

ASSESSING SOCIO-ECONOMIC AND ENVIRONMENTAL LOSSES OF DAM-FAILURE FLOOD RISK: A REVIEW ON SUSTAINABLE FRAMEWORK

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Abstract: Floods from dam hazards pose more catastrophic consequences than equivalent flood events due to their sudden, high-speed water flows, and lack of warning. They result in the loss of human life, the destruction of communities, and significant socio-economic and environmental losses. This paper aims to review previous studies on dam hazard flood risk assessment, identify gaps in existing models, and propose a practical methodology for a sustainable assessment framework. Through a systematic literature review using keywords like “dam failure”, “flood risk”, and “socioeconomic impact”, 179 relevant papers were found, with 20 being significant, and 5 focused on dam failure events. Prior studies mostly concentrated on technical or country-based approaches, neglecting community-based assessments. The gaps identified included a lack of consideration for social, economic, and environmental impacts, with most studies focusing solely on structural effects. This study presents an integrated framework linking flood characteristics to three main variables: (1) Social-community well-being and loss of life, (2) economic losses (both direct and indirect), and (3) environmental impact on water quality and biodiversity. To assess dam failure scenarios, a guideline for scenario-building analysis is adopted, incorporating primary and secondary data. The proposed framework aims to be concrete and user-friendly, assisting policymakers and stakeholders in assessing dam hazard-flood risks. However, it acknowledges that the effectiveness of the framework may vary based on specific dam features and the surrounding demographic, topographic, and socio-economic conditions. Although a more comprehensive assessment method is necessary, this framework represents a crucial step towards improving dam risk evaluations.

Keywords: Dam failure, flood risk, socio-economic impact, assessment tools, sustainable framework.

Abbreviations: Independent Variables (IV), Dependent Variables (DV), Geographic Information System (GIS).

Introduction

Flood is the most common weather phenomenon around the globe and its frequency is increasing as the earth's temperature rises. Although most flood events are natural phenomena, man-made causes cannot be overlooked, especially from dam breaches. About 300 major dam failures have been reported since the year 1800 by the International Commission on Large Dams (ICOLD) (Mamat *et al.*, 2019). Even when a dam system is equipped with precautions and early warning measures, undesirable incidents still happen due to uncontrolled situations. Dams bring many benefits in fulfilling human

needs such as water supply, flood mitigation, recreational activities, and electricity generation. Their risks and hazards are often overlooked (Shahrim *et al.*, 2019). Living downstream of a dam has serious risks of a life-threatening event that is hard to anticipate. Dam risk management should be a priority of the government and society to minimise the occurrence of unwanted events (Li *et al.*, 2019). The impact of a flood on the social, economic, and environmental fabric of a community in the downstream area needs to be given attention. The long-term study of the socio-economic impacts of flood events has led

to improving flood management strategies. Year by year, the study of natural floods has been deepened as disasters become more frequent in most of the country, yet, little has been done on dam breach accidents.

In recent years, many parts of Asia experienced extreme flood damage, indicating that structural flood control measures need to be re-checked and re-studied because they have not been sufficiently resilient. A recent example of a manmade flood is the Sultan Abu Bakar (SAB) Hydropower Dam in Cameron Highland, which released its water because of the heavy rainfall, resulting in a mud flood flow that resulted in the loss of four lives and the destruction of 80 houses (Mohamad-Faudzi, 2019). Although Malaysia has not experienced a dam failure, this incident underscored the importance of improving dam catastrophe risk management. Multiple frameworks and plans have been suggested in previous studies that focused on the social impact, economic impact, environmental impact, or all of the above. The impacts can be divided into four (4) aspects: Loss of Life (LOL), social impacts, economic losses, and environmental impacts (Gu *et al.*, 2020). Each framework plan was unique and considered factors in the study area, the condition of the downstream society, the main daily activities of the community in the inundated area, and many more. Nevertheless, this life threatening event will lead to loss of life, especially for the people living in the inundated area. While loss of life will be the biggest concern among all other impacts, from a humanitarian view, saving human lives is more important than saving economic and environmental assets. Despite that, a sustainability plan needs to be developed so that one aspect will not be degraded by another for long-term impact.

The issue discussed in this research is the need for a comprehensive framework and implementable methodology for assessing dam's socioeconomic and environmental implications on flood risk management. Dam building and operation can have beneficial and harmful consequences for residents, ecosystems, and downstream river systems.

However, current techniques of analysing these consequences are frequently limited in scope and are lacking in terms of considering the interconnected and dynamic nature of social, economic, and environmental aspects. Previous scholars attempted to address this issue by conducting studies on the specific effects of dams on various sectors of society, the economy, and the environment. For example, there have been studies on the relocation of local communities, biodiversity loss, and the change in downstream river systems (Shabu & Musa, 2015; Lin *et al.*, 2020). However, they are often limited in scope and fail to reflect these issues' interconnected and dynamic nature. Furthermore, a previous study had concentrated on the technical aspects of dam design and operation rather than on the socioeconomic and environmental consequences. While these studies have provided valuable insights, they need to provide a comprehensive and integrated framework for examining dam impacts on flood risk management. Furthermore, while some academics have sought to build frameworks for measuring dam consequences, their breadth has been limited, sometimes focused on only one component of the problem such as environmental, social, or economic. Furthermore, these frameworks have been criticised for their inability to adapt to varied cultural, political, and economic settings.

This paper aims to assess the present level of research on dams' socioeconomic and environmental consequences on flood risk management. The goal is to propose an implementable methodology for assessing dam impacts on flood danger that considers these components' interconnectedness and dynamic character. Based on a systematic evaluation of the literature, including case studies and best practices, the proposed framework would strive to provide a holistic and integrated approach to flood risk management in the context of dam construction and operation. The proposed framework will be based on best practices and case studies worldwide to provide a comprehensive and integrated approach to flood risk management in dam construction and

operation. This paper performs a thorough and systematic evaluation of the subject's literature and provides a framework that considers the interconnected and dynamic nature of social, economic, and environmental aspects.

Literature Review

This section presents the dam breach, flood event, and hazard risk assessment while focusing on the socio-economic impacts on society and stakeholders

Dam Hazard Risk and Flood Issues

According to Viseu and Almeida (2009), upgraded engineering knowledge or improved construction quality cannot give full assurance against a dam failure. Viseu and Almeida (2009) also recommended dam break risk assessment to ensure a safer environment downstream. Zhang *et al.* (2015) attempted to statistically assess the features of a dam that had previous failures by developing a database of 1,600 dam failures in the world, excluding those in China. In Europe, Zech and Soares-Frazão (2007) focused on the risk assessment and risk reduction of extreme flooding and attempted to develop a database by using real case data of dam failure through a combined method of laboratory work, mathematical simulations, field testing, field observations, and theoretical studies. Zacchei and Molina (2021) tried to develop a methodology to assess the grades of risk of a dam collapse under an earthquake situation by adopting an innovative set of Importance Factors (IF).

In Central Java, Indonesia, Yudianto *et al.* (2021) employed a hypothetical dam break scenario to propose a framework of dam break hazard risk mapping by using hydrological databases, i.e., TRMM, CHIRPS, and the SCS method and for flood simulation i.e., Digital Elevation Model Merit Hydro and NUFSAW2D as a water model. To facilitate dam-break flood hazard risk quantification, considering the necessity of identification of flooding variables, Aureli *et al.* (2021) were involved in reviewing previous dam-failure

events and laboratory tests on real topography for validating numerical models. Therefore, previous literature in various countries has focused on assessing dam hazard risk from historical dam-break events or hypothetical dam failure scenarios, by developing a database, mapping the possible hazard area, or developing risk grades. Furthermore, most of the previous studies employed various mathematical and hydrological models to assess dam hazard risk or to facilitate dam hazard risk assessment.

While assessing dam hazard risk, most of the past studies claimed that the dam-break flood would be the worst and most common consequence of any dam breach. The reason for the catastrophic floods that happened in the Mekong Basin (Laos) and Brazil after a dam breaching event in July 2018 was poor engineering and poor dam hazard assessment, which caused fatalities and relocation of thousands of people (Latrubesse *et al.*, 2020). To describe the major characteristics of dam breaks and its possible social impacts, He *et al.* (2020) stated that dam breaks may cause floods of large, high-speed, and sudden water flows containing soil, gravel, and sediments, which may cause loss of life and tremendous socio-economic and environmental losses. In the US, Ellingwood *et al.* (1993) mentioned that floods resulting from dam failure may cause greater damage than comparable floods due to less predictability and less probability of occurrence. Therefore, proper dam hazard risk assessment, taking into consideration dam failure flooding is a must to ensure dam safety, as well as social safety as dam hazards and flooding are very closely involved.

Most of the past studies evaluated dam-break flood risk through the assessment of inundation areas or engaged in developing methods for inundation mapping using a GIS-based approach, hydrodynamic modelling, or numerical approach. For example, Nugusa (2018) engaged in flood inundation mapping to assess dam failure, flood risk, and impact. To propose a GIS-based framework for dam-break flood hazard risk analysis, Cannata and Marzocchi (2012) proposed a GIS-embedded

approach to assess 2-D dam break simulation. Although some studies of dam failure impact such as by Cannata and Marzocchi (2012), He *et al.* (2020) and Latrubesse *et al.* (2020) — assessed dam failure losses by considering only specific loss elements instead of assessing all social, economic, and environmental losses, other studies were involved only in assessing environmental impacts. Wu *et al.* (2019) introduced an improved set pair analysis combined with evaluation grades/indexes to evaluate dam break environmental impact. In Brumadinho, Brazil after a devastating tailing dam collapse event that caused 270 deaths and tremendous environmental impact, Parente *et al.* (2021) tried to assess the contamination in sediment, fish, and macrophytes along the Paraopeba River, upstream, and downstream from the dam failure site while for Wu *et al.* (2019) and Latrubesse *et al.* (2020) also assessed the environmental impacts of dam failures.

Only a few studies attempted to assess dam failure flood losses considering all the aspects such as dam benefit losses and all the social-economic losses. For example, in the US, in 1993, Ellingwood *et al.* (1993) proposed a framework that considered dam-related cost, social-economic, and environmental losses by utilising financial, mathematical, and engineering approaches. In the US, Parente *et al.* (2021) proposed probably the most comprehensive methodology for assessing the economic consequences of dam failure by considering dam benefit losses, and direct and indirect economic losses at the local and national levels using financial and engineering techniques. Therefore, there is a lack of research in assessing dam-break flood hazard risk and its impact assessment that considers all the aspects of losses such as dam benefit losses, dam failure flood-related socio-economic and environmental losses.

Dam Safety Studies in Malaysia

The United Nations' Sendai Framework for Disaster Risk Reduction (SFDRR) 2015-2030 and Sustainable Development Goals (SDG)

are centred on ensuring the safety of human life and property through the development of a society that is resilient to all natural and manmade disasters. SFDRR and SDG both aim to reduce the risk of dam-related catastrophes. In accordance with the SFDRR and SDG, Malaysia has also implemented measures to reduce the likelihood of dam safety risks. To assure the safety of all registered dams and their downstream communities, the Drainage and Irrigation Department (DID) in Malaysia has developed the Dams Safety Management Guideline (MyDAMS) (Toh *et al.*, 2020). Disaster management authorities such as the National Disaster Management Agency (NADMA) and the Malaysia Civil Defence Force (MCDF), which are responsible for disaster management at the state, district, and community levels make strategic decisions regarding dam safety management (Shahrim *et al.*, 2019). In addition, Tenaga Nasional Berhad (TNB), the owner of the majority of the largest dams in Malaysia has implemented a plan to raise awareness and prepare dam owners, communities, and local authorities for dam-related disasters. TNB undertook a program known as Integrated Community-Based Disaster Management (ICBDM), which adopts the concept of 3Es; embrace, educate, and empower dam-surrounding vulnerable communities against any potential dam-related flood hazard (Rahsidi *et al.*, 2021).

Besides government, policymakers, and disaster management authorities, researchers are also concerned with dam safety issues, dam-related flood risk, and community engagement. For instance, Universiti Tenaga Nasional (UniTEN) has developed new application software for the Sultan Abu Bakar Dam called INSPiRE (Interactive Dam Safety Decision Support System), which is an intelligent dam safety software capable of addressing emergencies, quick decision-making, and effective multi-stakeholder collaboration (Sidek *et al.*, 2018; Hidayah Ishak & Mustafa Hashim, 2018) examine dam pre-release as a crucial dam management strategy to reduce regular flood impact as well as the risk of flood-induced dam-

break hazards; Md Said *et al.* (2016) outlined the identification of an organisation chart and responsibility for the emergency management team of Sultan Abu Bakar Dam ERP; Sidek *et al.* (2022) used the hydrological model (HEC-HMS) to estimate probable maximum precipitation and other meteorological data in order to predict dam safety in Cameron Highlands' probable maximum flood; Rahsidi *et al.* (2021) investigated how knowledge transfer through a people-centered approach from local authorities can enhance a community's capacity to mitigate the negative effects of dam-related disasters with the aid of technological strategies such as sirens and disaster response exercises; Mohd Sidek *et al.* (2014) described how TNB developed an Emergency Response Plan (ERP) to implement a dam safety management programme in Malaysia from theoretical and practical perspectives; Shahrim *et al.* (2019) discussed dam safety issues in Malaysia and suggested strengthening governance, risk communication, and community resilience to face any future dam-related flood hazard; Muda *et al.* (2019) discussed dam safety Emergency Action Plan (EAP) and its application in Malaysia; Hasim *et al.* (2023) conducted a pre-qualitative analysis of prospective dam dangers at selected critical dams. Norlida (2014) discussed issues and challenges of the sustainable dam management system in Malaysia; Allias *et al.* (2022) were involved in the hydrological analysis of the flood and failure of Batu Dam, Selangor in an urban area; Rahsidi *et al.* (2017) analysed perception of public awareness and preparedness towards Early Warning System (EWS) for dam safety; Tipol *et al.* (2020) discussed the challenges in preparing and implementing the dam safety emergency plan. Dam safety concerns and dam failure have gained considerable research interest. Unfortunately, there is still a lack of literature regarding the assessment of the socioeconomic and environmental impact of dam failure floods before the occurrence of a disaster, whereas, without a proper understanding of the potential impacts of any destructive event, mitigation planning cannot be fruitful.

Social Safeguard Rating for Flood Risk

The assessment of dam-failure flood risk goes beyond just evaluating physical infrastructure; it must also incorporate the potential impact on communities, livelihoods, and ecosystems. A key aspect of this assessment is the Social Safeguard Rating, a tool that measures and evaluates the social vulnerabilities and safeguards in place to mitigate the adverse effects of flood events (Efthymiou *et al.*, 2017). The ranking method also considers the presence and effectiveness of current protections such as early warning systems, emergency response plans, evacuation protocols, and social support networks. The Social Safeguard Rating uses these criteria to identify groups at higher risk and locations where intervention and support are most needed. For example, the Reservoir Conservation Model RESCON 2 (2017) is a comprehensive tool for assessing the environmental and social implications of various sediment management options. It divides these effects into four categories: Significant impact, moderate impact, minor impact, and none. The assessment considers several factors, including natural habitat, human uses, resettlement, cultural assets, indigenous peoples, and transboundary impacts. This transition has also been aided by improved social protection legislation in host and funder countries, stronger requirements for funders, and developer engagement with international organisations. Plenty of the literature argues that safeguarding has become increasingly serious in recent years and that the primary cause of increased safeguarding implementation is social mobilisation (Grant, 2017).

One of the review studies from Grant (2017) in Laos, where several ethnic minorities and vulnerable groups were recognised during the drafting of the Resettlement Action Plan (RAP). Ethnic minorities are culturally separate from mainstream Lao culture, rely largely on natural resources, have distinct languages and traditions, and lack political representation. While the majority of inhabitants in the project region are lowland Lao or related groups, there are also smaller Mon-Khmer groups (about 60

households) with traditional houses in the central hills and the Hmong, an upland community (about 80 households). The Asian Development Bank maintains an Indigenous Peoples and Ethnic Minorities Safeguard Policy. Households with insufficient labour resources such as single parents with young children, elderly couples, and households with disabled members are classed as vulnerable. Previous experiences with hydropower and other infrastructure development have proven that more resources and funding are required to improve the living conditions of ethnic minorities and vulnerable groups and make them project beneficiaries. In response, the Social and Environmental Division has taken several steps, including hiring ethnic minority personnel to facilitate consultations with these groups, holding separate consultations and intensive discussions at both the group and household levels, arranging regular visits and reports from an international anthropologist to assess the situation, and assigning staff to closely monitor these groups.

To include safeguards in the early stages of project planning and budget for sufficient resources and time for the effort, early action is required to get a complete understanding of the borrower's project, procurement, and budget cycles, as well as safeguard management capacities and duties. This methodical approach guarantees that safeguards and a functional grievance resolution process are in place well before land acquisition and civil works begin. Early monitoring is crucial to focus on delivering entitlements during the critical phase. This also allows for the proper categorisation of safeguards as well as the implementation of well-planned livelihood restoration programmes, with specific consideration paid to the needs of the poor and vulnerable in impacted areas.

This concept of Social Safeguard Rating (SSR) by Grant (2017) can be used to assess and measure the social risks and impacts of development projects, policies, or initiatives. It aims to identify potential adverse social consequences and provides a framework for managing and mitigating these impacts to

ensure that the project benefits are equitably distributed and that vulnerable groups are not disproportionately affected.

Triple Bottom Line (TBL) as A Reference for Segregated Assessment

The proposed framework segregated social, economic, and environmental loss in assessing the impact. Hence, this segregated framework adopts the Triple Bottom Line (TBL) theory that Elkington (1999) proposed to explain the holistic assessment and improved assessment tool compared to the previous framework. The TBL is a framework for accounting that considers the social, environmental, and financial aspects of performance. These will be referred to as the 3Ps. The triple bottom line encourages organisations and firms (in this case, the dam owner) to consider their activities in terms of multiple or condensed environmental, social, and economic values in addition to the monetary value they produce.

In the tightest meaning, TBL is used to report and measure the organisation's performance in terms of business, social, and environmental parameters. In the widest meaning, this concept is to comprehend entire set of values, problems, and processes that an entity needs to consider to minimise the harmful impact resulting from its activities (i.e., flood risk due to the dam failure). This is connected to having a distinct understanding of the organisation's goal, which is to take stakeholders' needs and expectations into account when making decisions and carrying out operations (Jonker *et al.*, 2014). In this sense, TBL is helpful to assist stakeholders who will be impacted by the dam failure disaster by providing a clear picture of what the dam owners', policymakers', and government emergencies' action plan and how to mitigate the risks at minimum loss.

In terms of social impacts, TBL aids in examining just and beneficial actions toward the community near the dam. An organisation establishes a social structure in which its reputation and the interests of its constituents are intertwined. Owners of dams will consider

the importance of safety and protection, as well as educate the public and provide them with enough information to respond effectively in the event of a disaster. Providing a mitigation plan to a high-risk community is one of the most efficient tools for reducing social loss. A Sustainable Development Goal (SDG) objective must be connected to the potential loss from a dam failure when reporting on an organisation's economic performance. TBL helps with this by stating that the community will suffer significant harm due to economic loss. When reporting on environmental performance, TBL may in many instances serve as a tool to help management entities focus on factors other than just economic value but also towards environmental and community value which an entity generates by increasing and destroying this capital (Zak, 2015). As a result, this concept supports the ecosystem service valuation methodologies which enable the financialisation of otherwise intangible values, like the value of biodiversity in a company's local business environment, not only for value-added activities but in terms of environmental losses due to a disaster like dam-failure flood risk.

The TBL concept is crucial for businesses, firms, and organisations in various commercial environments because it upholds the idea that organisations are jointly responsible for their effects on socioeconomic development through its implementation (Zak, 2015). This concept also emphasises how this three-sphere (economic, social, and environmental) model facilitates the segmented framework in the case of social, economic, and environmental damages. Hence, this theory will provide a clear picture of how dam failure losses could be measured using this concept and lead to sustainable mitigation of risks due to dam failure events.

Methodology

A comprehensive literature review was used to choose papers for this research. The researchers explored relevant literature that addressed dam flood risk assessment. To accomplish this, the researchers used specific

terms to search electronic databases such as Scopus, ScienceDirect, and Google Scholar. The following keywords were used: "Dam failure", "flood risk", "socioeconomic impact", "environmental impact", "assessment", and "framework or methods".

The initial search generated a pool of 179 papers on the subject. The researchers screened a large number of papers and identified the most relevant and significant ones. They began by evaluating the paper titles and abstracts to determine their relevance to the research objective. At this stage, papers that were unconnected to dam flood risk effect assessment or did not match the specified inclusion requirements would be rejected.

Following the initial screening, the researchers conducted a more in-depth review of the remaining papers. The papers were read in their entirety to judge their quality, relevance, and contribution to the field. The 20 most exceptional publications were chosen for being the best in addressing their research objectives. The articles chosen addressed numerous frameworks and methods used in dam flood risk assessment, reflecting the various purposes and objectives of each study. These frameworks and approaches were created to provide reliable and thorough data on dam failure, flood danger, socioeconomic impact, and environmental impact. The scholars could get multiple viewpoints and achieve a holistic understanding of the topic by considering various techniques.

Five of the 20 papers focused on case studies on dam failure or dam breaches. The other 15 papers were about flood risk occurrences as explained in Figure 1. Among the 20 papers selected, the publication years were between 1993 and 2020 (Figure 2). Although the time range was large, the majority of the papers were published in recent years, so, most of the data are current. Several countries involved in these studies also included the major continents as shown in Figure 3 but there was no specific study in Malaysia. This paper fills the gap in the study of dam-failure flood risk in Southeast Asia, especially in Malaysia, regarding

assessing socioeconomic and environmental losses. Despite this contrast, the researchers recognised the close relationship between dam failure and flood episodes. They understood that a dam break or failure may cause flooding in downstream areas or inundation zones. As a result, the researchers regarded both sort of studies as significant and necessary for their investigation.

Overall, the researchers chose publications for their comprehensive and rigorous analyses, ensuring that they had a solid base of literature on dam flood risk effect assessment. This meticulous screening process almost certainly contributed to the dependability and trustworthiness of their research findings and conclusions.

Results and Discussion

By reviewing past studies of related dam flood risk impact assessments, various frameworks have been suggested and implemented to get the most accurate and holistic result. This paper selected the 20 most outstanding papers. 5 out of 20 papers are primarily on dam failure or dam breach events while the rest are on flood risk events. Both type of papers are considered for the current study as dam breach or failure will most likely lead to floods in inundation or downstream paths. Different models or frameworks have been used in each paper but the most intriguing were the studies that used GIS or 3D modelling to simulate the event, thereby, offering clear views of which part and

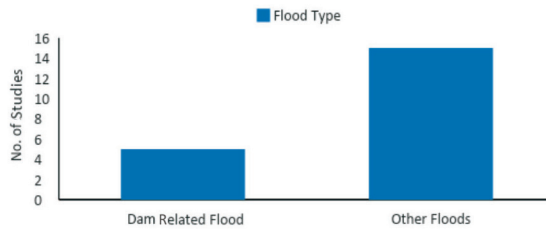


Figure 1: Number of studies included in the review based on “type of flood”

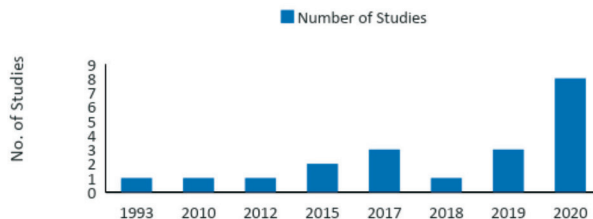


Figure 2: Number of studies included in the review based on “year of publication”

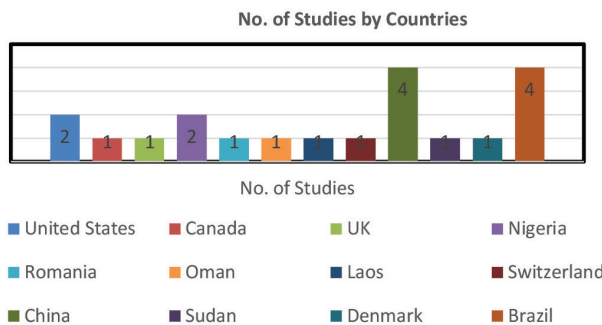


Figure 3: Number of studies included in the review based on “countries”

aspect will be affected when a flood happens. Likewise, an integrated framework where two models were combined achieved a more comprehensive and reliable result. Studies by Cannata and Marzocchi (2012) and Al Ruheili *et al.* (2019) combined the hydrodynamic model with GIS to have a better simulation of the intensity of dam-break floods. They mapped the data of land use to see which area was affected. But these efforts were only basic simulations without considering other effects on the social, economic, or environmental aspects. Unlike Kaspersen and Halsnaes (2017), used both primary flood simulation and also considered the impact of climate change and calculated the cost of damage borne by the community and government. Using the Danish Integrated Assessment System (DIAS), they integrated a framework between analytical tools with secondary data which gives wider but more accurate results. Hence, the implication in terms of losses in the social aspect cannot be defined by this method.

In dam break cases, Wang and Zhou (2010) and Latrubesse *et al.* (2020) used simulation tools to study engineering aspects like velocity, water level, flood dynamics, and flood depth but the difference was their little add-on focus on the geological factors – mineralogical analysis in the case of Latrubesse *et al.* (2020) and environmental factors – water quality in the case of Wang and Zhou (2010). In terms of loss of life for dam-break events, Lin *et al.* (2020) used the Cloud Model to map the life-loss risk grade and identify the possible mortality rate while Shabu and Musa (2015) considered not only the number of affected people but also damage and losses on the health sector, livestock, fish production, and commercial activities and employment using the Economic Commission for Latin America and the Caribbean (ECLAC) framework. Nevertheless, Shabu and Musa (2015) may be close to this paper's objective but it neglects environmental impact and total loss borne by the community, unlike Ellingwood *et al.* (1993), where all losses are counted. Another interesting paper by Mahmood *et al.* (2017)

analysed primary and secondary data to come up with a result that involved people's opinions on flood events and social impact.

The analytical tool was another majority model and framework example used by Lins-de-Barros (2017), Diakakis *et al.* (2020), and Țincu *et al.* (2020), where the result was calculated by integrating the data into mathematical or analytical software/tools to come up with visible graph, matrix, or scale that can be easily analysed based on the goal of the research. Besides, most of these analytical tool models will be paired with other tools like vulnerability assessment, damage analysis, or indexes. Rezende *et al.* (2020) used index data to do flood risk mapping on building susceptibility and socioeconomic factors. GIS-based approaches are usually combined and integrated with another approach, like the FLUS model and Markov chain model by Lin *et al.* (2020) to do land-use simulation and its impact on urban areas and the environment while Hossain and Meng (2020) reverse the sequence by using Quantitative Cartographic to be integrated into GIS to estimate how the flood will affect minority communities. A little bit similar to Chakraborty *et al.* (2020), where Principal Components Analysis (PCA) was used by constructing the socioeconomic status (SES) index and mapping its spatial variability to see which area is the most densely populated, which would be the most affected area by the flood.

In terms of socioeconomic assessment, Dolman *et al.* (2018) collected primary data using Forms of Information of Disasters (FIDE) and Sexual Orientation Method (SOM) questionnaire distributed to the community; then, the data would go through uncertainty analysis. However, loss of life has been left out. One unique framework from Vamvakeridou-Lyroudia *et al.* (2020) used Risk and Resilience Modelling to identify cascading effects on CI assets, which means infrastructure and estimate their level of damage. Some papers adopted economics models, for example, Zeng *et al.* (2019) used the Adaptive Regional Input-Output (ARIO) model to identify the supply and demand for a flood event while Haddad and

Teixeira (2015) adopted the Spatial Computable General Equilibrium (SCGE) Model to know the effect of flood on businesses. In both cases, they focused only on economic impact. Figure 4 shows the summary of past studies on the research approach explained above.

Despite this, various gaps from the previous studies have been noted such as the fact that all papers only focus on one or two primary

impacts, although three main impacts, namely social, economic, and environmental impact assessment should be included. Nevertheless, integrated qualitative and quantitative frameworks have been suggested to adapt to achieve broad, holistic, and accurate results while some are focused on only one approach. Meanwhile, many of the studies originated from the Middle East and the West; they should be adapted to Asian countries, especially South-

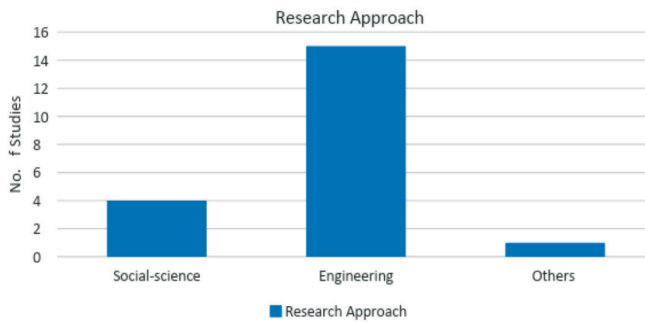


Figure 4: Type of research approach from past studies

Table 1: Summarisation of past studies' framework and elements

| No. | Title | Author | Elements | Framework/ Model | Gaps |
|-----|--|-----------------------|--|---|--|
| 1 | Downstream socio-economic impact of dam failure: A case study of 2012 river flooding in Benue State, Nigeria | Shabu and Musa (2015) | <ul style="list-style-type: none"> • Number of people affected • Value of damage and loss in the health sector • Estimated needs for the health sector • Flood impact on livestock • Flood impact on fish production • Affected Commercial activities • Impact on employment and income in commerce | <ul style="list-style-type: none"> • Economic Commission for Latin America and Caribbean (ECLAC) | Ignored the environmental damage and total loss that the community must bear |

| | | | | | |
|---|---|---------------------------------|--|--|---|
| 2 | Dam failure and a catastrophic flood in the Mekong basin (Bolaven Plateau), southern Laos, 2018 | Latrubesse <i>et al.</i> (2020) | <ul style="list-style-type: none"> • Estimating water level changes • Modeling of peak discharge, velocities, water stage, and flood dynamics • Sediment grain size and XRD-mineralogical analysis | <ul style="list-style-type: none"> • DIFFRAC.EVA software | Concentrating solely on engineering aspects of the geological component - mineralogical analysis |
| | Two-dimensional dam-break flooding simulation: A GIS-embedded approach | Cannata and Marzocchi (2012) | <ul style="list-style-type: none"> • Intensity flood map | <ul style="list-style-type: none"> • Hydrodynamic model • GIS-embedded | Simple simulation without addressing any further implications on the social, economic, or environmental factors |
| 3 | Assessing the cost of dam failure | Ellingwood <i>et al.</i> (1993) | <ul style="list-style-type: none"> • Property damage • Disrupted activities • Emergency response • Morbidity and mortality • Environmental effects • Cultural and historic • Reported monetary damage • Loss of life | <ul style="list-style-type: none"> • Cost-measurement (data-type) | Neglected environmental impact |
| 4 | Study on environmental risk of dam failure | Wang and Zhou (2010) | <ul style="list-style-type: none"> • Flood velocity • Flood depth • Dam-break routing • Water quality | <ul style="list-style-type: none"> • 3-D turbulence model for dam-break flow coupled with the Volume of Fluid (VOF) | Focusing solely on engineering issues of environmental impact - water quality |
| 5 | Risk evaluation model of life loss caused by dam-break flood and its application | Li <i>et al.</i> (2019) | <ul style="list-style-type: none"> • Map of life-loss risk grade • Mortality rate | <ul style="list-style-type: none"> • Cloud model | Only considers the impact of life loss |

| | | | | | |
|----|---|-------------------------------|--|---|---|
| 6 | Lessons learned from Khartoum flash flood impacts: An integrated assessment | Mahmood <i>et al.</i> (2017) | <ul style="list-style-type: none"> • Rainfall conditions • People perception • Flood impacts on water supply and quality • Morbidity and mortality • Social vulnerability and risk • Mitigation measures | <ul style="list-style-type: none"> • Secondary and primary sources | The economic and environmental consequences are not addressed |
| 7 | Integrated climate change risk assessment: A practical application for urban flooding during extreme precipitation | Kaspersen and Halsnaes (2017) | <ul style="list-style-type: none"> • Flood modeling • Impact of climate change on extreme precipitation • Damage cost assessment | <ul style="list-style-type: none"> • Danish Integrated Assessment System (DIAS) | Disregard social impact comprehensively |
| 8 | Integrated coastal vulnerability assessment: A methodology for coastal cities management integrating socio-economic, physical and environmental dimensions - A case study of Regiao dos Lagos, Rio de Janeiro, Brazil | Lins-de-Barros (2017) | <ul style="list-style-type: none"> • Coastal vulnerabilities dimensions map • Urban population living on the erosion and wash-prone shoreline • Coastal vulnerability index (matrix value) | <ul style="list-style-type: none"> • Matrix of exposition degree versus adaptive capacity • Diagram for Integrated Coastal Vulnerability Assessment - DICVA | The emphasis is solely on coastal communities, which may or may not apply to other sorts of communities |
| 9 | Scenario-based flood risk assessment for urbanizing deltas using future land-use simulation (FLUS): Guangzhou metropolitan area as a case study | Lin <i>et al.</i> (2020) | <ul style="list-style-type: none"> • Land-use simulation • Impacts of urbanisation and environmental changes | <ul style="list-style-type: none"> • FLUS model • Markov chain model • ArcGIS | The economic impact was not discussed in depth |
| 10 | Quantitative micro-scale flood risk assessment in a section of the Trotuş River, Romania | Țîncu <i>et al.</i> (2020) | <ul style="list-style-type: none"> • Damaged houses and annexes • Houses destroyed • Communal road • Village road (alleys) • National road • Culverts • Agricultural land | <ul style="list-style-type: none"> • Vulnerability analysis • Damage analysis • Loss exceedance curve | Losses borne by the community are not reflected, nor is the social impact |

| | | | | | |
|----|--|--|---|--|---|
| 11 | Proposal of a flash flood impact severity scale for the classification and mapping of flash flood impacts | Diakakis <i>et al.</i> (2020) | <ul style="list-style-type: none"> • Impact on the built environment • Impacts on man-made mobile objects • Impacts on the natural environment • Impacts on the human population | <ul style="list-style-type: none"> • 10-class severity scale | Economic impact is not adequately discussed and monetary value loss is also ignored |
| 12 | Mapping the flood risk to socioeconomic recovery capacity through a multicriteria index | Rezende <i>et al.</i> (2020) | <ul style="list-style-type: none"> • Mapping of building susceptibility indicators • Socioeconomic mapping (average income) • Flood mapping • Mapping of the vulnerable and non-vulnerable people | <ul style="list-style-type: none"> • Risk to Socioeconomic Recovery Capacity Index (Ri-SoRCI) | Neglected environmental impact |
| 13 | A thematic mapping method to assess and analyse potential urban hazards and risks caused by flooding | Hossain and Meng (2020) | <ul style="list-style-type: none"> • Children and elderly • Female • Hispanic • African-American • White • Not enrolled in school • Studied below 12th grade • Rented homes • Housing units without a vehicle available • Mobile homes | <ul style="list-style-type: none"> • GIS • Quantitative cartographic | SVI cannot reveal the precise vulnerable level of individual minority or economic factors |
| 14 | Assessing and visualising hazard impacts to enhance the resilience of critical infrastructures to urban flooding | Vamvakeridou-Lyroudia <i>et al.</i> (2020) | <ul style="list-style-type: none"> • Affected buildings • Level of damage | <ul style="list-style-type: none"> • Climate risk management • Risk and resilience modelling | Only calculate infrastructure damage and determine its severity |

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|----|---|----------------------------------|--|---|--|
| 15 | A place-based socioeconomic status index: Measuring social vulnerability to flood hazards in the context of environmental justice | Chakraborty <i>et al.</i> (2020) | <ul style="list-style-type: none"> • Socioeconomic • Demographic • Ethnic • Cultural | <ul style="list-style-type: none"> • Principal Components Analysis (PCA) | The environmental impact seems to be ignored |
| 16 | Flood footprint assessment: A new approach for flood-induced indirect economic impact measurement and post-flood recovery | Zeng <i>et al.</i> (2019) | <ul style="list-style-type: none"> • Capital loss • Labour constraints • Basic demand • Supply bottleneck • Rationing scheme | <ul style="list-style-type: none"> • Adaptive Regional Input-Output (ARIO) model | Only consider the economic impact of a flood on supply and demand. Also, the monetary value is not derived from this study |
| 17 | Re-thinking socio-economic impact assessments of disasters: The 2015 flood in Rio Branco, Brazilian Amazon | Dolman <i>et al.</i> (2018) | <ul style="list-style-type: none"> • Loss of belongings • Agriculture loss • Income loss • Services loss • Damages to housing | <ul style="list-style-type: none"> • Forms of Information of Disasters (FIDE) • Sexual Orientation Method (SOM) questionnaire • Uncertainty analysis | The loss of life has been omitted |
| 18 | Wadi flood impact assessment of the 2002 cyclonic storm in Dhofar, Oman under present and future sea-level conditions | Al-Ruheili <i>et al.</i> (2019) | <ul style="list-style-type: none"> • Simulated maximum flood extent • Residential buildings • Commercial buildings • Industrial buildings • Agricultural lands • Roads | <ul style="list-style-type: none"> • Hydrodynamic model • Damage model | Further studies on an integrated framework to allow for the monetary quantification of wadi flood risk using an economic valuation model |
| 19 | Economic impacts of natural disasters in megacities: The case of floods in Sao Paulo, Brazil | Haddad and Teixeira (2015) | <ul style="list-style-type: none"> • Number of businesses impacted • Foregone labour income | <ul style="list-style-type: none"> • Spatial Computable General Equilibrium (SCGE) model | To understand the effects of flooding on the company without considering social status and economic impact |

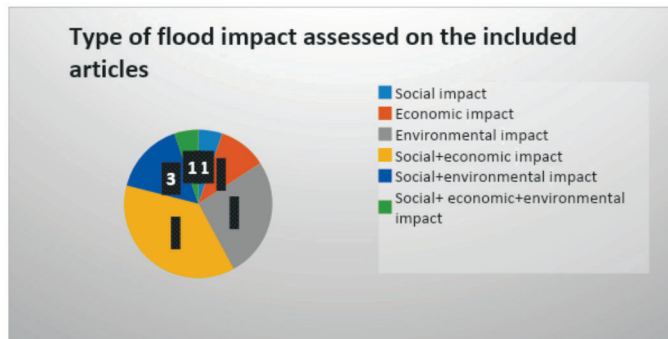


Figure 5: Type of flood impact assessed in the reviewed papers

East Asia, where floods are most likely a yearly event. Thus, this study attempts to develop a comprehensive framework of all possible impacts on all stakeholders, especially the community downstream of the dam or inundated area. All discussions are summarised in Table 1.

These past papers have gaps in their analyses that need to be addressed since they need to correctly evaluate the wide variety of consequences that dam failure can have on communities. In addition, they have been criticised for being overly focused on the engineering components and ignoring the social, economic, and environmental factors that a dam failure would impact. The majority of the articles studied in this paper must account for the community's environmental damage and complete loss. Dam failure has a substantial environmental impact since it can cause water contamination, ecosystem damage, and wildlife habitat loss. Again, past papers failed to address this topic thoroughly. Furthermore, some articles have been rebuked for focusing solely on the cost of life loss and failing to address dam failure's economic and environmental consequences. This is essential because dam failure can result in enormous economic costs in terms of infrastructure damage and loss of livelihood for people in affected communities. Past reports have been criticised for failing to analyse the full social impact of dam failure, focusing primarily on coastal areas, and failing to discuss the economic implications in depth.

They are also chastised for failing to disclose the vulnerabilities of specific minorities or economic considerations, ignoring the environmental impact, and providing an integrated framework for the monetary calculation of flood risk. Furthermore, the articles are criticised for failing to evaluate the consequences of flooding on businesses, specifically how it may impair their operations based on the community's social status and economic impact (Figure 5). Summarise the past paper cover topics for better understanding.

To bridge the gaps mentioned above, the paper's goals should include a comprehensive framework considering dam failure's social, economic, and environmental consequences. In addition, an integrated strategy should be employed to examine the probable consequences of dam failure. This should include using models and simulations that account for dam failure's social, economic, and environmental effects. This might be accomplished by including the following elements.

Environmental Impact Assessment

A detailed examination of the potential environmental harm caused by a dam failure should be carried out. This should include a consideration of the potential effects on water quality, ecosystems, and wildlife habitats (Diakakis *et al.*, 2020).

Social Impact Assessment

A study of the probable social consequences of dam failure should be done. This should include a consideration of the potential displacement of communities, loss of cultural assets, and loss of social cohesiveness (Shabu & Musa, 2015; Hossain & Meng, 2020).

Economic Impact Analysis

A study of the probable economic consequences of dam failure should be carried out. This should include an assessment of probable infrastructure damage, loss of livelihoods, and economic value loss (Zeng et al., 2019).

Community Participation

Communities should be involved in assessing the potential consequences of dam failure. This will ensure that the viewpoints and concerns of people affected by dam failure are considered (Mahmood et al., 2017).

Monetary Quantification

Using an economic valuation model, the study might include a monetary quantification of the risk of dam failure. This will aid in comprehending a dam failure’s economic consequences and the worth of monetary loss. In addition, the study should look into how dam failure affects minority and economic groups and how flooding affects businesses and their operations regarding the community’s social and economic status (Ellingwood et al., 1993). By including these factors, the article will bridge

the gap and present a comprehensive framework that considers dam failure’s social, economic, and environmental consequences.

Findings

Given the above mentioned gaps in the existing literature to assess socio-economic losses due to flood risk, this study proposed a new framework aimed at facilitating the socio-economic impact assessment of dam hazard flood risk in a more comprehensive and less complicated way as well as filling the gaps in the previous studies to build a more resilient society.

As the number of studies on flood risk impact assessments is higher compared to dam hazard risk impact assessments, dam failure flood loss elements are assumed to be the same as common flooding. Other than dam benefit losses, dam repair, or replacement cost, the proposed framework in Figure 6 considered the flood characteristics and loss elements addressed by previous studies on both flood risk impact assessment and dam hazard risk impact assessment. Considering this, the proposed framework modified the most used damage model to assess tangible flood damage addressed by Hammond and Chen (2013) and Berkman and Brown (2015) which shows how flood characteristics influence damage to inundated structures such as residences, infrastructure, etc. In the proposed framework “**Flood Risk**” is taken as the independent variable and includes **three** most widely used flood characteristics to

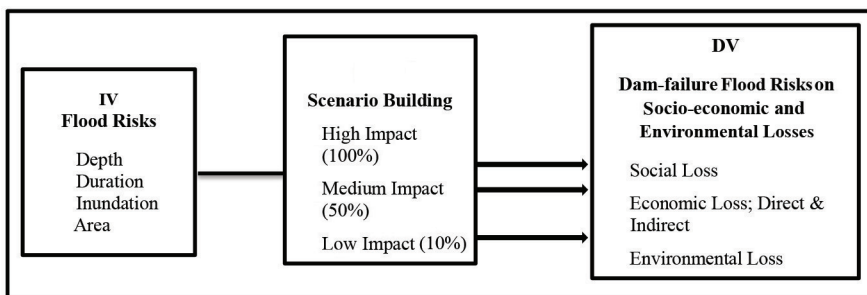


Figure 6: Proposed framework for assessing dam-failure flood risk on socio-economic and environmental losses

assess the extent of flood risk: “Flood Depth”, “Inundation Area” and “Flood Duration”.

The proposed study will adhere to recommendations from the Federal Emergency Management Agency (FEMA) for consequence assessment of dam failure published in 2012 for high (100%), medium (50%), and low (10%) levels of damage based on the anticipated level of damage. The preliminary estimate of the anticipated level of damage has to be made for the scenario using descriptive terms such as high, medium, and low. The goal is to differentiate among assets that would be seriously damaged, assets that would experience some flooding, and assets that would not be expected to be damaged by dam failure because of their location at the periphery of the inundation area. If information about the topography of the inundation area and the possible depth and velocity of water following dam failure is limited, base the anticipated level of damage on distance from the dam. Then, this anticipated level of damage will lead to a damage factor which will influence the monetary losses. Decisions may be made to revise the damage factors and repeat the analysis to reach conclusions that seem more appropriate to local stakeholders (FEMA, 2012). FEMA (2012) also stated that low flood severity occurs when no buildings are washed off their foundation at a “Flood Depth” of less than 10 feet, medium flood severity occurs when homes are destroyed but trees or severely damaged homes remain where people can seek refuge at a “Flood Depth” of greater than 10 feet, and high flood severity occurs when nothing is left and the flood sweeps the area clean, resulting in very deep floodwater reaching its ultimate height in a matter of minutes. Suggestions from regional experts in flood risk management will be used for the other two independent variables, inundation and flood duration, for each dam failure scenario.

Dam-failure flood risks on socio-economic and environmental losses are the Dependent Variable which includes various social, economic, and environmental loss elements which were addressed or proposed in previous

flood impact assessment studies. For collecting primary data, the proposed framework will use two questionnaire surveys: A community-based questionnaire and an expert or opinion-based questionnaire. Secondary data will be collected from concerned authorities such as dam owners, ministries, government offices, government database, and other stakeholders. Community-based data will be collected to assess the current socio-economic status of the dam’s surrounding community and previous loss experiences because of the flood. Expert or opinion-based questionnaires will be used to collect qualitative impacts such as environmental impact, which will be collected from local stakeholders, scientific experts, etc. All these kinds of questionnaires have been proposed to fulfil the integrated framework that has been proposed as the need for community perception of flood risk. The questionnaire was adopted and adapted from past studies regarding flood risk and most of the questions used the Likert Scale. The Likert Scale has been used to quantify “attitude” in a scientifically approved and validated way (Joshi *et al.*, 2015). Data related to probable flood duration and inundation area will be collected from secondary sources such as government or relevant authorities and experts to assess flood risk. Tables 2, 3, and 4 represent sources of data collection of social, economic, and environmental loss elements, respectively.

Since the proposed framework will involve knowing the current value of socio-economic and environmental assets in the dam’s surrounding area, besides quantitative data some uncertainties and opinion-based qualitative data to predict and quantify probable future losses as a result of the plausible level of flood risk is needed. Economic scenario building is found to be the most suitable method regarding this. According to Berg *et al.* (2016), scenario building involves assessing the influence of key factors of possible changes and their complex interactions to know multiple plausible futures within a certain probability space. It is a widely used method to explore possible socio-economic and environmental changes (Metzger *et al.*, 2010). Hence, the proposed framework will use

Table 2: Suggested elements with sources to assess social losses

| Elements | Direct Loss | Indirect and Additional Cost | Sources of Data Collection |
|---|--|--|--|
| Household Adeel et al. (2020) | <ul style="list-style-type: none"> Household items Dwelling Cleaning | <ul style="list-style-type: none"> Increase in house rent | Community questionnaire |
| Education Awopetu et al. (2013); Adeel et al. (2020) | <ul style="list-style-type: none"> Building Classroom Cleaning | <ul style="list-style-type: none"> Missing loss days due to school closure Temporary classroom Reset service | Community questionnaire |
| Health Awopetu et al. (2013); Adeel et al. (2020) | <ul style="list-style-type: none"> Loss of life Physical damage Medical equipment | <ul style="list-style-type: none"> Increase number of patients in the emergency room Post-disaster disease and related cost Workdays lost due to psychological problem Hospital-related cost | Community questionnaire |
| Water and sanitation Awopetu et al. (2013); Adeel et al. (2020) | <ul style="list-style-type: none"> Rebuilding Distribution network Storage tank | <ul style="list-style-type: none"> Temporary water supply | Secondary source community questionnaire |
| Cultural resource Adeel et al. (2020) | <ul style="list-style-type: none"> Worship places Recreational places Graveyard | | Secondary source community questionnaire |
| Loss of livestock Jega et al. (2018) | <ul style="list-style-type: none"> Disease Death | | |
| Local government and community Adeel et al. (2020) | <ul style="list-style-type: none"> Damages of local infrastructure provided by local government | <ul style="list-style-type: none"> Loss of tax revenue | Secondary sources |
| Food security Jega et al. (2018) | <ul style="list-style-type: none"> Shortage of food stock during flood | | Community questionnaire |

Table 3: Suggested elements with sources to assess economic losses

| Elements | Items | Sources of Data |
|---|--|--|
| Direct economic impact | | |
| Dam benefit loss Munger (2009) | <ul style="list-style-type: none"> Agriculture Recreation | Secondary source community questionnaire |
| Property damage Munger (2009) | <ul style="list-style-type: none"> Residential | Secondary source community questionnaire |
| Indirect economic impact | | |
| Labour reduction Munger (2009) | <ul style="list-style-type: none"> Number of workers Workers affected Wages per month | Secondary source community questionnaire |
| Capital loss of production Munger (2009) | <ul style="list-style-type: none"> Production cost per month Capital cost | Community questionnaire |

Table 4: Suggested elements with sources to assess environmental losses

| Elements | Items | Sources of Data |
|---|-------------------------------------|---|
| River morphology and water quality Wu <i>et al.</i> (2019) | Sediment value per length and width | Secondary sources Expert/opinion-based interview |
| Vegetation cover Wu <i>et al.</i> (2019) | | |
| Biodiversity Markantonis <i>et al.</i> (2013); Gu <i>et al.</i> (2020) | Land damage rate and severity | Secondary sources Expert/opinion-based interview |
| River morphology and water quality Wu <i>et al.</i> (2019) | Changes in biological habitat | Secondary sources Expert/opinion-based interview |

the scenario-building method to deeply analyse the dam-break event and its potential socio-economic and environmental consequences by using Hybrid Techniques as it needs the interaction of both quantitative and qualitative data (Berg *et al.*, 2016). Before doing a scenario-building analysis for consequence assessment, the proposed framework suggests making a list of social, economic, and environmental inventory assets that may be in potential inundation zones if the dam fails. In addition,

it is essential to identify assets in the area that are vulnerable to flood as well as infrastructures and resources that rely on the impoundment. The local flood risk management organisation, aerial photos, land use plans, Emergency Action Plans (EAP) for dam failure, GIS databases, economic studies, state, district, or municipal data, and interviews with locals can be used to gather information about vulnerable assets. An example of such a list is adapted from FEMA (2012) which is presented below in Table 5.

Table 5: List adopted from FEMA (2012)

| Asset | Location | Approximate Distance from the Dam (in km) | Estimated Occupancy (number) | Replacement Value (in million) | Content Value (in million) | The Presence of Large Quantities of Pollutants in the Assets |
|--------------------|------------|---|------------------------------|--------------------------------|----------------------------|--|
| Reservoir | Behind dam | 0 | 0 | X | X | N/A |
| Restaurant | X | X | Total no. of seats and staff | X | X | N/A |
| Industry XYZ | X | X | X | X | X | Large quantities of salt/other pollutants |
| Agricultural Land | X | X | X | X | X | N/A |
| Single family home | X | X | X | X | X | N/A |
| Single family home | X | X | X | X | X | N/A |

*X: Representing number that should be obtained.

The tax assessor, the local engineer, and the local planning documents may have the information to help figure out how much it would cost to fix or replace the building. For a start, an estimate of 50% of a building’s replacement value is to figure out how much its contents are worth. For irreplaceable artefacts in museums, libraries, and other historic buildings, discussions need to be had with institution administrators to determine the value of the items. When making this inventory assets, it is important to find out if any of the structures contain pollutants that could contaminate the water. After collecting all of the quantitative and qualitative data for social, economic and environmental impact, scenario-building analysis will be performed under different probabilities of dam failure flood risk scenarios to determine all the potential effects of dam failure. All processes in the framework are simplified in Figure 7.

Therefore, the proposed framework will add a new dimension to the existing dam hazard impact assessment studies in terms of its uniqueness for considering all possible social, economic, and environmental loss elements in a single frame which will also fill the gap in existing literature, as most of the previous studies on dam failure did not consider community-based impact assessment whereas the relevant community suffers the most from such an event. Another distinction of this proposed framework is to consider possible social impacts, as most of the previous dam hazard impact assessment studies ignored important elements such as household losses, losses due to closure of educational institutions, health impact, loss of livestock, social morale, etc. The proposed method is also significant for it requires comparatively less complexity as most of the previous dam hazard risk assessment methods

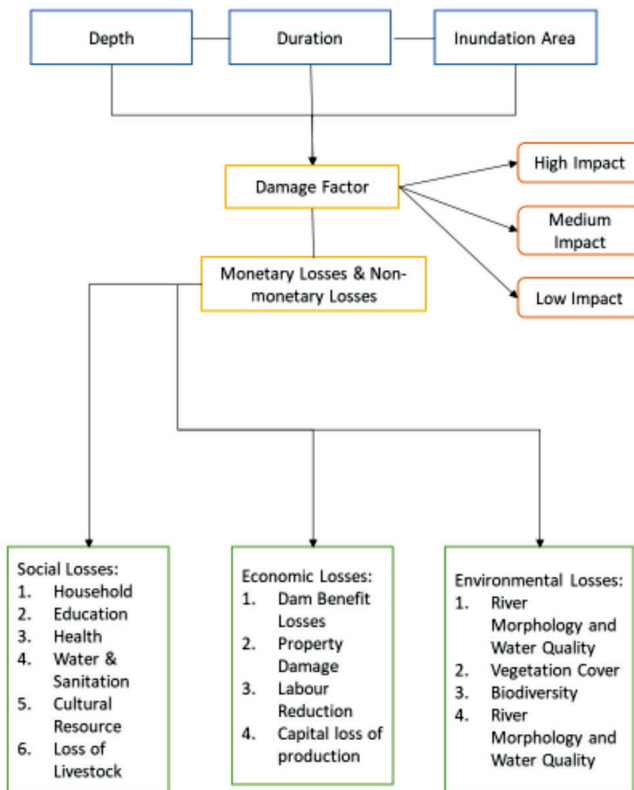


Figure 7: Suggested process flow of proposed framework

were involved in engineering approaches or complex mathematical approaches. Furthermore, the proposed framework will help to go one step towards sustainability by supporting Sustainable Development Goals (SDG) related to Sustainable Cities and Communities (UN, 2020). Overall, it is a holistic approach considering all possible loss elements, with less complexity with the involvement of all community and possible stakeholders for impact assessment.

Conclusion

Dams are usually built to serve various purposes such as water supply for household use, irrigation, industrial use, hydroelectric power plant, as well as for recreation. Most dams also work as a flood control barrier against common floods. Despite being a rare incident, the failure of a structure that acts as a flood control barrier may bring extreme and uncontrollable flooding that may cause severe destruction and loss of life. The study reviewed the prior works of literature in three aspects: Literature related to dam hazard risk assessment, the literature on dam failure flood that considered the losses to the communities and environment due to dam hazard risks, and the existing frameworks or models for assessing flood risk as well as assessing socio-economic and environmental losses. Most of the studies which attempted to estimate total losses considering socio-economic impacts were engaged in post-flood impact assessment by reviewing prior literature on flood risk assessment that considered socio-economic losses. It is found that integrated risk assessment requires complex mathematical and engineering methods, computer-based hydraulic modelling, or risk grading using mathematical techniques. Most of the studies assessed only limited elements of flood losses. This study proposed an integrated framework to predict dam-failure flood risk consequences comprehensively in less complicated methods in a single frame considering all possible elements such as social, economic: direct and indirect, and environmental.

The proposed framework assesses dam hazard flood risk impacts on the socio-economy and environment through socio-economic scenario building analysis: A hybrid method using both quantitative and qualitative techniques to know the level of dam hazard risk in three possible scenarios, i.e., high, medium, and low impact. As a causal factor of the losses, the proposed framework will consider two flood characteristics elements, i.e., flood duration and inundation area. Hence, the proposed framework will add a new dimension to assessing dam hazard flood risks and socio-economic and environmental consequences in a more concrete and less complicated way and it will help policymakers and stakeholders of dams such as owners, safety management, and surrounding communities, as well as help to ensure socio-economic and environmental sustainability. For future study, potential improvements can be made in the proposed framework by considering other flood risk elements and modifying loss elements based on differences in demography, topography, socio-economic conditions, dam use, and specific features.

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Conflict of Interest Statement

The authors declare that they have no conflict of interest.

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