International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 09 Issue: 03 | Mar 2022 www.irjet.net p-ISSN: 2395-0072

Challenges in global flood hazard mapping

Hayder Al Hudaib 1, Richard P. Ray2

1 Ph.D. Student, Széchenyi István University, Department of Transportation Infrastructure, and Water Resources Engineering Egyetem tér 1, 9026 Győr, Hungary
2 Professor, Széchenyi István University, Department of Structural and Geotechnical Engineering Egyetem tér 1, 9026 Győr, Hungary

---***---

Abstract - *Global flood hazard assessment and resilience implementation have become increasingly important in the last decade. The heightened impact has been due to anthropogenic developments changing the natural flow regime of rivers through dam construction or the increasing risk of flooding on a global and national scale due to climate change and land use/cover changes. Such a global impact requires a global response and those efforts have produced methods to assess global flood hazards through simulation of natural and human activities. Implementation of this scale of assessment however is quite challenging on both the analysis and the implementation side. Analysis requires global hydro-meteorological datasets that are applied to regional watershed models. Additional information on hydraulic behavior, control structures, flood defense, and risk exposure are also required. The most recent effort to model at this scale is the global flood awareness system (GloFAS) combined with re-analysis of global data sources such as ERA5 river discharge datasets (1979-2020). While there are many apparent limitations, the future looks promising for the development of large regional hydrological models and the development of global data sources focused on global flood simulation. Getting beyond the limitations in the availability of real-time observed datasets will require international initiatives through collecting and improving the temporal and spatial resolution of hydro-meteorological datasets, and other challenges that affect the efficiency in simulating and forecasting flood events. Finally, we highlight limitations, opportunities, and suggestions in the short and long term for future developments.*

Key Words: Global flood awareness system (GloFAS), satellite images, flood mapping, reanalysis dataset, flood risk.

1. INTRODUCTION

Water is vital to life. Increasing or decreasing water resources represents the main challenge for life and human security. A major threat to water resources comes from extreme climate events such as floods, drought, hurricanes, etc., from natural or human activities. These threats are further amplified by global climate change due to greenhouse gases and carbon cycle emissions from fossil fuel combustion, land use cover changes, and other activities [1]. Floods may be classified as urban flash floods, coastal, riverine, fluvial, pluvial, dam failure, and storm surges. Of course, extreme flood events are becoming more frequent and challenging due to climate change [2]. In summary, weather and extreme climate have had significant impacts on social, ecological, and economic networks across most regions of the world [3]. Flood events in Europe, such as the 2002 Elbe floods, and the 2007 UK floods, are considered national crises and are estimated to have caused around 15 and 6.5 billion euros of damage, respectively [3].

Early Warning Systems (EWS) has developed and widely adopted in recent years to predict the probability of floods and reduce their hazard impact. Cooperation between authorities and countries through early warning, information, and data sharing is particularly important for transboundary river basins to facilitate water resources management, especially in flood season, and coordinate actions [4]. The main challenge in hydrological studies is to estimate past, present, and future hydrological conditions in rivers around the world [5].

The limitation of hydro-meteorological observations represents a major barrier to our ability to provide monitoring and early warnings of hydrological extreme hazards, such as floods and droughts. Global flood modeling for large-scale catchment river basins requires unique models and assistance tools such as Geographic Information System (GIS) and Remote Sensing (RS) techniques. The European Flood Awareness System (EFAS) provides operational flood prediction data sets for major European rivers as a part of the Copernicus Emergency Management Services. Flood hazard maps are produced by using mathematical models to simulate the physical state of river basins and predict flood levels.

These are very useful tools to show the probability of occurrence, magnitude, and flood footprint extent as well as potential consequences over a certain area. Results can provide a supporting tool for decision-makers to enhance land use planning and disaster risk management. Long-term global river discharge re-analysis datasets were produced as part of the Global Flood Awareness System (GloFAS) jointly developed by the European Commission and the European Centre for Medium-Range Weather Forecasts (ECMWF).

Numerous international agencies are gathering and refining the spatial and temporal resolution of satellite data to produce better flood maps. With the aid of advanced numerical weather prediction (NWP) models, they generate re-analysis datasets for the land, ocean, and atmospheric variables that serve as a key starting point.

A new revolution has begun in the development of supporting tools for academic research in the field of global flood hazard forecasting and disaster mitigation. Various previous studies were carried out by Alfieri et al., Winsemius et al., and Sampson et al., [6,7,8]. included more detailed studies to evaluate official high-resolution flood hazard maps in large river basins in Canada, Great Britain, and Germany. This paper reviews some recent academic research papers that have implemented the methodologies, models, and reanalysis datasets for flood hazard maps, and comparison techniques for different case studies worldwide.

2. LITERATURE REVIEW SUMMARY FOR GLOBAL FLOOD HAZARD MAPS AND MODELING

Numerous studies have carried out assessment and evaluation of the flood hazard mapping, the following literature review is summarized in Table (1) for the period from (2005 to 2020).

TABLE (1): LIST OF LITERATURE REVIEWS FOR GLOBAL FLOOD HAZARD MAPS AND MODELING FROM (2005-2020).

N.	Agencies / Authors and year	Name of application or model	Details and features	Ref.
1	Hotspots project, World Bank (2005)	Global flood hazard maps	Grid database (5×5 km) for period (1985-2003).	[9]
2	United Nations Office for Disaster Risk Reduction (UNISDR) (2009)	Improved hazard maps with Global Assessment Report (GAR)	Inundation maps include flood extent for limited return period flood years.	[10]
3	United Nations (UNISDR) and CIMA research foundation (2011)	Enhancing probabilistic flood hazard and risk assessment	Develop Global Assessment Report (GAR), 2015	[11]
4	Joint Research Centre (JRC) of European Weather Forecasts (ECMWF).	Global Flood Awareness System (GloFAS)	Flood hazard mapping based on the Global Flood Awareness System (GloFAS).	[12]
5	Neal et al., (2012)	LISFLOOD- FP	Applied LISFLOOD Model.	[13]
6	Pappenberger et al. (2012)	Developed flood hazard model	Simulate the flood hazard maps for various return period	[14]
7	Yamazaki et al. (2013)	River routing model to improve the global flood hazard maps.	Updated flood model derived by Pappenberger et al. (2012).	[15,16]
8	Hirabayashi and Ward et al, (2013)	Developed modeling for flood hazard maps	Flood maps for period (1971-2000) and future climate conditions for the period (2071-2100)	[16]
9	Ward Philip et al. (2013)	Developed the global flood risk model GLOFRIS.	Flood hazard maps for various years return period flood under current climate condition.	[17]
10	Schumann et al. (2013)	Ensemble LISFLOOD-model.	Calibrated flood model and applied over a reach of the Zambezi River.	[18]
11	Alfieri et al. (2014)	Derived a flood hazard map for Europe	Developed streamflow data for the European Flood Awareness System	[6]
12	Sampson et al. (2015)	Developed the flow global flood hazard model.	Model simulates inundation by solving hydrodynamic.	[8]
13	CIMA research foundation (2015)	Developed Global Flood model for Global Report	Developed the Disaster Risk Reduction (GAR).	[20]
14	Jongman et al., (2015,2016)	Assess flood risk for period (1960 -1990), (2050 -2080).	Flood hazard approach by assessing the flood probability of the current 100 years as peak discharge.	[21]

15	Winsemius et al., (2016).	Presented global drivers for rivers flood risk	Flood risk, climate change impacts, and planning effective adaptation strategies.	[7]
16	Dottori et al. (2016)	Develop global flood maps	Flood hazard maps with resolution (1 km × 1 km).	[15]
17	Hirpa et al. (2018).	Global Flood Awareness System (GloFAS)	Calibration of the GloFAS using daily streamflow data from 1287 catchments worldwide.	[22,23]
18	Harrigan et al., (2020)	GloFAS- ERA5	GloFAS-ERA5 Operational global river discharge reanalysis 1979– present	[24]

3. MODELS AND METHODOLOGIES

The Global Flood Awareness System (GloFAS), jointly developed by the European Commission and the European Centre for Medium-Range Weather Forecasts (ECMWF), fully operational as a Copernicus Emergency Management Service (EMS) since April 2018.

GloFAS is a global hydrological forecast model and monitoring system independent of administrative and political boundaries (GloFAS website). The main GloFAS produces daily flood forecasts (since 2011) and monthly seasonal streamflow (since November 2017). The latest version GloFAS v3.1, Pre-Release on 15/04/2021, calibrated over 1226 river basins, the dataset is already available through the website of Copernicus Climate Data (CDS).

The GloFAS with the LISFLOOD model process (Fig.1), has been developed for hydrological simulations by using a land surface scheme coupled to a river routing model.

The ECMWF- IFS is European Centre for Medium-Range Weather Forecasts - Integrated Forecasting System (IFS), while H-TESSEL is a scheme for surface exchanges over land that is used for generating surface and subsurface runoff as input for LISFLOOD, Balsamo, et al., [26].

The LISFLOOD is a rainfall-runoff, spatially distributed water resources model, that has been developed by the Joint Research Centre (JRC) of the European Commission since 1997. It is used for flow routing and simulation of groundwater processes developed to simulate hydrological processes in large catchments, De Roo et al., Van Der Knijff et al. [27,28].

The global reanalysis data set GloFAS-ERA5 v2.1 was evaluated against 1801 observed hydrological stations for daily river discharge along with the main global rivers networks [24].

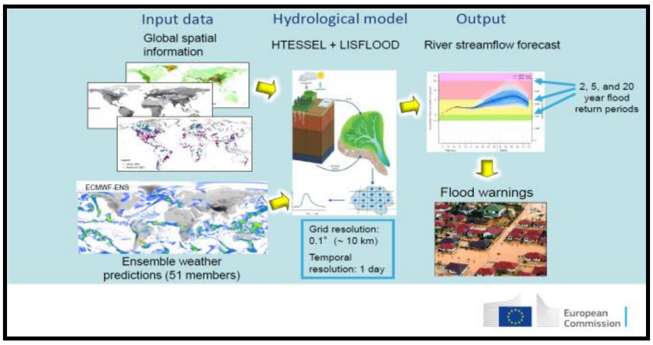

Figure (1): Global Flood Awareness System (GloFAS) system overview (Joint Research Centre (JRC) of the European Commission's science website).

4. CASE STUDY REGIONS

The Global flood hazards were applied to various locations worldwide, Dottori et al., [15]., carried out flood hazards mapping on river basins including Severn and Thames in UK, Po in Italy, Elbe in Germany, Niger in West Africa, Tocantins in Brazil, Indus, Irrawaddy, the Mekong in Vietnam, and Ganges-Brahmaputra transboundary rivers in India and Bangladesh. Also, the research included a scientific evaluation of socio-economic impacts in various countries located in southeastern Europe due to flood events and evaluated the 2014 flood in the Sava River basin. Harrigan et al [24] applied global reanalysis discharge datasets on 1801 observation stations worldwide.

5. EVALUATION METHODOLOGY

The methodology for evaluating various products of flood hazard mapping, through comparing to official historical flood hazard maps as well as satellite-derived flood maps, also performance indexes, Bates and De Roo, [28]; Alfieri et al., Sampson et al., [6,8].

The authors implemented an extra comparison with the results of various previous studies carried by Alfieri et al., Winsemius et al., and Sampson et al. [6,7,8], which included more detailed studies and evaluations of official high-resolution flood hazard maps in large river basins in Canada, Great Britain, and Germany. The researchers used observed flows for the flood period of May 2014 and flood records and information on levees and other flood protection breach structures and compared them to European Flood Awareness System (EFAS) forecasting datasets, then evaluated forecast flood hazard maps against reference flood simulation along river sections and flooded urban areas.

Also, statistical evaluation by GloFAS-ERA5 simulation reanalysis produced discharge datasets that were compared to a global network of daily river discharge observations. The evaluation used the modified Kling–Gupta efficiency metric [24].

6. DATASET SOURCES

The review research papers implemented flood extent satellite map datasets, which were developed by Dartmouth University in the United States, and flood maps from the United Nations operational application (UN-OSAT). The European Union's Earth Observation Programme (Copernicus) provides land cover map datasets.

7. RESULTS AND DISCUSSION

The comparison for various flood hazard maps with return periods of (10, 25, 50, 100, 250, 500, and 1000) carried out for the Po River basin in Italy between simulated flood extent and official flood maps were carried out for the 500-year return period. Also, the research study carried out an extensive comparison between GloFAS simulated discharges against observation for several rivers, such as Amazon, Mississippi, Indus, and Niger river basins. The results are yield acceptable performance in the Amazon River, while in the Niger river, where located in the semi-arid zone showed in Figure (2) overestimated discharges due to modeling limitations and underestimated for both evaporation and infiltration losses [15].

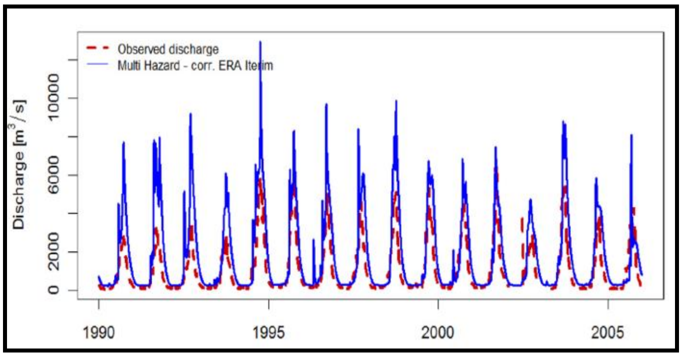

Figure (2): GloFAS simulated Vs observed discharges for Niger River at Koulikoro, Mali. [15].

The 2014 flood on the Sava River was studied and a technical report was issued by the International Commission for the Protection of the Danube River and the International Sava River Basin Commission (ICPDR and ISRBC, 2015), the results show flood overestimation for all cases compared to satellite flood extent areas due to the satellite image acquired on 19 May onwards. The real flood events occurred between 15-17 May 2014; also flood extent areas reported by ICPDR and ISRBC were underestimated for both satellite and simulated results [25,29].

The results of the reanalysis of simulated discharge, compared to observed flow and model performance by using Kling–Gupta efficiency (KGESS), is about 86% for river catchments. The best results were achieved in the Amazon river basin (Brazil), eastern and western regions of the United States, and central Europe, while poor results were achieved in many catchments in Africa and North America, eastern Brazil, Thailand, and southern Spain [24].

8. LIMITATION OF GLOBAL FLOOD HAZARD MAPS

The conceptual scheme for global flood hazard mapping by using GloFAS in some cases is limited to the availability of the observed dataset. The precise computation of river discharge reflects the precision of the data and information on water storage systems like dams, hydraulic control structures, lakes, reservoirs, watercourses, flood defense, etc. Some flood areas were not considered in the modeling scheme and it directly impacted the simulation results for peak wave attenuation.

The satellite image products such as MODIS imagery, are also limited for various cases when the catchment river basin is located in high altitudes with steep slopes in mountain areas. Image processing is also compromised when there may be a mix of heavy clouds, water surfaces, and snow cover.

Projection and georeferencing errors induce a significant dispersion in some areas and low accuracies, and the DEM-SRTM often may not cover the river floodplain and channel water depth. A measured cross-section river survey database is necessary to simulate the true state of the river morphology and network.

Hydrological flood routing and forecasting limitations are often due to the lack of available observed/measured flow and extreme climate events datasets. This leads to difficulty in predicting peak discharge and time to peak along the rivers and tributaries. Finally, human-induced changes such as new hydraulic structures (dams, barrage, irrigation projects, etc) as well as forest clear-cutting, agricultural development, and alterations to topography and vegetation directly impact the river flow regime.

9. CONCLUSIONS AND RECOMMENDATIONS

The research papers included here review, assessment, evaluation, and simulation of hydrological modeling applications for flood hazards and global reanalysis datasets related to flood maps and forecast techniques. The methodologies included a focus on integrated hydrological modeling using the most recent and re-analyzed hydro-meteorological datasets from various international agencies such as (ECMWF), Copernicus EMS, and various universities around the world that contribute to developing the Global Flood Awareness System (GloFAS), ERA5 reanalysis using hydro-meteorological datasets from 1979 to present and high-resolution satellite imagery enhance hydrological modeling, especially in transboundary river basins and data-scarce areas. They contribute to better accuracy with high-resolution flood hazard maps. The maps may then be used to enhance flood awareness systems and forecast hot spots in flood areas, eliminate hazards, and reduce economic losses. Recent research studies included clear methodologies for the assessment of hydrological simulation of the Global Flood Awareness System (GloFAS) model through testing and applying the model in various river basins worldwide. The basins reflect different climates, terrain and catchment characteristics. The authors performed comparisons to official and satellite maps to evaluate the accuracy of their models. Other researchers examined a real flood event on the Sava River in 2014. They evaluated the hydrological modeling for simulating and forecasting flood events by comparing them to other resources. Also, the latest updating of GloFAS-ERA5 river discharge re analysis datasets from (1979 to 2020) with refinement in both spatial and temporal resolution features for the reanalysis database at 1801 locations worldwide by statistical techniques.

Despite the development of the hydrological model for flood prediction and the updating of the global reanalysis database, many challenges and limitations in the models still exist. Spatial and temporal resolution hydro-meteorological data-set is still not precise enough in most regions. The information and hydrological Dataset for the existing hydraulic structures were still required for updating due to changing the river flow natural regime by the anthropogenic developments process such as dams, river regulations, and water withdrawal, which directly impact simulation modeling are often missing. On the other hand, the Probable maximum precipitation (PMP) and probable maximum flood (PMF) with climate change will require updating. Another recommendation for future development is to apply flood hazard modeling (GloFAS) to some parts of large river basins, such as the Colorado River in the U.S., Danube River in Europe, Tigris and Euphrates in Asia, Nile River in Africa, New South Wales River in Australia, and Ganga River in India. After updating and sharing observed input datasets for the integrated models, proactive action plans and large-scale hydrological modeling may become support tools for increasing flood awareness systems in the next decades.

REFERENCES

[1] IPCC (2014). Mitigation of climate change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).

[2] Jonkman, S.N., 2005. Global perspectives on loss of human life caused by floods. Natural hazards, 34(2), pp.151-175.

[3] Easterling, D.R., Evans, J.L., Groisman, P.Y., Karl, T.R., Kunkel, K.E. and Ambenje, P., 2000. Observed variability and trends in extreme climate events: a brief review. Bulletin of the American Meteorological Society, 81(3), pp.417-426.

[4] Thielen, J., Bartholmes, J., Ramos, M.H. and Roo, A.D., 2009. The European flood alert system–part 1: concept and development. Hydrology and Earth System Sciences, 13(2), pp.125-140.

[5] Harrigan, S., Zsoter, E., Alfieri, L., Prudhomme, C., Salamon, P., Wetterhall, F., Barnard, C., Cloke, H. and Pappenberger, F., 2020. GloFAS-ERA5 operational global river discharge reanalysis 1979– present. Earth System Science Data, 12(3), pp.2043-2060.

[6] Alfieri, L., Salamon, P., Bianchi, A., Neal, J., Bates, P. and Feyen, L., 2014. Advances in pan-European flood hazard mapping. Hydrological processes, 28(13), pp.4067-4077.

[7] Winsemius, H.C., Aerts, J.C., Van Beek, L.P., Bierkens, M.F., Bouwman, A., Jongman, B., Kwadijk, J.C., Ligtvoet, W., Lucas, P.L., Van Vuuren, D.P. and Ward, P.J., 2016. Global drivers of future river flood risk. Nature Climate Change, 6(4), pp.381-385.

[8] Sampson, C.C., Smith, A.M., Bates, P.D., Neal, J.C., Alfieri, L., and Freer, J.E., 2015. A high-resolution global flood hazard model. Water resources research, 51(9), pp.7358-7381.

[9] Dilley, M., 2005. Natural disaster hotspots: a global risk analysis (Vol. 5). World Bank Publications.

[10] Peduzzi, P., Deichmann, U., Dao, Q.H., Herold, C., Chatenoux, B., and De Bono, A., 2009 Global Assessment Report on Disaster Risk Reduction: patterns, trends, and drivers.

[11] UNISDR, a. (2015). Global assessment report on disaster risk reduction 2015: Making development sustainable: The future of disaster risk management. United Nations International Strategy for Disaster Reduction. pp.1(316).

[12] Alfieri, L., Burek, P., Dutra, E., Krzeminski, B., Muraro, D., Thielen, J. and Pappenberger, F., 2013. GloFAS–global ensemble streamflow forecasting and flood early warning. Hydrology and Earth System Sciences, 17(3), pp.1161-1175.

[13] Neal, J., Schumann, G. and Bates, P., 2012. A subgrid channel model for simulating river hydraulics and floodplain inundation over large and data-sparse areas. Water Resources Research, 48(11).

[14] Pappenberger, F., Dutra, E., Wetterhall, F. and Cloke, H.L., 2012. Deriving global flood hazard maps of fluvial floods through a physical model cascade. Hydrology and Earth System Sciences, 16(11), pp.4143-4156.

[15] Dottori, F., Salamon, P., Bianchi, A., Alfieri, L., Hirpa, F.A. and Feyen, L., 2016. Development and evaluation of a framework for global flood hazard mapping. Advances in water resources, 94, pp.87-102.

[16] Hirabayashi, Y., Mahendran, R., Koirala, S., Konoshima, L., Yamazaki, D., Watanabe, S., Kim, H. and Kanae, S., 2013. Global flood risk under climate change. Nature climate change, 3(9), pp.816-821.

[17] Ward, P.J., Jongman, B., Weiland, F.S., Bouwman, A., van Beek, R., Bierkens, M.F., Ligtvoet, W. and Winsemius, H.C., 2013. Assessing flood risk at the global scale: model setup, results, and sensitivity. Environmental research letters, 8(4), p.044019.
[18] Schumann, G.P., Neal, J.C., Voisin, N., Andreadis, K.M., Pappenberger, F., Phanthuwongpakdee, N., Hall, A.C. and Bates, P.D., 2013. A first large-scale flood inundation forecasting model. Water Resources Research, 49(10), pp.6248-6257.
[19] Alfieri, L., Zsoter, E., Harrigan, S., Hirpa, F.A., Lavaysse, C., Prudhomme, C. and Salamon, P., 2019. Range-dependent thresholds for global flood early warning. Journal of Hydrology X, 4, p.100034.
[20] Ward, P.J., Jongman, B., Salamon, P., Simpson, A., Bates, P., De Groeve, T., Muis, S., De Perez, E.C., Rudari, R., Trigg, M.A. and Winsemius, H.C., 2015. Usefulness and limitations of global flood risk models. Nature Climate Change, 5(8), pp.712-715.
[21] Jongman, B., Hochrainer-Stigler, S., Feyen, L., Aerts, J.C., Mechler, R., Botzen, W.W., Bouwer, L.M., Pflug, G., Rojas, R. and Ward, P.J., 2014. Increasing stress on disaster-risk finance due to large floods. Nature Climate Change, 4(4), pp.264-268.
[22] Hirpa, F.A., Salamon, P., Beck, H.E., Lorini, V., Alfieri, L., Zsoter, E. and Dadson, S.J., 2018. Calibration of the Global Flood Awareness System (GloFAS) using daily streamflow data. Journal of Hydrology, 566, pp.595-606.
[23] Hirpa, F.A., Pappenberger, F., Arnal, L., Baugh, C.A., Cloke, H.L., Dutra, E., Emerton, R.E., Revilla-Romero, B., Salamon, P., Smith, P.J. and Stephens, E., 2018. Global flood forecasting for averting disasters worldwide. Global Flood Hazard: Applications in Modeling, Mapping, and Forecasting, pp.205-228.
[24] Harrigan, S., Zsoter, E., Alfieri, L., Prudhomme, C., Salamon, P., Wetterhall, F., Barnard, C., Cloke, H. and Pappenberger, F., 2020. GloFAS-ERA5 operational global river discharge reanalysis 1979– present. Earth System Science Data, 12(3), pp.2043-2060.
[25] Dottori, F., Kalas, M., Salamon, P., Bianchi, A., Alfieri, L. and Feyen, L., 2017. An operational procedure for rapid flood risk assessment in Europe. Natural Hazards and Earth System Sciences, 17(7), pp.1111-1126.
[26] Balsamo, G., Beljaars, A., Scipal, K., Viterbo, P., van den Hurk, B., Hirschi, M. and Betts, A.K., 2009. A revised hydrology for the ECMWF model: Verification from field site to terrestrial water storage and impact in the Integrated Forecast System. Journal of hydrometeorology, 10(3), pp.623-643.
[27] Van Der Knijff, J.M., Younis, J. and De Roo, A.P.J., 2010. LISFLOOD: a GIS-based distributed model for river basin scale water balance and flood simulation. International Journal of Geographical Information Science, 24(2), pp.189-212.
[28] De Roo, A.P.J., Wesseling, C.G. and Van Deursen, W.P.A., 2000. Physically based river basin modelling within a GIS: the LISFLOOD model. Hydrological Processes, 14(11-12), pp.1981- 1992.
[29] ICPDR-ISRBC (2015). The international commission for the protection of the Danube River and ISRBC international Sava River basin commission: Floods in May 2014 in the Sava River basin.