Flood Risks Management: State of Practice

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Abstract

A thorough investigation of flood dangers will be required, starting with hydrometeorological evaluations of runoff and flow and concluding with an evaluation of the vulnerability of individuals at risk. Although there is a lot of knowledge on these subjects, climate change, population increase, and changing land uses provide data issues for flood risk assessments.This paper reviews the current state of the practise of assessing flood risk, including flood scenarios, hydrometeorology, inundation modelling, flood frequency analysis, interrelationships with water infrastructure, and vulnerability of people and places. Recent studies have provided comprehensive reviews of advancements in the water sciences arena. There is a substantial body of study on each of these subjects. While some of the techniques in these fields, like hydrologic modelling, have decades' worth of research advancements, others, like numerical weather prediction, have more space for development. All studies have shown that information is essential at every stage, from climatic conditions through the impact on flood victims.

Keywords: Flooding forecasting • Risk assessment • Vulnerability • Weather prediction

Comprehensive flood risk assessment

Flooding is frequently cited as the natural hazard with the highest danger, and it continues to afflict flood-prone areas and may happen in unexpected ways. Natural catastrophes and extreme weather are among the biggest hazards confronting the world, according to the World Economic Forum's Global Risks Report 2023, and improved early warning systems may significantly reduce casualties and damage.For decision support to inform tools for forecasting, planning and design, regulatory controls, and post-event research, such warning systems will need accurate and trustworthy data. Particularly for a comprehensive method to identify risks of growing flood impacts on people and places, the collection of necessary data for these applications to enable flood risk assessment presents tremendous hurdles.

Experience has shown that gathering all data on one platform, whether they are utilised for forecasting or more lengthy planning, design, and post-event research, is particularly difficult. Due to ongoing changes in the climate, land usage, and socioeconomic situation of susceptible places, these assessments will need to be renewed on a regular basis.Analysis at key locations where risk is raised or lessened, from meteorological conditions and beginning precipitation through control points and ultimately to places of vulnerability where victims are affected by floods, is necessary for thorough flood risk assessments. A holistic picture of flood risk encompasses the danger, the possible damages, and the susceptibility of the people or places who can be impacted. Flood risk is commonly mistaken with the likelihood of flooding. Hydrometeorology serves as a starting point, but a thorough risk assessment process includes additional phases to pinpoint the areas where actions will most significantly reduce overall flood damages. As targets are exposed to threats and protected by infrastructure and/or nonstructural programmes, every step in the chain of crucial points necessitates analysis to estimate the possibility of damaging events or the vulnerability of targets.Although flood risk assessment methods contain a wealth of information, their usefulness is threatened by growing dangers brought on by factors such as population increase, climate change, and changing land uses, among others. Flood exposure continues in developed areas and grows in low-income areas as a result of ineffective responses.

Because it can reduce the relevance of prior experience in determining danger, climate change presents a unique difficulty. It may also be linked to other hydrologic changes, such as more intense rainfall, dependent phenomena like sea level rise, altered weather patterns that transform snowmelt floods into more extreme rain-on-snow events, and other dependent phenomena like sea level rise. From predicting to planning, changing land uses and geomorphological forms present additional difficulties.

Even if integrated non-structural solutions have replaced structural ones in flood risk reduction plans, risk variables must still be evaluated from the first storm occurrences through the causes and effects chains. In order to create a thorough understanding of these causes and consequences, this study will start with hydrometeorology before moving on to hydrological phenomena and finally to potential implications on the economy, society, and environment. By adopting such a broad perspective, it is possible to offer an overall picture of the state of the practise of flood risk assessment and identify areas for development.

The foundation of flood risk assessment toolkits lies in the field of water sciences, which has a rich body of knowledge. In a recent state-of-the-art report regarding developments in flood science, including risk management, with over 250 references, its principles, difficulties, and future research paths were evaluated.

These varied aspects of flood knowledge necessitate the participation of specialists from a variety of fields, including climate scientists, engineers, hydrologists and other geoscientists, statisticians, geographers, economics, behavioural scientists, and lawyers. Another thorough article that offered a bibliometric examination of the development and future of flood risk assessment assessed these contributions. According to the bibliometric study, resilience is receiving more attention, while land planning, risk perception, and flood warning have less studies. The main discussion regarding riverine and coastal flooding was global warming. Data science and remote sensing information appeared to be promising, as did economic evaluation and social effect analysis. The majority of publications, according to the authors, were in environmental sciences, followed by studies on water resources, meteorology, and atmospheric science. There were also a few papers in geology, engineering, mathematics, and other subjects.Such categorization might be troublesome as usual.

Flood risks locations

Flood dangers cascade through the water cycle and involve a variety of interconnected factors, including as meteorological conditions, precipitation, runoff, flow or surge, and victim exposure. Local metropolitan areas, river basins, and coastal regions are some of the places where unfavourable effects might happen. Performance of stormwater and stream conveyance infrastructure, as well as barriers provided by dams, levees, and surge protection barriers all have an impact on risk. Risk is affected by the effectiveness of management systems like flood forecasting, warning, and insurance, as well as by the susceptibility of victims and locations. People who are elderly or immobile, for instance, are typically the most susceptible and at risk for many health issues. The number of buildings in an area and any safeguards, such as flood proofing, determine its vulnerability. Because of how closely accuracy and timeliness connect to the amount of time and opportunity victims have to prevent losses, flood forecasting is particularly crucial.Despite the fact that it is widely believed that the risk of flooding is rising, it is unclear how much. For instance, climate change may result in more intense precipitation but may not necessarily raise the maximum annual flood levels. More specifically, adaptation strategies that might lessen negative effects will have an impact on the frequency and severity of catastrophes. For instance, the authors of a research on flood exposure in 37 European nations since 1870 showed increases in the regions inundated and the number of people impacted, but they also observed recent decreases in fatalities and yearly financial losses. It is possible to pinpoint the locations where risk assessments are required based on exposure to various flood types. These floods can occur in riverine and coastal locations as well as in cities with stormwater management issues. In addition, combined occurrences like coastal and riverine flooding are possible.These tools are employed in scenarios of flood risk assessment that occur at small, medium, and large sizes, and the studies call for somewhat different methodologies .Urban stormwater, tiny watersheds, or site-based dam or levee safety are typical scenarios at small sizes.

Hydrometeorology

Numerical weather prediction, which offers data for uses like flood forecasting and warning systems, is the starting point for hydrometeorological data and models for flood risk assessment. People have grown used to accurate long-range weather forecasts thanks to satellites' ability to provide remotely sensed data and developments in simulation modelling. Equations relating to the physical rules of atmospheric dynamics are solved by numerical weather models. Supercomputers assist weather service centres in providing forecasts at progressively smaller scales as computational power increases. The larger the scale and the need to incorporate variability of spatial extent, time period, and modelling of specific phenomena, the more computational power is required.

Flood risk assessments can be used to inform integrated modelling studies, where climate projections and statistical data are used as forcing functions for hydrologic runoff and streamflow models that are used to inform forecasting, planning, and design, or forensic investigations of flood disasters. The Advanced Hydrological Prediction Service (AHPS), a recent addition to the National Weather Service, is the centre of integrated platforms in the United States. The AHPS is a framework for putting together a variety of forecast products to show the size of floods at various time frames.

Although established and in use, forecasting systems like the AHPS are still being improved through research and development using next-generation global models like the Model Prediction Across Scales (MPAS) system to enable the transition from global to regional scales for downscaling to more effectively inform flood forecasts. For climate and weather research, MPAS connects atmospheric, oceanic, and terrestrial data [h] and may be used in conjunction with the Weather Research and Forecasting (WRF) Model to provide numerical weather predictions. Flood forecasters will benefit from the advancement of numerical weather prediction methodologies and technologies, which will also have positive knock-on effects for planning, design, and forensic investigation. The ability of scientists and system developers to incorporate research results determines the status of the profession. An substantial body of literature discusses improvements in global climate models and downscaling for usage at appropriate places in the context of research on general circulation models.

Expected extreme precipitation

Expected values of severe precipitation are required for applications at many scales and time intervals, whether they are utilised for forecasting, planning and design, or forensics. Different situations, from regular to uncommon floods, and for different locales are involved in the relationships between intense precipitation and flooding. According to certain data, even while the frequency of very uncommon floods is rising and severe precipitation is increasing, overall flood magnitudes are dropping. Depending on the scenario of flood risk assessment, users of precipitation data can rely on numerical weather prediction to anticipate precipitation or utilise statistics of historical data. Calculations of anticipated rainfall totals and, in certain situations, the length of storms are produced through numerical weather prediction. Radar technology advancements have enhanced QPF for nowcasting, and approaches are always changing, from cheap and simple to sophisticated and expensive. Forecasting local circumstances from right now to six hours from now is known as nowcasting. In order to do this, it is necessary to handle a variety of weather phenomena, such as convective weather phenomena involving local to mesoscales and brief time intervals. To enhance short-term predictions, researchers have devised a variety of strategies for correlating data sources. These are crucial to enhancing resistance against dangers like abrupt urban flooding or flash floods in streams. The World Meteorological Organization (WMO) has produced an assessment of the current state of the practise, with a focus on offering recommendations for new projects.

The recommendations outline the WMO strategy for creating an integrated Data-processing and Forecasting System (DPFS) to aid in the implementation of nowcasting systems by national meteorological and hydrological services.

Although techniques for statistically analysing excessive precipitation in the U.S. are improving, the validity of predicted values for use in predictions of the frequency of flooding is still under scrutiny due to the effects of climate change. The collection of statistical data will be more challenging in regions of the world where data are poor or unavailable, and alternative approaches to estimating predicted severe precipitation are still required. The ideal strategy will integrate readily accessible local precipitation data with distant sensing information, such as that from the Tropical Rainfall Measuring Mission (TRMM).

Runoff modeling

Planning and design, forensics, and the prediction of watershed reaction are all necessary for flood forecasting . By the 1960s, flood hydrology methods were already developed and utilised for flood routing and prediction, but they rely on data availability, which is problematic in many areas. In modern integrated software packages that are offered commercially and through open source, the earlier technologies have been included. In order to estimate runoff, the US Geological Survey, Agricultural Research Service, US Army Corps of Engineers and Natural Resources Conservation Service all have their own software programmes. Each of these programmes has a unique background. Similar model packages are available from national hydrology centres and research organisations in other nations. The models may be used for a variety of purposes, including mapping floodplain regions and examining the prevalence of floods in various contexts, including those following wildfires.They may be used to continuous simulation or utilised to forecast flood occurrences. They are especially effective in urban stormwater studies and smaller catchments where land usage and presumptive rainfall patterns are more predictable than in bigger basins.Due to the geographical heterogeneities of watersheds and rainfall patterns, statistical analysis of past floods is frequently applied for larger basins. Consider a sizable watershed that is fed by several tiny streams and has a number of sizable tributaries. Such basins will have a variety of geomorphic traits, and the absence of spatial homogeneity limits good runoff forecast for various storm features.

Predicting floods following fires, which has become a more frequent issue as a result of climate change and drought, is one challenge for modelling. As an illustration, the Colorado Water Conservation Board, which is responsible for flood risk planning on a state-wide level, has conducted studies in a number of watersheds affected by fire, and it is currently conducting studies to apply the HEC HMS simulation programme in order to improve understanding and create guidelines that can be applied in the State of Colorado and other western regions. Regardless of the method used to estimate runoff, problems will still exist, especially those connected to changing land use and the climate. It will be crucial to incorporate new research as it is conducted into solutions that are suitable for the time and space scales required for flood risk reduction. Government-sponsored research can be distributed by public organisations or integrated into commercial goods in the continuing public-private endeavour of providing these items.

Flood frequency analysis

For the purpose of assessing flood risk, the idea of flood frequency analysis offers a comprehensive technique for estimating the size and likelihood of maximal instantaneous peak flows. Uniform and consistent procedures can aid in enhancing communication among public and private parties. Professionals are familiar with flood frequency measurements, but communicating with the general public is still difficult, especially when non-stationarity is involved. Federal authorities have created a set of Guidelines for Determining Flood Flow Frequency, officially known as "Bulletin 17C," in response to the need to address statistical complexity and recognise the need for a uniform methodology. Bulletin 15: "A Uniform Technique for Determining Flood Flow Frequencies," published by the U.S. Water Resources Council in 1967, was one of Bulletin 17C's forerunners. It advocated using the log-Pearson Type III distribution to yearly peak flow data. In 1976, Bulletin 15 was replaced by Bulletin 17 as "Guidelines for Determining Flood Flow Frequency," which included procedures for handling outliers, using historical data, and taking into account regional skew. The history of Bulletins 17A and 17B, which introduced new techniques later, is outlined in reference. Incorporating new research-based techniques, Bulletin 17C now reflects the status of flood frequency determination practise in the United States .Although it still poses the biggest obstacle to using historical data to fit distribution functions to flood rates, non-stationarity has recently been solved.

In order to estimate skew coefficients, Bulletin 17C advises using a variety of types of flood frequency information, including gauging data, historical information, paleo flood and botanical data, regional information, comparison with similar watersheds, and runoff calculations based on precipitation. It warns the analyst to keep an eye out for data problems such measurement mistakes, arbitrary occurrences, trends, persistence, mixed populations, watershed changes, and climatic variability. The recommendation also suggests taking into account cumulative risk in addition to yearly probability. Risk is described in the guideline paper as the likelihood that one or more occurrences will be more severe than a certain flood during a particular time frame.

A strategy to account for uncertainty in estimates is not included in the guidelines, although it may be after more study. Results from flood frequency analysis, regardless of the technique employed, may be unreliable owing to unknown factors including inadequate data, non-stationarity, and other issues. An example of this was the work done by a National Research Council group to provide a trustworthy estimate of the frequency of floods on the American River in Sacramento, California. Due to difficulties it ran into, the committee reported how various data types should be utilised to estimate flood frequencies, consistent with those ultimately included in Bulletin 17C.

Infrastructure and management programs to reduce flood risk

The efficacy of flood protection measures offered by infrastructure or management systems, such as forecasts, flood alerts, and flood plain land use regulation, determines the risk of flooding. Dams and levees, as well as stormwater collecting and conveyance systems, are examples of infrastructure.Underground pressure pipe breaches can potentially result in flooding, therefore risk analysis should take this into account. The original quality and present state of the infrastructure's components determine flood hazards. Dam safety initiatives have been put in place to mandate regular condition checks.Effectiveness of management programmes has an impact on vulnerability and is a factor in evaluation. Floodplain regulation, zoning, and insurance premium calculation all depend on accurate floodplain mapping. In order to construct inundation estimates to show flood damages on maps, the outputs of hydrologic and hydraulic models are integrated with topographic data, the stock of buildings, and other land use models.The value of floodplain maps to the U.S. National Flood Improvement Program has long been acknowledged, and several evaluations of the programme have been carried out, resulting in suggestions to address inadequacies. The improvements in hydrologic and hydraulic models that are now obvious were necessary for their evolution, and mapping also depends on the precision and granularity of data for topography and land uses. Flood maps still include a lot of unknowns, mostly because there aren't enough hydrologic and land use data.The availability and quality of digital elevation models are more crucial as flood mapping becomes more automated, especially in areas with a lack of data . With more precise map observations and the use of statistical techniques to extrapolate, interpolate, and evaluate elevation data, the DEMs' accuracy keeps growing. DEMs must be dynamic to account for ongoing land use changes as flood risk assessment uses artificial intelligence advancements.

Consequences

Each of the three types of effects—economic, social, and environmental—involves a unique set of risks and experiences harm in a variety of ways. A few decades ago, information on the financial effects of flood damage was scarce. Flood damage estimates are now considerably more accurate because to the availability of much more data, primarily for the benefit of the insurance sector. They are reliant on the kind, location, and other related variables that influence vulnerability in the building stock. Land development, which alters location and susceptibility, continues to pose a challenge to flood risk reduction. Threats to susceptible properties are increased as a result of sea level rise in coastal locations, as is the possibility of negative outcomes.In terms of equality and justice for vulnerable groups, social repercussions relating to special populations, poverty, housing, grieving, and loss continue to be key problems.The use of social media to manage flood preparedness is a potential approach for increasing community resilience . With so many human factors at play and social repercussions being challenging to categorise and quantify, it is doubtful that a single index or standard approach would be widely recognised. In one research, there were 24 factors split into "physical exposure" and "resistance" indications. Variables include the percentage of the senior population served as an indication for physical exposure (9 indicators). Protection (3 indications), response capability (4 indicators), and coping capacity were the three areas of resistance (8 indicators) the exposure variables belong in the "victims" group, whereas the resistance factors belong in the "barriers" category. In this sense, local emergency management and the ability of the local community to successfully respond to emergencies combine to form the resistance factors. The integrated assessment methodology Hazus, which will be covered in more detail in the next section, assesses social vulnerability and effects in terms of "direct social losses," which are represented by displaced populations and persons seeking refuge.

Integrated risk management tool

All the components of the flood risk assessment have been brought together on one platform. An integrated programme called Hazus has been created to estimate the risk of earthquakes, hurricanes, floods, and tsunamis under the support of USFEMA . The development of the flood module of Hazus was overseen by an engineering committee, which the writer was a part of, starting in the 1990s and lasting more than ten years. The tool is offered as a free desktop GIS software that incorporates building stock inventories and other information that aid in the evaluation of flood risk. Hazus may evaluate the economic, social, and physical effects of flooding for use in planning for response, recovery, preparedness, and mitigation measures. Hazus data sets cover physical damage to homes, businesses, schools, critical infrastructure, and other buildings; economic loss, including job losses and business interruptions; repair and reconstruction costs; social effects on displaced families and populations exposed to flooding; and cost-effectiveness of mitigation measures like elevating buildings or retrofitting existing ones.

Hazus is a genuine screening method that, when combined with correct local data, may give complicated sets of vulnerability data to support risk assessments. However, because Hazus integrates many different forms of data, it does utilise certain simplified approaches.There are now over 40 groups in the United States that are Hazus users. The Hazus website lists 18 success examples, one of which was a post-flood evaluation of how effectively stricter floodplain laws may have decreased flooding from the catastrophic 2013 Colorado flood.

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