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FLOOD FORECASTING AND DISASTER RISK MANAGEMENT – A CASE STUDY OF DANUBE RIVER

ABSTRACT

The Danube and its tributaries have been crossing mountains and plains in their almost unchanged riverbeds for thousands of years, regardless of national and administrative boundaries. Nevertheless, even decades ago, several countries provided access to only limited data and information concerning the water level and flood protection status of their rivers. In recent years, information was exchanged mainly on the basis of bilateral agreements and on successful activities of basin-wide organizations, but for others, information could only be obtained by browsing the Internet, which is sometimes rather complicated and definitely time-consuming. The EU Strategy for the Danube Region Environmental Risks Priority Area initiated a project aimed at developing the Danube Hydrological Information System, which was supported by the International Commission for the Protection of the Danube River. A comprehensive overview of the complex national flood and ice forecasting systems, identification of the shortcomings of the existing forecasting practices as well as an improvement of the exchange and availability of hydrological and meteorological data between the involved countries constituted crucial fields of interests for the project.

Hence the main aim of the article is to present and discuss key data and functionalities of the system. The key findings show that all authorized meteorological and hydrological data of the Danube River are stored in a central database and made available online to all licensed hydrological and flood protection institutions for further processing in virtually real time. At this moment 12 countries of the Danube have joined forces to work out the proposals that are essential for the future, for safer Danube.

KEYWORDS

Danube river basin, Danube, Hydrological Information System, flood forecasting, ice forecasting systems, forecasting systems, macro-regional strategy, environmental risks, priority area

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PROGNOZOWANIE POWODZI I ZARZĄDZANIE RYZYKIEM KATASTROFY STUDIUM PRZYPADKU RZEKI DUNAJ

ABSTRAKT

Dunaj i jego dopływy przecinają góry i równiny w swoich prawie niezmienionych korytach od tysięcy lat, nie zważając na granice państwowe i administracyjne. Mimo to jeszcze kilkadziesiąt lat temu kilka krajów udostępniało jedynie ograniczone dane i informacje na temat poziomu wód i stanu ochrony przeciwpowodziowej swoich rzek. W ostatnich latach informacje przekazywane były głównie na podstawie umów dwustronnych i pomyślnie realizowanych działań organizacji działających w całym

dorzeczu, ale dla innych informacje można było uzyskać jedynie poprzez przeglądanie Internetu, czasem w dość skomplikowany sposób i z pewnością wymagający czasu. Strategia UE dla Obszaru Priorytetowego Ryzyko Środowiskowe Regionu Dunaju zainicjowała projekt mający na celu rozwój Systemu Informacji Hydrologicznej Dunaju, który był wspierany przez Międzynarodową Komisję Ochrony Rzeki Dunaj. Kompleksowy przegląd złożonych krajowych systemów prognozowania powodzi i oblodzenia, identyfikacja braków w istniejących praktykach prognozowania, jak również poprawa wymiany i dostępności danych hydrologicznych i meteorologicznych pomiędzy krajami uczestniczącymi w projekcie stanowiły kluczowe obszary zainteresowania projektu.

Dlatego też głównym celem artykułu jest przedstawienie i omówienie kluczowych danych i funkcjonalności systemu. Z najważniejszych ustaleń wynika, że wszystkie autoryzowane dane meteorologiczne i hydrologiczne dotyczące rzeki Dunaj są przechowywane w centralnej bazie danych i udostępniane online wszystkim licencjonowanym instytucjom hydrologicznym i ochrony przeciwpowodziowej do dalszego przetwarzania w czasie praktycznie rzeczywistym. W tej chwili 12 krajów naddunajskich połączyło siły, aby wypracować propozycje, które są niezbędne dla przyszłości, dla bezpieczniejszego Dunaju.

SŁOWA KLUCZOWE

Dorzecze Dunaju, Dunaj, system informacji hydrologicznej, prognozowanie powodzi, systemy prognozowania zamarzania, systemy prognozowania, strategia makroregionalna, zagrożenia dla środowiska, obszar priorytetowy

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1. INTRODUCTION

The Danube River Basin (DRB) is the "most international" river basin in the world that covers territories of 19 countries. Those 14 countries with territories greater than 2,000 km^2 in the DRB are cooperating in the framework of the International Commission for the Protection of the Danube River (ICPDR). The DRB is the second largest in Europe with an area of 807,827 km^2. In accordance with the EU Water Framework Directives, the Danube and its tributaries, transitional waters, lakes, coastal waters and groundwater form the Danube River Basin District (DRBD). The DRBD covers the DRB, the Black Sea coastal catchments in Romanian territory and the Black Sea coastal waters along the Romanian and partly Ukrainian coasts. The work of the ICPDR is based on the Danube River Protection Convention (DRPC), the major legal instrument for cooperation and transboundary water management in the Danube River Basin.

Floods, drought, wildfires and low-flow events, as well as water scarcity situations and extreme storms, are likely to become more intense, longer and more frequent. Natural disasters are perceived as a worldwide increasing phenomena which seriously impact human life [1]. Van Aalst (2006) proves that there are several reasons for this, however, the key one is climate change that results in severe atmospheric and hydrologic events [2]. An intensification of floods, hurricanes, droughts and other disasters obviously leads to high losses in human life. Furthermore, it has devastating consequences for private and public property, agriculture, forestry, industry and critical infrastructure having a specific feature of multiplying negative impact through cascading effects [3, 4, 5]. An increase in air and water temperature, combined with changes in precipitation, water availability, water quality and the increase in extreme events may lead to changes in ecosystems, life cycles, and biodiversity in the Disaster Resistance Business (DRB) in the long period. This is frequently mentioned to be one of the most relevant climate change consequences [6]. Therefore, high impact, low probability events, such as major disasters, are recently becoming more and more common. Among them, flood tends to be broadly recognized to be the highest risk event among natural disasters in Europe and world-wide.

Globally, in 2019 this type of disaster took the lives of more than five thousand people and affected 31 million others [1]. In recent years this hazardous tendency has also been observed on a regional level. For example, in the Danube River Basin, most notably in 2002, 2006, 2013 and 2014, parts of the district were affected by very strong or extreme flooding events. They caused a significant human and economic impact. In 2006, four casualties were reported in the Czech Republic and Slovakia. The costs of damage amounted to almost 600 million Euro in the whole basin area. In 2010, it increased even further and as a consequence there were 35 casualties, and financial damage amounting to around two billion Euro. The figure was surpassed to a greater extent in 2013 with 2.3 billion Euro of damage, mostly in Germany and Austria as well as nine additional casualties reported from Austria and Romania. And, most recently, the Sava River Basin in Croatia, Bosnia and Herzegovina as well as Serbia was hit very hard in May 2014, affecting 2.6 million people, killing 79, and causing almost four billion Euro of further damage across the three countries [6]. As the impacts of climate change are getting more drastic, the situation is becoming more complicated. The three biggest floods on the Danube happened in the last two decades, whereas on the Tisza four record breaking floods occurred within 36 months around the millennium. The floods of the past 20 years made it clear that Hungary has to be prepared for extreme floods in the future. Flood forecasting, data collection and harmonized data sharing is becoming of crucial importance along countries of the Danube River Basin. There are many examples of the use of new technologies for flood response purposes [7], however, forecasting precipitation, water stage, discharge, water temperature and ice phenomena appear to be far more important since it provides crisis managers a chance to prevent and mitigate flood consequences in advance. Pulling and sharing data among countries is necessary in order to protect the entire DRB while these data are measured separately in each country.

Therefore international cooperation is a highly valuable tool to increase EU resilience to disasters, preventing and if needed responding to them in an appropriate manner [8, 9, 10]. Hence ICPDR is obliged to contribute to the process of disaster risk management, and flood forecasting appears to be a crucial tool to make it happen. Consequently, ICPDR does it best to enhance international cooperation aimed at increasing the DRB flood protection. The Danube River Basin Enhanced Flood Forecasting Cooperation (DAREFFORT) project was one of very tangible and valuable measures taken by ICPDR in this respect. The key goal of the project was launching the Danube Hydrological Information System (DanubeHIS), however, it has been challenged by several circumstances, such as different type of hydrological data being collected by different DRB countries. Thus the article is aimed to presenting and discussing key data and functionalities of the DanubeHIS system in comparison to the European Flood Awareness System (EFAS).

1.1. EU Strategy for the Danube

The EU Strategy for the Danube Region (EUSDR) is one of four EU macro-regional strategies (MRS) in Europe. The EUSDR provides an integrated framework for strengthening of this cooperation between nations. Bringing together 115 million people from nine EU member states, three EU candidate countries and two EU neighbouring countries, it has an important integrative and cohesive function.

The Danube Region Strategy addresses a wide range of issues; these are divided among 4 pillars and 12 priority areas. Each priority area is managed by two countries acting as Priority Area Coordinators. The coordination of the Environmental Risks Priority Area (hereafter: EUSDR PA5) is managed by Hungary and Romania. The main focus of the work is to address the challenges of water scarcity and droughts in line with the Danube River Basin Management Plan, the report on the impacts of droughts in the Danube Basin and the ongoing work in the field of climate adaptation. Therefore, in the past few years EUSDR PA5 contributed to the elaboration of the ICPDR Climate Change Adaptation Strategy Update 2018, supported project elaboration and implementation in the field of drought management and climate change related spatial planning, disseminate scientific results to anticipate regional and local impacts of climate change through research.

Flood risk management is also a significant target of the priority area. In order to reduce flood risk events, EUSDR PA5 provides and enhances continuous support to the implementation of the Danube Flood Risk Management Plan. In case that these prevention measures fail to be sufficiently effective, disasters occur, hence EUSDR PA5 supporting the assessment of disaster risks in the Danube Region, encouraging actions to promote disaster resilience, preparedness and response activities.

1.2. Flood Forecasting in EU

After the Danube and Elbe floods in 2002, the European Commission initiated the development of EFAS to increase the preparedness for floods in Europe. The system was developed in close collaboration with the ICPDR and the national hydro-meteorological services sharing the Danube river basin amongst others. The aim of EFAS is to gain time for preparedness measures before major flood events strike, particularly for large trans-national river basins such as the Danube, both on a national as well as a European level. This is achieved by providing complementary, added value information to the national hydrological services and by keeping the European Response

Coordination Centre (ERCC) informed about ongoing floods and about the possibility of upcoming floods across Europe (Figure 1). Since 2012 EFAS is running fully operational as part of the Copernicus Emergency Management Service.

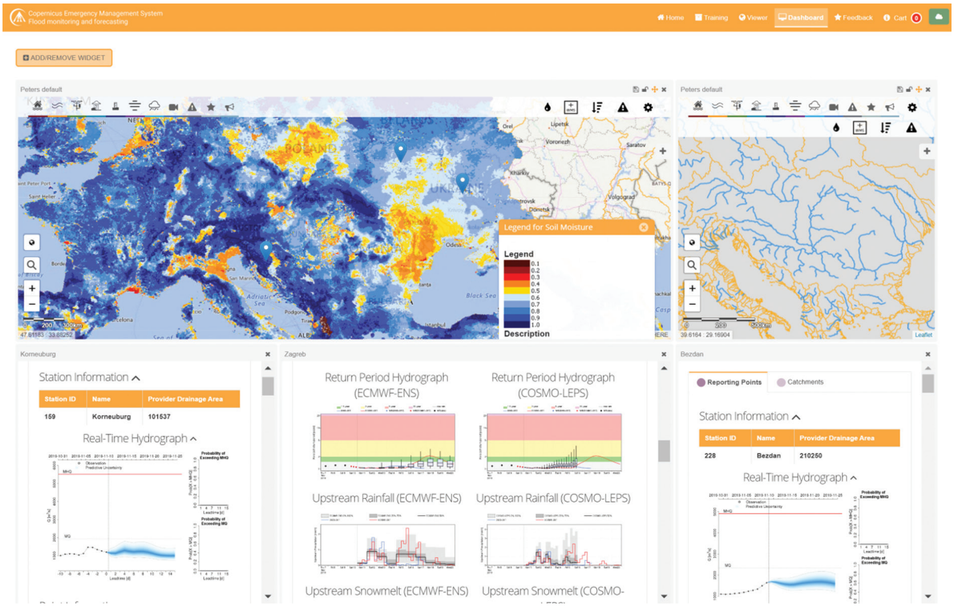

Figure 1 Screenshot of the EFAS web interface
Source: https://www.efas.eu/ (Access: Dec 1, 2021).

The system provides the national authorities with a wide range of flood forecast information, such as medium-range flood forecasts with a lead time of 10–15 days, impact forecasts, flash flood forecasts with up to 48 hours lead time and seasonal outlooks for the coming months. The information can be accessed through web services. All relevant flood forecasting authorities in the Danube river basin are the EU system partners. The system is being constantly developed with regular new model calibrations including more in-situ data or changes to the model setup and by improving its products. Through collaboration at the Danube river basin as well as at the European scale, EFAS fosters knowledge exchange and data sharing amongst the national hydro-meteorological authorities and hence is an essential tool to improve overall flood risk management in the Danube river basin.

2. MATERIALS AND METHOD

There has been a review of the EU Strategy for Danube River as well as several sources of information on EFAS conveyed for purposes of the article. Furthermore, data presented in the article have been gained from a series of conferences and workshops organized under of EU Interreg Program co-funded project titled The Danube River Basin Enhanced Flood Forecasting Cooperation (DAREFFORT). The project has delivered an outstanding overview concerning the present status of the national forecasting capabilities and from the partners and the stakeholders from the DRB. Under the DAREFFORT project the partners jointly worked out policy recommendations for the ICPDR in support of the establishment of the Danube Hydrological Information System (DanubeHIS), which is a fundamental step towards flexible and sustainable data exchange for the DRB countries. The main focus is to enhance access to the recorded hydrological data and to provide harmonized distribution for all the countries in the Danube catchment area. For this purpose, an interface software has been installed in the national hydro-meteorological institutes of the DRB to provide standardized data services being also a data source for the EFAS. The data and experiences generated in the course of the software practical use have been furtherly analysed and synthetized in order to achieve the aim of the article.

The DAREFFORT project was a transnational initiative led by Hungary (VIZITERV Environ Ltd) and received a Letter of Recommendation from the Steering Group of EUSDR PA5. The project preparation was supported by the Hungarian Ministry of Foreign Affairs and Trade, and it was financed by the Interreg Danube Transnational Programme.

3. RESULTS AND DISCUSSION

None of the flood risk mitigation measures serves better the protection of human lives and the social estate than enhancing the preparation time to avoid catastrophes that could be potentially caused by predicted floods. The reliable and comprehensive hydrologic data serve as a basis for sound forecasting in any country of the Danube Basin. The most cost effective non-structural tangible solution that highly reflects the solidarity principle is the improvement of forecasting capabilities on basin-wide scale.

3.1. Meteorological data

Meteorological observations are an essential part of flood and ice warning and forecasting systems. Generally, various data are collected within meteorological networks. The most important variables include precipitation, air temperature, air humidity, wind speed, air pressure, solar radiation, sunshine duration, evaporation, soil moisture, snow depth, and snow water equivalent.

It has been found that actual measurements of evaporation and transpiration are performed only in some countries at few meteorological stations. Furthermore, potential evaporation is measured only in some places. Soil moisture measurements are hardly ever taken. Composite weather radar imagery to be used in hydrological models is not available in all countries. In most countries, there are no systematic measurements of the snow water equivalent or its spatial distribution, despite the fact that the floods in DRB are mainly generated in mountainous areas in combination with snowmelt.

3.2. Evaluation of forecasting

The availability and access to meteorological data varies across the countries of the Danube River Basin. Furthermore, not all the data are free of charge in the respective countries. This applies to the availability of meteorological data, terms of use for the countries involved in the DAREFFORT project, the number of on-line meteorological stations operated in the Danube River Basin, and information about the type of data provided on the public website.

3.3. Hydrological data

Under hydrological monitoring all countries collect data on hydrological parameters, i.e., water level, discharge, and water temperature. Some of them collect information concerning sediment and ice, while there are practically no systematic measurements of water flow velocity. Bed load transport is hardly ever measured. There are no systematic measurements of channel morphology either, with the exception of navigable waterways along the Danube and its tributaries. Measurements of river stages, and indirectly river discharges, are well developed in all hydrological services. However, the number of observation stations has unfortunately decreased over recent decades and we lost valuable information regarding the heterogeneity and dynamics of the phenomena measured. Furthermore, digitalisation of historical data is lacking in all services. The availability and access to hydrological data is also different across the DRB countries and not all the data are free of charge in the respective countries. All countries foster an extensive exchange of meteorological and hydrological data and information with domestic and foreign institutions and users. They provide data to international organizations such as the Global Runoff Data Centre (GRDC), the Hydrological Information System of the Sava River Basin (SavaHIS) and EFAS. Data are exchanged on the basis of relevant agreements. Procedures for national and international exchange of meteorological and hydrological data exist in all countries.

The countries used their own criteria for selecting the representative hydrological stations on the main rivers and their tributaries in the Danube River Basin proposed for the DanubeHIS. The location of the selected stations is presented in Figure 2.

Figure 2 Map of networks and proposed hydrological stations. Additionally, stations from Bosnia and Herzegovina and Montenegro were added
Source: https://environmentalrisks.danube-region.eu/ (Access: Dec 1, 2021).

3.4. Ice data

Ice measurements are conducted along the Danube River's main flow and its navigable tributaries, according to the recommendation adopted by the Danube Commission. In other water bodies some ice measurements or observations are executed. Because of the frequent problems with ice and historical floods, these services are well organized in Hungary.

3.5. Hydrological forecasting

The type and manner of hydrological forecasting are mostly subject to regional natural conditions. In upper and high-slope river reaches, the discharges mostly depend on the local precipitation type and its intensity. In such regions, monitoring systems with as short as possible data transfer time steps are needed for forecasting due to the fact that the hydrological conditions are prone to rapid changes. The water levels of the lower river reaches are strongly influenced by the drainage from the upper catchments and the low slope of the river channel. Here, the change of hydrological conditions is slower, and the hydrological conditions are maintained for longer periods. Water levels of low-slope rivers may also be affected by ice.

The national hydrological and meteorological forecasting services of the Danube River Basin countries mostly operate within the same institution, on a door-to-door principle, which means that hydrological services have access to meteorological data and predictions free of charge, daily consultations with meteorologists are in place and usually both services prepare a joint warning product as well. A large diversity among the Danube River countries in terms of hydrological and hydraulic models used and the number of models applied was recognized. Among the hydrological models, the deterministic/conceptual/lumped model type predominates over the deterministic/physically based/distributed model type. The lumped models are often used in the semi-distributed manner by catchment division into sub-catchments and/or elevation zones. The hydrological models used in more than one country (organisation) are DHI NAM, HBV/HBV-light and HEC-HMS. Among the hydraulic/routing models the dynamic wave – hydraulic routing model type predominates over the hydrologic routing model type. Forecasting accuracy assessment is systematically undertaken only by some services, mostly on an occasional basis only. Systematic assessments of forecasts are only performed by the European Commission's Joint Research Centre (JRC) – for its EFAS forecasts, covering EU member states and associate members. The hydrological and hydrodynamic modelling system uncertainty is further weighted with the uncertainty from the meteorological forecasts. Therefore, the hydrological services tend to issue descriptive forecasts rather than quantitative ones originating from the modelling systems. Thus, experienced hydrological forecasters hold a key role in the critical evaluation of the modelling system results as well as within the decision-making processes of the hydrological forecasting service.

4. CONCLUSIONS

The regular network of meteorological and hydrological gauging stations in the Danube River Basin started to develop in the 19th century. Nowadays almost all countries provide a modern network of hydrological and meteorological stations to ensure real-time data used in forecasting and warning procedures and flood forecasting models.

All countries have an extensive exchange of meteorological and hydrological data and information with domestic and foreign institutions. Hydrological services exchange data and information with neighbouring countries for border and cross-border watercourses. The harmonization of flows for border profiles is performed in accordance with pre-defined hydrological criteria and agreements.

Flood forecasting, data collection and harmonized data sharing is becoming of crucial importance along the countries of the Danube River Basin. Precipitation, water stage, discharge, water temperature and ice phenomena are measured individually in each country.

The EU Strategy for the Danube Region Environmental Risks Priority Area initiated a project to support ICPDR in developing the Danube Hydrological Information System. The main aim of DAREFFORT project is to give a comprehensive overview concerning the complex meteorological and hydrological measurements and data collection, which has a long history in all countries (more than a hundred years). The main aim of the activity is to enhance access to the recorded hydrological and ice data and to provide harmonized distribution for all the countries in the Danube catchment. For this purpose, for all partners interface software will be installed to provide standardized data services also as data source for EFAS. Consequently, the Danube Hydrological Information System (DanubeHIS) is to serve as a complementary tool to EFAS, which is aimed to facilitate flood forecast and management on regional level of the EU. DAREFFORT project was a horizontal initiative to implement a flood risk mitigation measure in a joint and sustainable way on the catchment level. Based on analyses executed in the scope of DAREFFORT, recommendations for improvement of flood and ice forecasting systems were prepared. Some recommendations apply to both meteorological and hydrological data, including ice. Accordingly, the Danube river countries should consider such issues as: the need to improve the measuring network terms of the stations' density and the inclusion of measurements of additional variables; the need for developing meteorological and hydrological products also at regional level; provision of free access to some of the meteorological and hydrological data related to the national forecasting services; collection of historical data records, digitalization, and storage in a database; provision of strong arguments for obtaining financial, technical, and human resources to operate meteorological and hydrological services; a common updating interval at least on a daily basis for the parameters. All countries should provide the following hydrological and meteorological parameters for exchange: water level, discharge, water and air temperature, and precipitation.

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Laszlo Balatonyi – Doktor nauk geograficznych, magister inżynier, ekspert ds. środowiska, który ukończył Uniwersytet Przyrodniczy w Peczu w 2009 r. Przez ostatnie 10 lat pracuje dla węgierskiej rządowej Służby Gospodarki Wodnej (Generalna Dyrekcja Gospodarki Wodnej, OVF), od 2016 r. jako kierownik jednostki (Miejska Gospodarka Wodna). Jest starszym wykładowcą w University of Public Service na wydziale Nauk o Wodzie i uczy studentów przedmiotów zorientowanych na praktykę. W dziedzinie dyplomacji wodnej jest koordynatorem obszaru priorytetowego (od 2019 r.) Strategii UE dla regionu Dunaju w obszarze priorytetowym Ryzyko środowiskowe. Kiedy środki zapobiegawcze nie są wystarczająco skuteczne, dochodzi do katastrof, dlatego EUSDR PA5 wspiera ocenę ryzyka katastrof w regionie Dunaju, zachęcając do działań promujących odporność na katastrofy, gotowość i działania w zakresie reagowania