recent studies highlight a wide range of problems related to flood forecasting and environmental safety. According to researchers O. Adamenko *et al.* (2020), the role of geographic information systems and satellite monitoring in modeling flood risks is considered. In particular,

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the works highlight the importance of integrating remote sensing for operational monitoring of watersheds and assessing the impact of climate change on the hydrological regime of territories. Ecological security is defined as the state of the environment that ensures comfortable living conditions for the population, sustainable development and restoration of ecosystems disrupted by anthropogenic processes. Researchers O. Adamenko *et al.* (2022) substantiated the structure of ecological security, which includes computerised and geoinformation systems for predicting and minimising the consequences of flood situations. This study proposes to combine existing approaches into a single ecological geoinformation system that integrates remote sensing methods to increase the level of ecological security in the Dniester Valley.

The studied area, according to researchers P. Lysytsia & O. Mudrak (2022) and A. Dzyba & V. Kyriienko (2024), in geomorphological and morphostructural terms covers fragments of two first-order morphostructures: East Carpathian and Podilsko-Kodrynska. Within their boundaries, second-order morphostructures are distinguished: Outer Carpathian, Precarpathian and Podilsko. Finer zoning into third-order morphostructures, according to the origin, forms and age of the relief, is carried out according to various schemes. The aim of the study was to develop geoinformation models and methods for predicting catastrophic floods in the Carpathian region (Dniester basin) based on the integration of historical, instrumental and satellite data to increase the effectiveness of early warning and minimise risks.

## 📌 Materials and Methods

The study used historical and instrumentally confirmed data, which was justified by the identification of patterns of flood periodicity. To create a periodisation of catastrophic floods on rivers such as the Dniester, both natural extreme phenomena and their interaction with anthropogenic factors were analysed. In particular, the recurrence of warm (dry) and cold periods and the floods associated with them was considered. The study took into account the stage of development of the Dniester valley and long-term observations of the Dniester river regime at the hydro-post of the city of Halych, since these processes are key for predicting changes in the behavior of the river and developing flood risk management measures. The method of correlation of water flow in the Dniester river (city of Halych), conducted on the basis of long-term observations, was analysed.

To assess flood risks in Galician Transnistria, a geomorphological map of the Dniester flood control site was created. The map was developed by D. Zorin (2022) with the participation of students, under the scientific supervision and editorial support of Professor O. Adamenko *et al.* (2022). The work included field expedition mapping, hypsometric analysis of topographic maps at a scale of 1:10,000, and processing of satellite images using MapInfo software. The use of the MapInfo geoinformation environment ensured accurate processing and visual display of spatial data, which contributes to improving the environmental safety of the studied area.

Thanks to cooperation with the Institute of Telecommunications and Global Information Space of the National Academy of Sciences of Ukraine, the National Space Agency of Ukraine, the Space Information Reception Center in Dunayevtsy, the State Emergency Service of Ukraine, the Dniester Basin Water Resources Management Board, the Ministry of Environmental Protection and Natural Resources, as well as with the involvement of open sources, in particular sentinel-hub.com and media materials, a comprehensive analysis of numerous satellite and aerial photographs was carried out. This made it possible to study in detail the spatial features of the distribution and intensity of the catastrophic floods of 2008 and 2020 in the Western region of Ukraine (Kuzmenko *et al.*, 2019). Also, in order to assess the impact of this extreme flood on the territory of the Carpathian region, the flood limits caused by the western cyclone in July 2008 were simulated. After digitising the flood zone based on the 2020 satellite image, the resulting model was overlaid with the contour of a forecast map developed back in 2015.

To predict the ecological risk of flooding of territories by catastrophic floods, a map was created for the Dniester Valley and adjacent territories of Podillia and Prykarpattia for the first time (Adamenko *et al.*, 2022). This cartographic model, authored by Denis Zorin, became the basis for analysing and forecasting flood situations in the region. To predict the flooding of the territory, it was necessary to create a 3D model. To achieve the desired level of detail, optimal value intervals and cell sizes were selected, which, although increasing the processing time, allowed for more accurate interpolation results. Additionally, transparency, legend, map name, and value elements were configured. The settings were saved as templates for reuse without the need to perform all actions from scratch. After creating the 3D surface, contours were constructed using the 3D View utility. The contour intervals were aligned with the thematic map to ensure consistency in the displayed data. The result allowed not only to analyse the risks of flooding, but also to generate reports with visualisation of the data, which were stored in the form of graphic images.

To predict floods, three-dimensional models of territories were created, which allow assessing the levels of flooding and determining environmental risks. An important stage in this process was the formation of a Grid Image using MapInfo Pro software. Using GIS technologies such as MapInfo Pro, the researchers created interpolated surfaces, constructed contours, and generated flood risk maps. For this purpose, interpolation methods were used, in particular, the inverse distance weighted (IDW) method and the irregular triangle network (TIN). The IDW method provided high modeling accuracy, especially for large amounts of data. This method turned out to be more effective than TIN, in addition, it provides more accurate results and works stably (Stetsenko, 1999; Sosonna *et al.*, 2023). Based on the revealed regularity, a system for predicting water rise during floods (AVIPS-Dniester) was further developed.

## Results and Discussion

The analysis of historical materials, chronicles and documents for the period of the 8th-19th centuries shows that climate change often causes catastrophic natural phenomena, including floods, severe winters, early frosts, epidemics and other emergencies. These phenomena had a certain periodicity, which can be used to predict them in the future. The recurrence of warm and cold periods and the associated floods demonstrates cyclicity: droughts occur in the 20s,

60s and 70s of each century, and significant disasters can recur every 300 years. Although modern reports of extreme events are described as “unprecedented” or “unheard of,” historical records show that similar events have occurred in the past. Therefore, studying historical climate processes and their impact on natural disasters helps not only to understand the past, but also to predict future extreme events. This highlights the need to analyse long-term data to develop an effective forecasting and warning system (Table 1).

**Table 1.** Recurrence of catastrophic floods over the last millennium, according to chronicle and historical data

Year of occurrence of the previous flood	Year of occurrence of the next flood	Interval in years between floods	Year of occurrence of the previous flood	Year of occurrence of the next flood	Interval in years between floods	Year of occurrence of the previous flood	Year of occurrence of the next flood	Interval in years between floods
1	2	3	1	2	3	1	2	3
987	989	2	1681	1686	5	1814	1815	1
989	991	2	1686	1688	2	1815	1820	5
991	1012	21	1688	1689	1	1820	1822	2
1012	1148	36	1689	1700	11	1822	1832	10
1148	1161	13	1700	1702	2	1832	1834	2
1161	1162	1	1702	1703	1	1834	1835	1
1162	1173	11	1703	1705	2	1835	1836	1
1173	1221	48	1705	1706	1	1836	1837	1
1221	1230	9	1706	1707	1	1837	1838	1
1230	1236	6	1707	1708	1	1838	1839	1
1236	1251	15	1708	1709	1	1839	1840	1
1251	1269	18	1709	1716	7	1840	1841	1
1269	1285	16	1716	1717	1	1841	1842	1
1285	1290	5	1717	1718	1	1842	1843	1
1290	1291	1	1718	1719	1	1843	1844	1
1291	1314	23	1719	1721	2	1844	1845	1
1314	1322	8	1721	1723	2	1845	1846	1

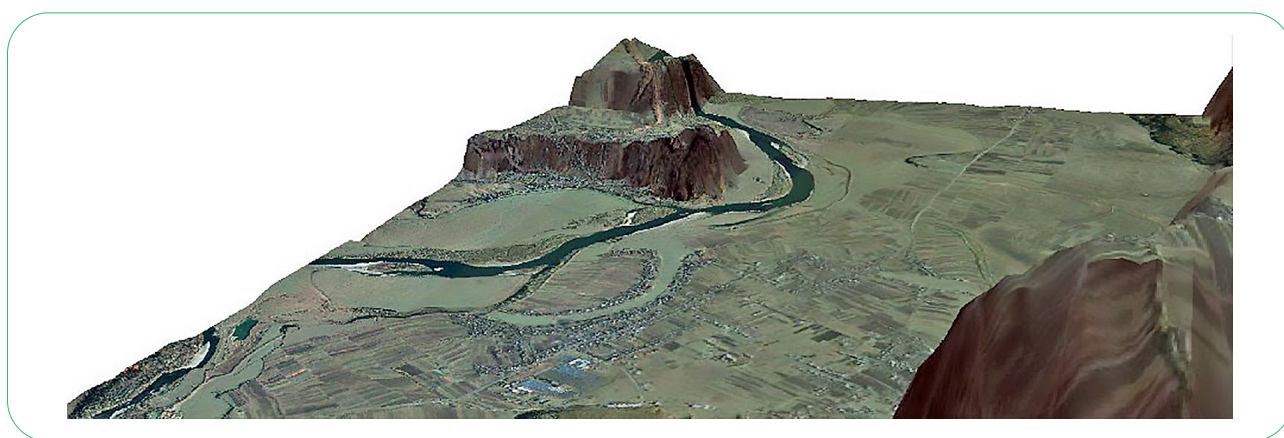
Source: developed by the authors

Analysis of previous studies and graphical data shows a certain pattern of recurrence of catastrophic floods. Annual spring floods are a common phenomenon with a one-year cycle. Usually, stronger spring floods occur with an interval of 3-4 years, which can be considered the first phase of periodic catastrophic phenomena. The most significant floods that leave significant consequences are repeated with a frequency of 15-20 years, forming the third phase. These cycles are interconnected: the first phase (3-4 years) is repeated twice within the second phase (5-6 years), while the second phase is included in the third (15-20, sometimes up to 33 years) and is repeated 3-4 times during this long cycle. This periodicity structure is

confirmed by long-term meteorological observations covering the instrumental period since 1881. Both regional and local floods are observed in the Carpathian region. Regional floods cover the entire northeastern macroslope of the Carpathians, while local floods occur only within individual river basins. According to G.I. Shvets, M.I. Kyrylyuk and other researchers (Ali *et al.*, 2020), in the 20th century, catastrophic regional floods on the northeastern macroslope of the Carpathians occurred in the warm season (June-August) in 1911, 1927, 1941, 1955, 1969, 1980, 1998, 2002 and 2008. In Transcarpathia, such phenomena were mainly recorded in the cold period (November-May) in 1926, 1947, 1957, 1970, 1998, 2002, 2008 and

2020. Local floods occur much more often - approximately every 2-3 years. Floods on the rivers of the Carpathian region are formed as a result of intense atmospheric precipitation, which is frequent in this region. However, catastrophic levels of water rise are reached only when the amount of precipitation exceeds 100 mm per day. Instrumental observations of the water resources of this region began in the middle of the 19th century, and systematic data have been available since 1895. Despite the complexity of predicting these phenomena, their increase in frequency is associated with global climate change. The author constructed graphs of global climate fluctuations, and researchers O. Adamenko *et al.* (2022) predicted a flood in 2020 back in 2014. The Dniester River Valley demonstrates a complex geomorphological structure and

development dynamics. The river within the valley it created meanders from one side of the valley to the opposite, going through several stages of its development. First stage: during tectonic uplift of the territory, the riverbed cuts into the root bank, forming a straight path. Second stage: the river goes into lateral erosion, forming meanders, the radius of which can be 18 times the width of the riverbed. This stage is considered the period of maturity of the river. Third stage: during new tectonic activation, the valley area rises again. The river cuts into the root bed, and the old meanders turn into incised ones. The riverbed straightens when the isthmuses between the meanders are cut by the current. The Dniester Valley is in the third stage of its development, which affects the formation of its relief and hydrological regime (Fig. 1) (Davybida *et al.*, 2021).



**Figure 1.** 3D model of a satellite image of the Mariyampil tablet

**Note:** the distance between the contour lines of elevations above sea level is 1 m

**Source:** developed by the authors

The right tributaries of the Dniester within the Dniester flood control area – Limnytsia and Lukva – are characterised by uneven flow throughout the year, which leads to a large number of floods. They are caused by both melting snow in the mountains and heavy rainfall. The Hnyla Lypa River and its tributaries have only one high level in spring, caused by melting snow cover. According to long-term observations of the Dniester River regime at the Halych hydro-station, the most characteristic feature of the Dniester River water regime is frequent floods throughout the year. The height of floods near Halych varies within 0.5-5 m. The rivers of the Dniester flood control area, which are right tributaries of the Dniester River, are mixed: in spring, the main source of runoff is snowmelt, from May to November – rain, after which groundwater dominates. In particular, the flow rate of the Lukva River is 141.6 million m<sup>3</sup>, the flow in low-water years with a provision of 75% and 95%, respectively, is 98.7 and 59.3 million m<sup>3</sup>. The river's own flow is not regulated. The left-bank tributary of the Hnyla Lypa River is characterised by spring floods. Summer precipitation here does not have a noticeable impact on the river regime, but there are individual significant floods (Mamo *et al.*, 2019; Bilas *et al.*, 2022). An analysis of water

flows in the Dniester River – the city of Halych, conducted on the basis of many years of observations, indicates their stability within 100-200 m<sup>3</sup>/s. The maximum water flow was recorded in 1943 in the city of Halych – 770 m<sup>3</sup>/s.

An assessment of the current state of surface waters of the upper Dniester indicates a significant anthropogenic impact on its water regime. The catchment area is home to a large number of settlements, industrial and agricultural facilities. Intensive wastewater discharge and pollution cause deterioration of water quality, siltation and bank collapse. In many places, the land is plowed up to the very banks, which intensifies erosion processes. Domestic wastewater from settlements, farms and social facilities adds to the overall pollution, creating urgent problems for ensuring the ecological safety of the Dniester River basin. To analyse flood risks in Galician Transnistria, a geomorphological map of the Dniester flood control site was created (Fig. 2). This map plays an important role in forming a system for predicting the sequential flooding of the Dniester Valley during catastrophic floods. It serves as a basis for creating ecological flood risk maps and contains information on the morphology, genesis (origin) and age of macroelements of the relief. These operations can be implemented not only in MapInfo, but also in

other GIS software environments, which provides flexibility and versatility of the approach. At this landfill, modeling, forecasting and development of practical measures to prevent catastrophic consequences of water events are carried

out. The results obtained are used not only in the Dniester Valley, but also in other water basins. One of the key research tools was 3D modeling, which provides the possibility of detailed analysis of orographic and hydrological factors.

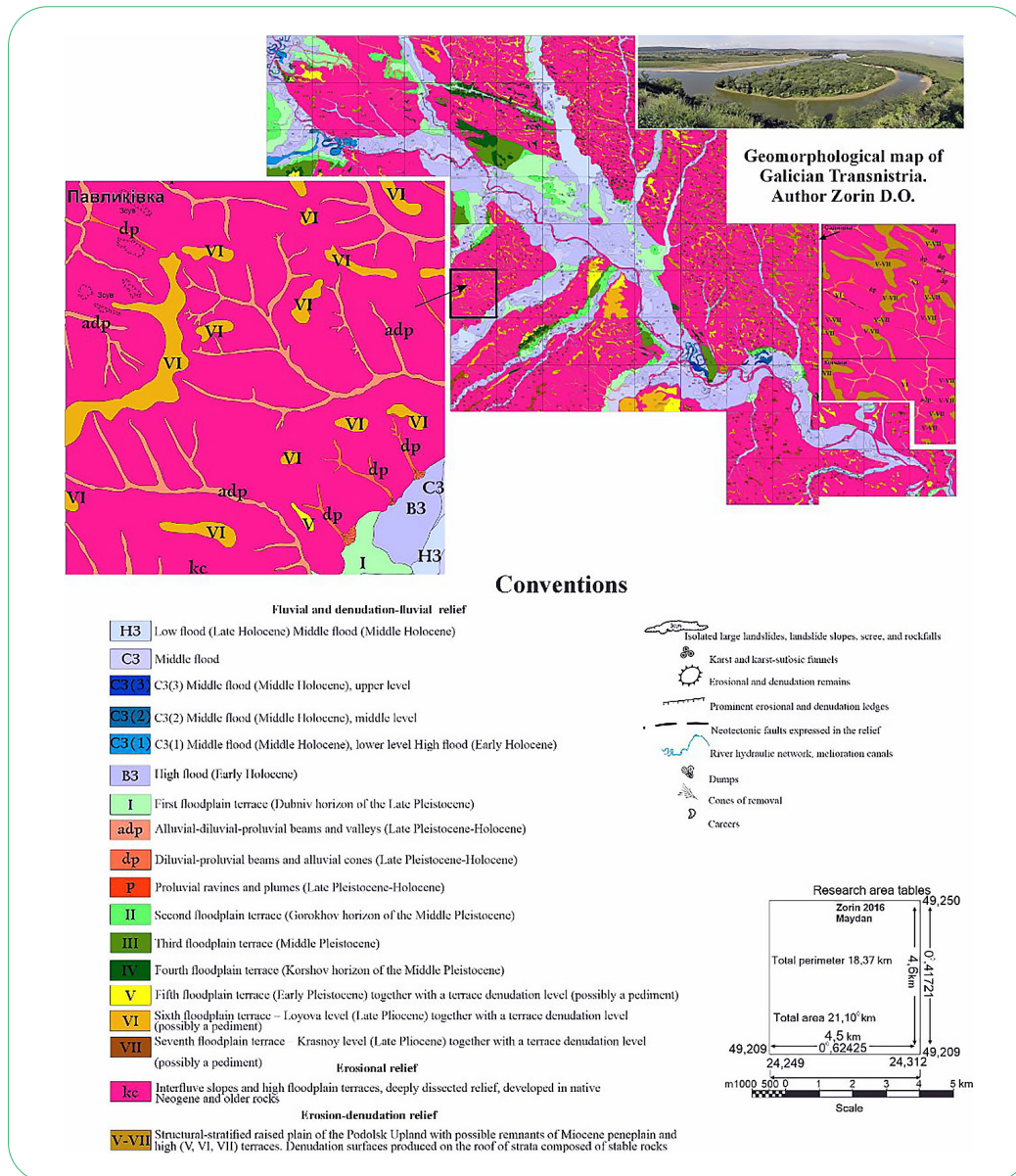


Figure 2. Geomorphological map of Galician Transnistria

Source: D. Zorin (2022)

An important element of the modern flood protection system is risk management, i.e. early prediction of dangerous processes, identification of the main causes, natural and anthropogenic factors of the development of floods and floods, development of measures to reduce them to a favorable level. The main tool of the flood risk management system is a management plan based on maps of the possible development of these dangerous processes. Such maps and plans should be developed for each catchment basin of the watercourse of the appropriate order, taking into account the principles of the basin approach and the

specifics of the hydrological and geomorphological conditions of a particular territory (Kozłowski *et al.*, 2023). The spatial features of the distribution and intensity of the catastrophic floods of 2008 and 2020 in the Western region of Ukraine were studied (Fig. 3-4). Figure 4 presents the vectorised flood boundaries. The study showed that the flooding process of the Dniester valley does not occur chaotically, but sequentially: first, the low floodplain is flooded (water rise +1 m), then the middle (+3 m), high (+5 m) floodplains and, finally, the first supraffloodplain terrace (+10-12 m).

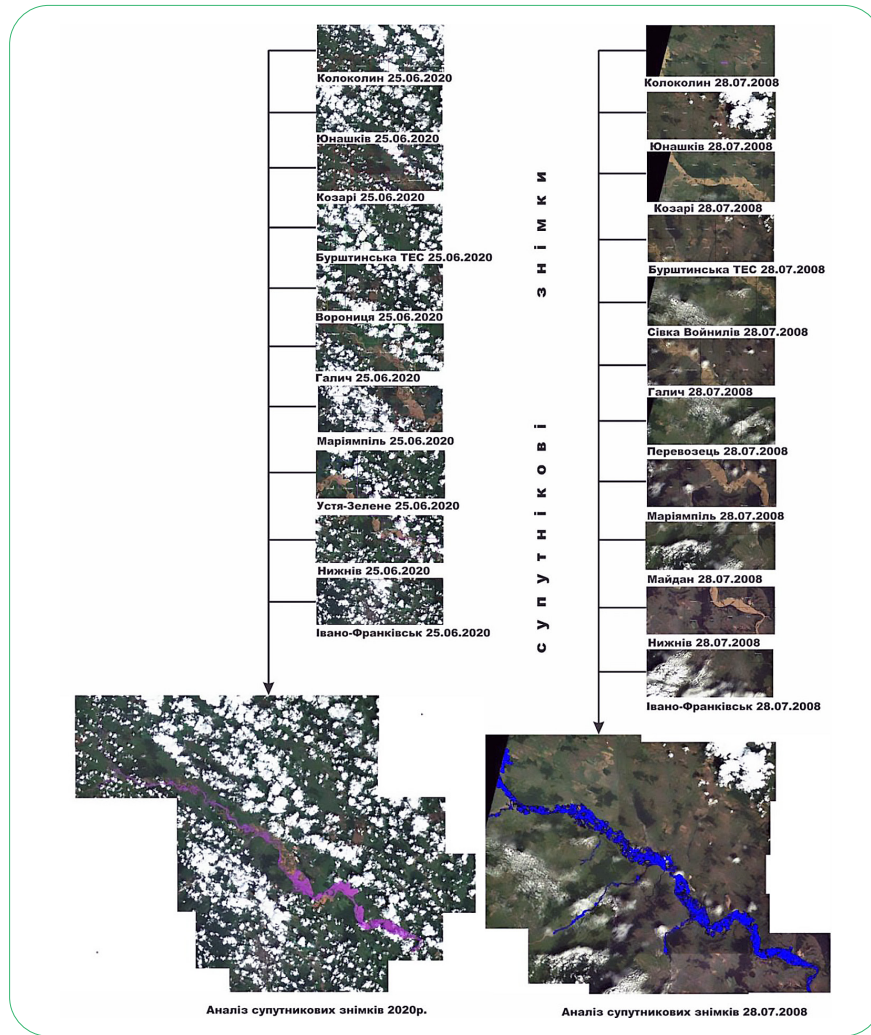


Figure 3. Comparison of satellite images from 2008 and 2020

Source: created by the authors

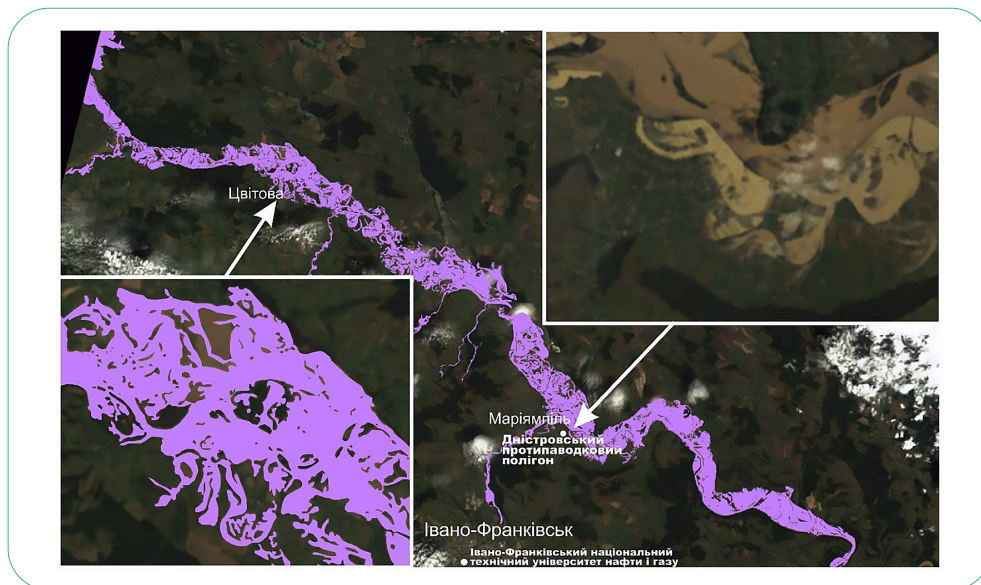


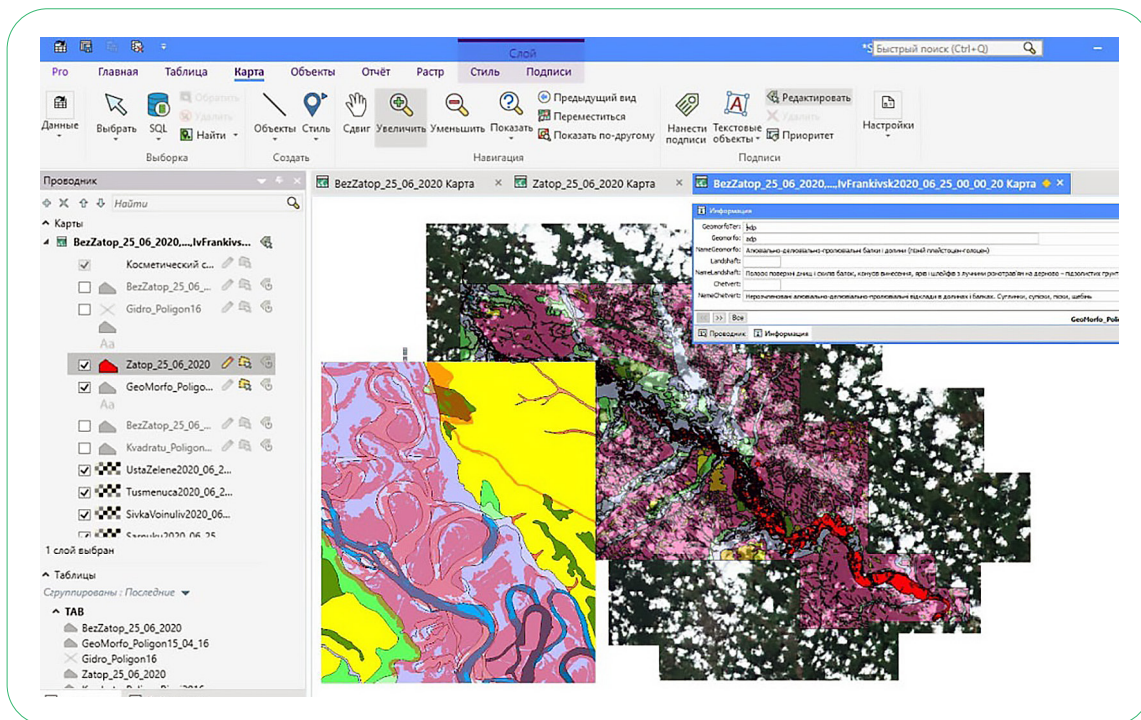
Figure 4. Vectorised flood boundaries of 2008

Note: satellite image sentinel-hub.com 07/28/2008

Source: developed by the authors

The analysis showed that the boundaries of the predicted and actual flood zones coincided, which confirms the high accuracy of the previous forecasts. These consequences could have been predicted in advance, which would have

allowed measures to be taken to warn the population and minimise damage (Fig. 5). The areas of actual flooding are marked in red, which reflected the scale of the real consequences of the flood.



**Figure 5.** Analysis of satellite images of 06/25/2020 and maps of environmental risk of flooding of territories of 06/15/2015

Source: developed by the authors

Scientists of the Ivano-Frankivsk National Technical University of Oil and Gas (IFNTUNG) are making significant efforts in the study of floods. In particular, on August 4, 2008, the researchers submitted their proposals to the Ivano-Frankivsk Regional State Administration on preventing the consequences of catastrophic floods. At the initiative of the rector of the university, Professor E.I. Kryzhanivskiy, in cooperation with the regional council, state administration and other organisations, the Dniester Scientific, Educational, Production Engineering and Environmental Flood Prevention Range was created with a center in the village of Mariyampil, Halytskyi district, Ivano-Frankivsk region (Fig. 5) (Myrontsov, 2020; Trigub & Domuschi, 2023). This work is long-term and follows the following character: it began back in 2008 after the catastrophic flood, which prompted the creation of the Dniester flood control site. Since then, starting in 2010, research has been conducted systematically. Within the framework of this project, data is accumulated, databases are formed and geoinformation models are created that allow improving the system of flood forecasting and analysis. The work continues as of 2025, providing a valuable basis for flood risk management (Table 1). A 3D model was created to predict the flooding of the territory, which provided a more accurate analysis and visualisation of risks (Fig. 6-7).

The analysis of the satellite image from June 25, 2020 and the ecological risk map of the territories created on June 15, 2015, showed a high correspondence between the predicted flood limits and the actual data. The contours of the flood zones, modeled five years before the event, almost completely coincided with the real limits recorded on the satellite image. This indicates the high accuracy of the applied forecasting methodology and the effectiveness of the integration of geographic information systems and satellite monitoring for flood risk assessment. The obtained result confirms the feasibility of implementing such approaches in the ecological safety and emergency management systems. The symbols of the flood risk zones are shown in Figure 8.

The Automated Information and Measurement Anti-Flood System – Dniester (AVIPS-Dniester) consists of three models – cartographic, mathematical and geoinformation, which must be included sequentially during the development of the flood as separate blocks: 1) automated hydrological post; 2) weather station; 3) telemetric system for transmitting information from hydroposts and weather stations to the crisis center of the State Emergency Service and from it to settlements; 4) marking on the ground in settlements of segments that will be flooded when the water level on the main river rises by 1, 2, 3... 10, 11, 12 m. The development of such models is a key stage in the creation of

long-term regional programs and operational measures to prevent and eliminate emergencies in the Dniester Valley and the Carpathian-Podilskyi region. In addition to forecasting, this system performs the function of notifying the population about catastrophic manifestations of water elements (Fig. 8). At this landfill, modeling, forecasting and

development of practical measures to prevent catastrophic consequences of water elements are carried out. The results obtained are used not only in the Dniester valley, but also in other water basins. One of the key research tools was 3D modeling, which provides the possibility of detailed analysis of orographic and hydrological factors.

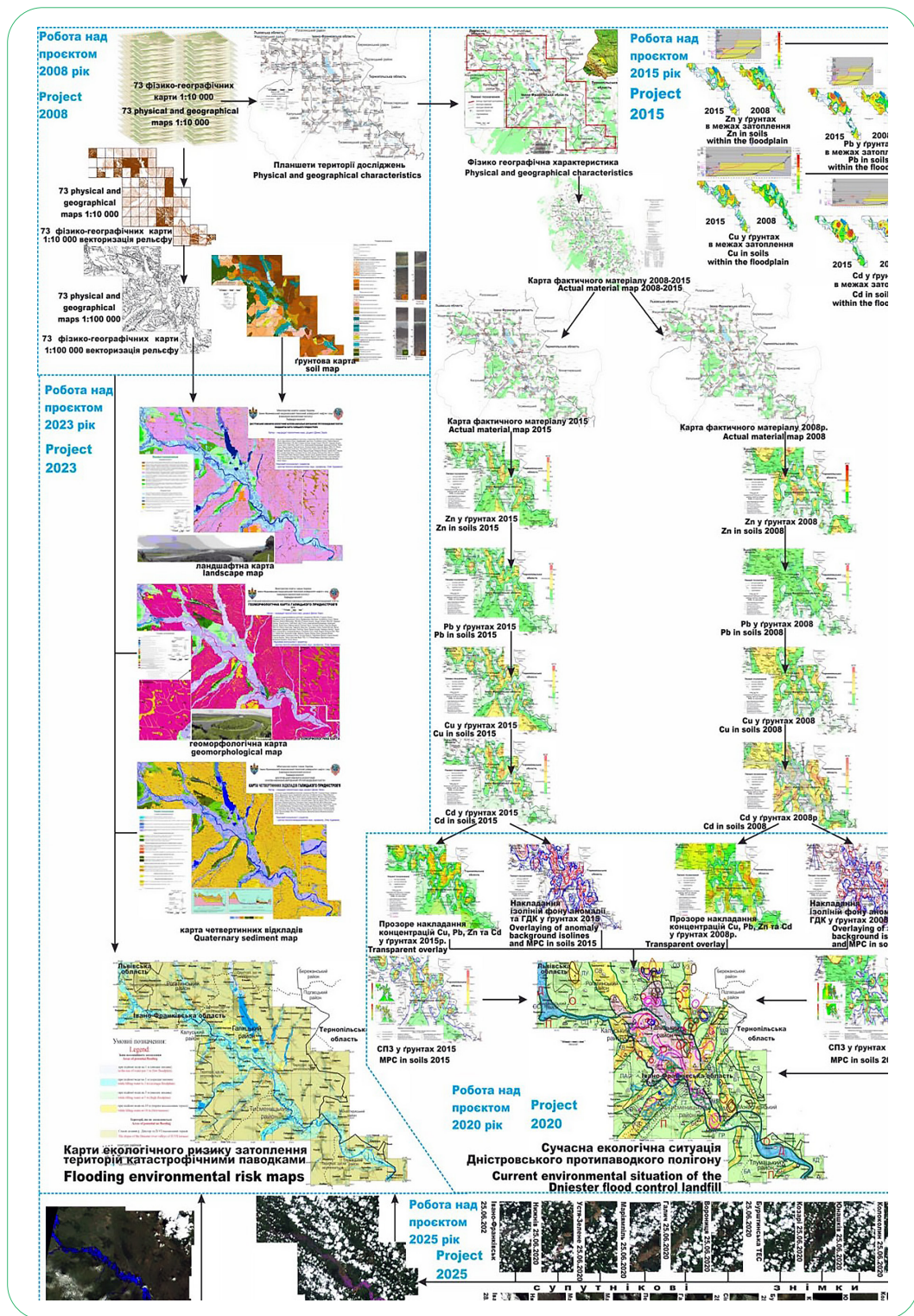


Figure 6. Scheme for creating ecological maps

Source: created by the authors

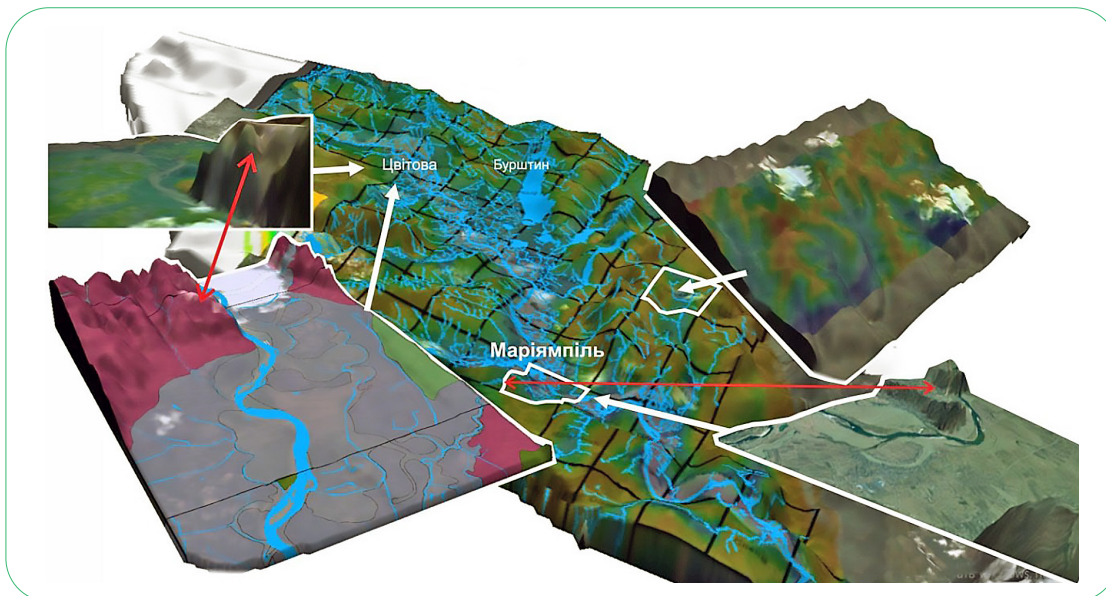


Figure 7. 3D model

Source: developed by the authors

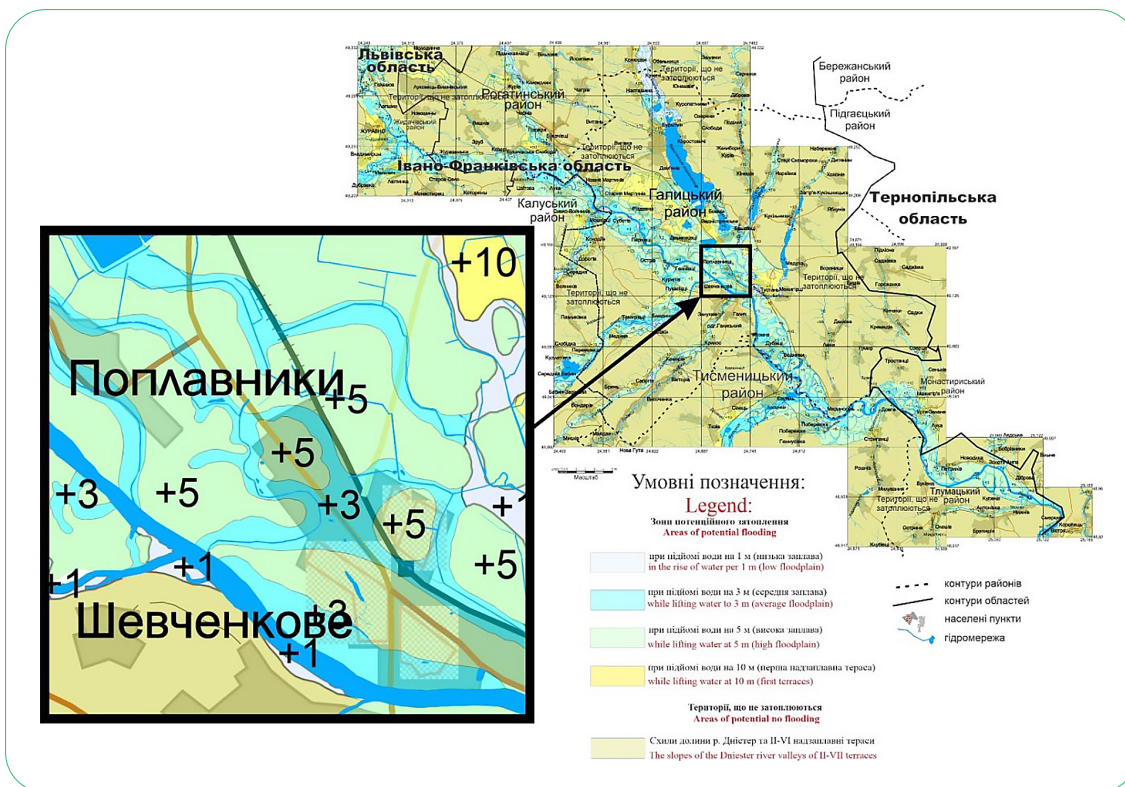


Figure 8. Maps of the ecological risk of flooding of territories by catastrophic floods

Source: developed by the authors

The study of orographic factors affecting the retention of cyclones in the Carpathians, where the bulk of precipitation falls in the Carpathian region, is considered as a possibility of retaining part of the runoff using hydraulic structures. The processes of water accumulation in the cirque-shaped upper reaches of small Carpathian rivers play a key role in the formation of flood waves. In the absence of intercepting hydraulic

structures (dams or water catchments), rain or snowmelt runoff is not delayed in these basins, but rapidly descends to the lower parts of the relief. This leads to increased erosion processes in the channels, destruction of banks, the formation of mudflows and the occurrence of landslides, especially in conditions of overwetting of slopes. Based on 3D modeling, recommendations are provided for reducing these risks.

Modern three-dimensional modeling technologies allow significantly increasing the efficiency of analysing flood formation processes. They provide an accurate representation of the relief, modeling of surface runoff directions, identification of water accumulation zones and potentially dangerous areas. This contributes to better forecasting of flooding, erosion processes and landslides, as well as optimisation of the placement of engineering protection. Thanks to modern 3D modeling technologies, it is possible to significantly improve the understanding of flood formation processes, which is important for preventing their catastrophic consequences and reducing risks for the population and infrastructure (Lou *et al.*, 2023). Recommendations for reducing flood risks based on 3D modeling:

1. Construction and reconstruction of intercepting hydraulic structures: installation of retention dams and water retention structures in the upper reaches of river basins to contain rapid surface runoff; use of floodplain reservoirs for temporary storage of flood waters.

2. Anti-erosion measures on slopes: carrying out afforestation in areas with high erosion risk; development of a terracing system in areas with steep terrain to reduce the force of surface runoff.

3. Optimisation of development and land use: restriction or prohibition of construction in areas identified by the model as high-risk (lowlands, valleys, channel terraces); change in land use type in critical areas (e.g. conversion of agricultural land to nature reserves).

4. Improvement of early warning system: integration of 3D models into monitoring and warning systems, in particular for prompt notification of the population in case of flood threat.

5. Regular updating of hydrological data: conducting periodic terrain scanning (LiDAR) and updating digital elevation models to increase the accuracy of forecasts; monitoring the dynamics of coastlines and flood zones.

6. Ecological reconstruction of river valleys: restoration of old rivers, wetlands and natural floodplains that can act as buffer zones during floods.

7. Community education and formation of emergency action plans: development of local evacuation plans; conducting training for the population on flood response taking into account the risk zones identified by the model.

Forecasting and warning local authorities and the population about floods remain difficult tasks due to the unpredictability of these phenomena and the speed of their development. The experience of previous floods has reached the level of public awareness. Ensuring safety in the Dniester River Valley and its tributaries includes reducing the risk of harmful consequences of catastrophic floods and floods. Floods and flash floods can occur suddenly and reach a peak intensity within a few minutes, which significantly complicates the possibility of early forecasting and effective warning of the population. Therefore, early planning, preparation and implementation of safety measures aimed at minimising risks to people and infrastructure are of particular importance. In such conditions, it is extremely important to know

whether your home is located in a potential flooding zone, as well as to assess the level of safety of staying at home or the need to find another shelter. Residents of risk areas should have a clear idea of the possible threats of this natural phenomenon and always be ready to take appropriate action in case of danger (Malkova *et al.*, 2023; Sysak, 2024).

First of all, it is necessary to determine whether the dwelling is located in a potential flooding zone. Find out whether floods or high water have been observed in this area before, when exactly this happened and to what level the water rose. It is important to take into account the distance of the house to the bank of a river, lake or old woman. An additional danger is the location near a steep slope of a valley, ravine or a place where a ravine turns into a valley. To obtain accurate information, it is worth familiarising yourself with the ecological flood risk map (Fig. 8). At a scale of 1:10,000, it shows segments of a settlement that may be under water when it rises by 1, 2, 3... 10, 11, 12 meters. It is advisable for local authorities, together with surveyors, to mark these segments directly on the ground. It is also necessary to check the accessibility of roads and bridges in case of evacuation (Hnatushenko & Kashtan, 2021; Trigub & Domuschi, 2023; Wang *et al.*, 2024).

The results of the study predicted floods, which made it possible to create a three-dimensional model of the territories, which allows estimating the levels of flooding and determining environmental risks. Using GIS technologies, such as MapInfo Pro, researchers create interpolated surfaces, build contours and generate flood risk maps. For this, interpolation methods are used, in particular, the inverse distance weighted (IDW) method and irregular triangle network (TIN). The IDW method provides high modeling accuracy, especially for large amounts of data (Myrontsov, 2020; Moss *et al.*, 2020).

In the dissertation work of M.K. Halochkin (2022) reviewed the theoretical principles and methods of hydrological modeling of flood zones using remote sensing materials and geographic information systems. The main attention was paid to the analysis of changes in channel processes, the classification of flood modeling models, the use of Saint-Venant equations, as well as experimental studies on individual sections of the Dniester. An important component is the use of UAVs, Landsat and Sentinel satellite data, as well as the use of HEC-RAS software. However, it should be noted that the use of satellite data and geographic information systems in it has long been an established practice in the industry. The novelty of the research approach lies not only in the application of these technologies, but in the development of a universal methodology that allows you to quickly import geographic information models built in the MapInfo environment into any other GIS environment for further analysis, adaptation and decision-making. This provides high flexibility, scalability and compatibility of the project with modern spatial analysis systems.

In addition, the proposed system integrates methods of satellite monitoring, real-time processing and visualisation of results, which allows for prompt information of

local communities, increase their level of flood preparedness and reduce socio-economic consequences. Thus, the author's approach combines the advantages of classical solutions with modern requirements for adaptive risk management in the context of climate change. In contrast to the mentioned work, the author's research methodology offers a comprehensive approach to the integration of satellite monitoring and flood risk forecasting in the context of climate change. In particular, the emphasis is on the use of the latest technologies, such as the Sentinel-1 and Sentinel-2 satellite services for prompt detection of changes in the water table, as well as 3D modeling of flood processes using modern geoinformation software (MapInfo, QGIS, ArcGIS). Dynamic forecasts mean the ability of the model to be promptly updated based on new satellite and hydro-meteorological data. This allows for a flexible assessment of the risk of flooding taking into account changes in weather conditions in real time or close to it. In addition to risk mapping, researchers have proposed a methodology for developing practices for the first time.

Geographic information systems remain a component for flood risk analysis in urban settings, as demonstrated in the study by other researchers such as J. Balch *et al.* (2020) on the case of the city of Midar in Morocco. This study focuses on the significant role of GIS not only as a mapping tool but also as a key element in urban planning and management. Extremely careful identification and mapping of areas at risk of damage and flooding will provide a deeper understanding of the vulnerability of urban landscapes. The practical utility of GIS in reducing material losses is particularly relevant for areas with increased flood risk. The analytical framework presented in this study provides several important conclusions on the effectiveness of GIS in urban management. Also, the approach focuses on the protection of the population and infrastructure of Midar, demonstrating the potential for adaptation. Overall, the study highlights the transformative potential of GIS in increasing resilience, making this technology a key tool in the fight against natural disasters.

## ✔ Conclusions

As a result of the study, the feasibility of using a geoinformation approach to forecast flood risks within the Dniester flood control area was comprehensively substantiated. Climate change, in particular the increase in the intensity of atmospheric precipitation, as well as anthropogenic factors such as irrational water use, deforestation and urbanisation, significantly affect the hydrological regime of the region. This necessitates the creation of effective tools for monitoring, forecasting and responding to flood situations in order to ensure environmental safety and protect the population. For the first time, a comprehensive spatial model was created for the territory of the Dniester Valley and the adjacent regions of Podillia and Prykarpattia, combining data from remote sensing, geomorphological analysis and historical observations. Detailed mapping of Quaternary deposits, landscape structure and elevation levels of the relief was

carried out, which made it possible to identify patterns in the formation of flood waters and create a forecast map of flooding at different water levels. A particularly significant result was the construction of a 3D map of the territory in the GIS environment, which served as the basis for modeling flooding using the inverse-weighted distance method. This method turned out to be optimal for assessing the spatial distribution of risk in conditions of uneven location of hydrological posts.

The study of historical sources, including chronicles, chronicles and meteorological observation data, made it possible to identify the cyclical nature of the occurrence of catastrophic floods. It was established that floods have a clear periodicity within 3-4, 5-6 and 15-20 years, which corresponds to different phases of recurrence of extreme hydroclimatic phenomena. These data became the basis for the formation of a forecasting system capable of taking into account not only modern instrumental observations, but also long-term historical dynamics. An important practical achievement of the work was the creation of an automated information and measurement anti-flood system AVIPS-DNISTER, which combines cartographic, mathematical and geoinformation models. The system allows not only to model possible scenarios of the development of a flood situation, but also ensures the functioning of prompt notification of the population and relevant civil protection services in case of a threat of flooding. The proposed model for predicting water rise allows determining the level of danger for each specific settlement, depending on the morphology of the territory and the degree of vulnerability of the infrastructure.

The results of the study demonstrated the effectiveness of combining GIS analysis, remote sensing, and historical climate analysis methods for flood risk assessment. The proposed approach is universal and can be adapted for other regions of Ukraine and Central and Eastern Europe with complex terrain and flood threat. The practical implementation of the flood monitoring and forecasting system within the Dniester flood control area opens up new opportunities for sustainable water resource management, minimising the consequences of emergencies, and preserving the ecological balance in one of the most important natural regions of Ukraine. Thus, the study made a significant contribution to the development of environmental safety and natural risk management within the Dniester Valley, proposing a scientifically sound and technologically implemented flood forecasting model that has high social, economic, and environmental significance. To increase the effectiveness of the proposed approach, it is advisable to expand the use of quantitative analysis methods, including machine learning, as well as to introduce interdisciplinary cooperation to improve the flood monitoring and forecasting system.

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## Інтеграція супутникового моніторингу для прогнозування паводкових ризиків на прикладі Дністровського протипаводкового полігону

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✔ **Анотація.** Актуальність дослідження полягає в розробці, вдосконаленні та практичному впровадженні геоінформаційного підходу до прогнозування паводкових ризиків у межах Дністровського протипаводкового полігону шляхом інтеграції супутникового моніторингу, просторового аналізу та інтерполяційних методів. Дослідження було спрямоване на створення ефективної системи виявлення потенційно небезпечних зон, аналізу забруднення паводкових вод та оцінки впливу кліматичних змін на гідрометеорологічні процеси з метою підвищення екологічної безпеки та забезпечення сталого управління ризиками на рівні територіальних громад. Виконано картографування четвертинних відкладів, геоморфологічних рівнів і ландшафтної структури, а також побудовано прогнозу карту затоплення територій за підйому води на 1, 3, 5 і 10-12 метрів. Остаточним результатом стала 3D-карта, яка представлена як інтерпольована поверхня, створена з використанням методу зворотних зважених відстаней. Підібрано оптимальні інтервали значення і розміру осередків: отриманий результат дозволяє не тільки аналізувати ризики затоплення, але й оформлювати звіти з візуалізацією даних, які зберігаються у вигляді графічних зображень. Уперше для Дністровської долини та суміжних територій Поділля й Прикарпаття була створена карта екологічного ризику затоплення Дністровського протипаводкового полігону катастрофічними паводками. Дослідження показало, що процес затоплення долини Дністра відбувається послідовно: спочатку затоплюється низька заплава (підйом води +1 м), потім середня (+3 м), висока (+5 м) заплави і, нарешті, перша надзаплавна тераса (+10-12 м). На основі виявлених закономірностей було розроблено систему прогнозування підйому вод під час паводків. Окрім прогнозування, ця система виконує функцію оповіщення населення про катастрофічні прояви водних стихій

✔ **Ключові слова:** інтерполяція; моделювання; дистанційне зондування; геоінформаційні системи; управління водними ресурсами