

# A Review of Flood Vulnerability Utilizing Geographic Information Systems

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**Abstract:** *Recent worldwide catastrophes have highlighted floods on their destructive consequences. Asia accounts for over half of worldwide flood damage, killing, destroying infrastructure, and causing fear. Understanding flood hazard management requires assessing flood vulnerability. In flood study and evaluation, vulnerability is key. Researchers have developed ways to estimate flood sensitivity and risk in GIS. Geographic information systems forecast and reduce catastrophes. GIS flood measuring and vulnerability techniques are discussed here. Review of 2010–2020 flood vulnerability papers. A comprehensive evaluation of five research engines reveals that high-resolution data and multidimensional vulnerability technique may address risk assessment deficiencies. Many vulnerability components and approaches were studied at different levels. Research shows the indicator-based technique improves vulnerability assessment. Precision mapping and analysis using GIS avoid flood damage.*

**Keywords:** Flood vulnerability, Geographic Information Systems (GIS).

## I. INTRODUCTION

Floods kill people and increase physical, social, economic, and environmental risk. When water levels rise, coastal, reservoir, stream, and canal flooding occurs (Abah and Clement, 2013). Global floods harm 350 million. Flood damage might treble by 2050. Scholars are studying one of society's largest environmental challenges due to ecological change. Population expansion and home development increase flooding danger. Floods will intensify with population growth (Walker and Burningham, 2011).

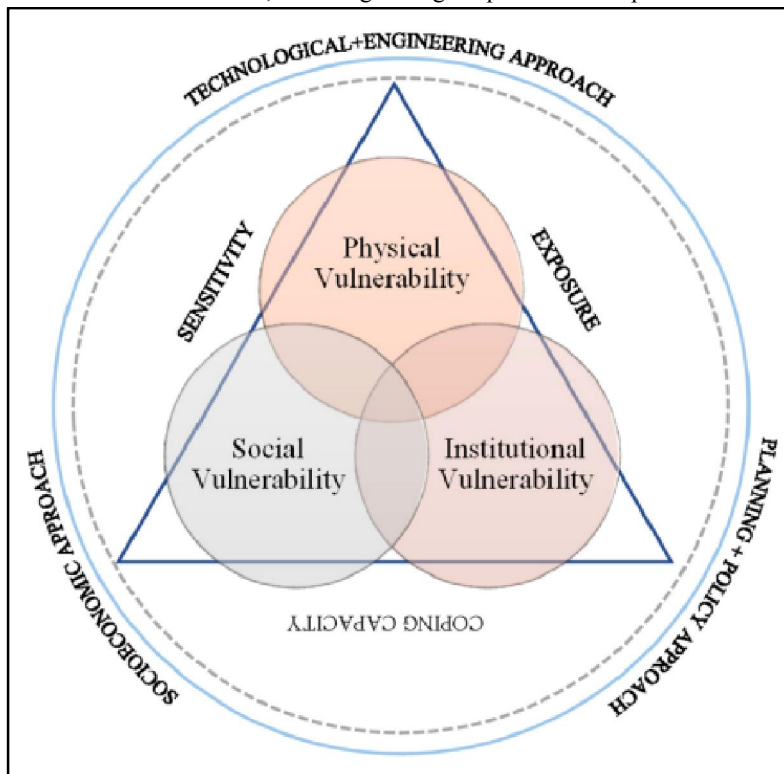
Abbas et al. (2009) expect major impacts for coastal residents within 100 km by 2030. Recent floods put doubt on climate change and human effect (Adams and Adams, 1984; Rehman et al., 2019; Abid, 2020). Population growth will enhance flooding (Adger, 2006). Population growth has increased erosion, natural rushes, and flood levels, making valued surfaces water-resistant. Recent flood damages averaged \$50 billion. Flooding rose from 2010 to 2019 (Adger et al., 2005).

Many were flooded in 2000, 2007, 2014, and 2015. Flooding affected 3.6 billion people 56% of the world's population between 2010 and 2020. Between 2010 and 2020, floods endangered 820,000 South and North Americans (Rehman et al., 2019). Floods caused human suffering, substructure damage, life hazards, and commercial expansion in developing nations.

In the last decade, Bangladesh, Mozambique, Germany, India, China, Malaysia, and the US have caused major damage and loss of life and property (Alias et al., 2020). The disaster affects most developed countries, particularly cities. From 1988 to 2000, nature and people cost Central America and Asia USD 3.64 trillion (Andrade and Szlafsztein, 2018). The American Andrew Hurricane produced \$27 billion in damages (Aroca-Jiménez et al., 2020). Examine flood damage and its devastating repercussions to solve the case. Cities flood more, affecting assets differently (Bajracharya et al., 2021).

Water pollution in cities boosts utility prices and health risks. Water damages surfaces too. Balica et al. (2009) report 52 nations losing USD 2 billion in buildings, animals, and crops since 2010. Southeast Asia, Africa, North, and South America had \$5 billion in flood damage in one year (Balica et al., 2013; Abid, 2021a, b, c). Unexpected southwest

Himalayan precipitation, tropical storms and depressions, riverbank withering, and insufficient high-discharge rivers cause Indian floods. Indian economy ravaged by 1980–2010 floods, second worst after famine. India, with 3.2 billion people, had the most fatalities in 1977 and 1978 and significant public service damage in 2001 (Andrade and Szlafsztein, 2018). Rivers are sensitive to people, illnesses, agriculture, and infrastructure. Disasters killed 80% of mothers, neonates, and vulnerable children (Balica et al., 2012). Geography affects the link between vulnerability and policy implementation (Bera and Dańek, 2018). Identifying flood-prone areas reduces community risk and improves flood response (Birkmann et al., 2013). Flood operations and strategic analysis need geographical and hydrological modeling, risk assessment, and model estimate. Real-time risk analysis, forecasting, and decision-making need temporal analysis. Natural and artificial catastrophes occur worldwide (Andrade and Szlafsztein, 2018). Garbutt et al. (2015) Sulaiman et al. (2020-b) Managing fast environmental changes requires a comprehensive vulnerability method to mitigate flood risk. Although flood assessments were formerly used for strategic planning and decision-making, their influence is still difficult to regulate. Due to environmental and physical changes, flood analysis demands rigorous methodology. The Netherlands minimized flood damage using probabilistic approaches (Kirby et al., 2019). Conventional spatial decision bridge approaches increase flood risk assessment and planning. Brooks et al. (2005) created a methodology and components to quantify socioeconomic vulnerability. Brouwer et al. (2007) assessed Malaysian local-scale flood risk and resilience, assessing damage exposure and response.



**Figure 1. Dimensions of flood vulnerability and flood risk assessment approaches; Modified from Cho and Chang (2017).**

Flooding increased poverty and economic disparity in Bangladesh, he added. Scholars have attempted to explain flood damage (Chang and Baiamonte, 2002). Water hazards create water vulnerability (Cannon, 2004; Chen et al., 2015; Chakraborty and Joshi, 2016; Canevari-Luzardo, 2017; Vazire, 2018). Hydrologic Engineering Centre (HEC-RAS) models provide river flood risk maps. These models have quantified Columbia River, Warsaw, Texas, and Dhaka flood risk (Creach et al., 2016; Rehman, 2019). GIS-based flood risk estimations benefit large regions, whereas hydrodynamic models concentrate on individual flood dynamics (Abid et al., 2021a, b, c). Linear water risk assessment is restricted compared to parametric approaches. Susceptibility assessment with these two methods is good (Dandapat and Panda,

2017). Sharma et al. (2018) studied how probability and penalty affect flood judgment. Andrade and Szlafsztein (2018) suggest hybrid and ensemble machine learning models may reduce flood risk in Iran's Haraz watershed. They noted that the correct model parameters may easily include flood vulnerability. Water responsibility is crucial in risk assessments. Flood susceptibility has been assessed using various methods for years (Rehman et al., 2019). Other aspects need comparison (Andrade and Szlafsztein, 2018). Previous research found several vulnerability assessment approaches. Vulnerability curve, indicator-based, analytical hierarchy, mapping, catastrophe loss data, and GIS modeling are examples (Ebert et al., 2009). Musa and Shabu (2019) (Abid et al., 2021a, b, c) Many academics and policymakers assess vulnerability using vulnerability indicator-based methods. Logical image indicator-based vulnerability assessment employs data. Hazard areas use indicator approaches to assess danger and reaction. The literature provides several susceptibility indicators (Nasiri et al., 2016). Garbutt et al. (2015) developed a 42-factor flood risk index.

**Table 1. Keywords search strings in the international database (2010–2020).**

Source	String
Francis & Taylor, Science Direct, Springer Link Sage Publication, and JSTOR	TITLE-ABS-KEY Flood Vulnerability using geographic information system AND, GIS OR Climate Change, Geographic Information Systems, Floods, Vulnerability, Remote Sensing, Decision Making, Flooding, Flood Mitigation " Hazard, Flood Control, Disaster Management, Flood Planning, Hazard, Assessment, Mapping, Flood Preparedness, Spatial Analysis, Risk Management, Geographic Information System, Hydrological Modeling, Assessment Method, Disaster, Mapping Me

This review research defined the conceptual and methodological limits of each flood risk factor to eliminate subjective interpretation in paper analysis and categorization. The definition of vulnerability is evolving, and various disciplines use different criteria and methodologies to assess it. This makes categorizing multi-dimensional aspects of urban flood vulnerability challenging, as shown in Figure 1.

The following research goal questions are answered in this systematic literature review (SLR) report. What are the parameters of flood vulnerability and how is it assessed using geographical information?

1. Which strategies and approaches have been utilized in previous research to address flood vulnerability?
2. How can these catastrophe methods, strategies, and approaches help communities?

## II. MATERIALS AND METHODS

### A. Search strategy

A geographic information system-based flood vulnerability evaluation was compiled from many international publications. Systematic literature reviews were used to evaluate previous efforts. The search string approach was used to five databases included in this research.

Table 1 outlines the usage of Francis & Taylor, Science Direct, Springer Link Sage Publication, and JSTOR database engine to choose research on flood vulnerability resolution and the function of GIS.

### B. Screening process

Only research publications were examined in the five databases. An extensive array of scholarly articles has been analyzed to give insight into further study on flood susceptibility. Keyword analysis focused on water, vulnerability, and the function of geographic information systems in the target study region. Step three is article review eligibility. This study examined 105 publications on flood vulnerability and 75 on the importance of geographic information systems. In the last step of the systematic literature review, we presented our research papers. Despite 180 studies were identified, 13 were not acquired owing to study limitations. As shown in Figure 2, the researcher selected 167 papers for systematic evaluation to maintain high quality assessment.

**III. INCLUSION/EXCLUSION CRITERIA**

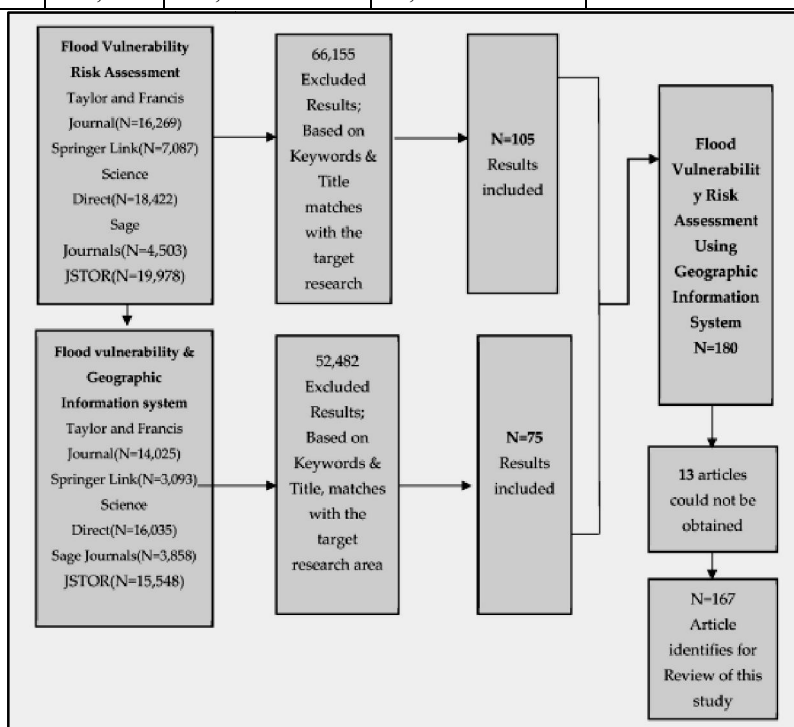
The Flood vulnerability systematic review extends recommendations for evaluating knowledge. Synthesis, formulation, and data gathering methodology are improved by the research. Systematic literature reviews need identification, screening, eligibility, and inclusion. The first phase involves identifying articles from various databases. For this evaluation, the researcher used five datasets (Tables 1 and 2). Through keyword and abstract title identification, the researcher identified 66,260 bad vulnerability results. The first review yielded 52,557 results for the keywords and abstract of flood risk and geographic information system. According to Table 3, relevant search phrases were used to determine inclusion and exclusion criteria. The inclusion and exclusion method includes identification, screening, eligibility, and inclusion, enabling us to analyze the chosen articles for the research. Along with the quality assessment, 167 articles were reviewed.

**IV. RESULTS**

Scholars focused on vulnerability, particularly in relation to natural catastrophes, for decades. Many writers have broadened the definition of vulnerability. For natural disaster vulnerability, Cutter and Adger have explored key contributions. Ratick, Brouwer, Revi, Kron, and Balica emphasize vulnerability evaluation. Cutter examined US susceptibility to natural catastrophes, floods, and cyclones.

**Table 2. Keywords, titles, and abstract identification and evaluation in the international database.**

Journals database	Flood	Vulnerability	Flood Vulnerability	Flood vulnerability & Geographic Information system
Taylor and Francis journal	160,247	379,338	32,967	14025
Springer Link	83157	66753	11389	3093
Science Direct	244,408	490670	38489	16035
Sage Journals	39319	151077	9438	3856
JSTOR	399,417	467,693	48,784	15548



**Figure 2. Stages of systematic literature review.**

Kubal, Haase, Meyer, Messner, and Scheuer analyzed flood risk. Social instability and vulnerability were examined. Land conversion and climatic change affect flood more. However, several studies have weighted climate change, particularly for flood triggers and susceptibility. Flood risks in vulnerability assessment have been challenged by various statistical methodologies, quantitative and qualitative techniques, and geospatial research.

**A. Concept of flood vulnerability**

Over the last two decades, researchers' views of vulnerability have altered, prompting attempts to quantify and measure damage or harm risk. Kelly and Adger (2000) emphasize that some vulnerability assessments should end, others begin. Van Der Veen and Logtmeijer (2005) linked water to economic instability. Gheorghe (2005) argues sensitivity, resistance, and knowledge determine susceptibility. Resistance, resilience, and susceptibility cause environmental vulnerability, say Klein and Nicholls. Mitchell (2006) defines vulnerability as a term, not objects at risk, exposure (harm potential), or loss susceptibility. The IPCC eventually defined vulnerability as climate change's impact on a system. According to Watson et al. (1996), a system's sensitivity and adaptation to climate change determine its harm or injury.

**Table 3. Inclusion/exclusion criteria.**

<b>Inclusion criteria</b>	<b>Exclusion criteria</b>
Papers defined flood vulnerability, methodology and approaches	Papers that do not define flood vulnerability and their methods.
Papers also investigated the floodvulnerability using geographic informationsystem	
Paper that defined social, physicalenvironmental, and economical flood vulnerability.	Papers that do not define approaches and methodology for floodvulnerability assessment
	Papers that specify vulnerability to other natural hazards in the GIScontext

Blaikie et al. (2005) define vulnerability as risk exposure and recovery. Green (2004) names receptor damage susceptibility. Three current vulnerability definitions are linked. Criteria for inclusion.

Exclusion criteria: exposure, resilience, resistance. Inflexible and sensitive to environmental and social changes, according to Adger (2006).

Chakra-borty and Joshi (2016) were the first to detect vulnerability and concentrate its inquiry, according to several experiments. His vulnerability identification course and Etinay et al. (2018) examined water vulnerability, severity, extremes, and climate change. Fariza et al. (2018) identified a strong climate-vulnerability link. Situational vulnerability and resistance vary. The scale evaluates insecurity and assists research (Füssel, 2007). The Garbutts (2015) Fernandez (2016) Fatemi (2017). Flood vulnerability assessment requires RH and hydrological models (Fernandez et al., 2016). Vulnerability was defined by Hadi et al. (2017) and 1980s-analyzing Hazarika (2018).

Climate change "vulnerability" has been misconstrued by scientists. Climate change risk detection was relatively effective. Research usually blends vulnerability with other syntaxes (Holand et al., 2011). Hoque (2019), Horney (2018). Etinay et al. (2018) suggested environmental vulnerability. Cutter and Liverman found disorder in their spheres. Holland (2011) and Huang (2012) define vulnerability as adaptation, sensitivity, fragility, resilience, and threat. Abid et al. (2021a-c).

To counteract global warming, consider risk, coping, and visibility (Huq and Hossain, 2015). 2016 (Islam et al). According to Fatemi et al. (2017), vulnerability puts individuals and places at risk and inhibits environmental response. Environmental, social, and engineering systems and their dynamic interactions are incorporated in vulnerability study, says Cutter. Risk varies by terrain.

Different locations need different solutions (Karagiorgos et al., 2016a, b). Many assessment approaches produced a complicated system with tolerance and resilience requirements (Karmaoui et al., 2016). Risk conceptual differences are widespread in academics. Environment differences are noted. Natural catastrophe intensity affects risk. Etinay et al.

(2018) define catastrophes as massive human damage. Examples include deforestation, floods, cyclones, storms, and industrial plant failures. Climate sensitivity is increased by understanding how people adapt to diverse climates (Brooks et al., 2005). Dealing with consequences is coping.

Well-studied natural catastrophe vulnerability (Chakraborty and Joshi, 2016). Unreliable data may hinder geophysical risk vulnerability evaluations. Rising human vulnerability contributes to catastrophes (Aroca-Jiménez et al., 2020). Biophysical and geographic threats must be identified. Vulnerability assessment swiftly reveals acceptable risk and natural catastrophe exposure (Khamespanah et al., 2016). Environmental change vulnerability, adaptation, and mitigation were reported by Khosravi et al. (2021). He also emphasized climate change risk mitigation and catastrophic occurrences to reduce exposure and effect.

### **B. Previous studies on flood vulnerability**

Flood risk is the failure to mitigate flood threats and people's or places' sensitivity (Lawal and Arokoyu, 2015). Flood management and societal effect reduction need natural hazards assessment and evaluation (Lianxiao and Morimoto, 2019). Social sciences suggested catastrophic research subject vulnerability (Liu et al., 2021). Multidimensional vulnerability combines risk, exposure, and sensitivity. Academics have argued class vulnerability assessment, assignment, and statistical quantification for decades (Lorente, 2019). Many studies have examined flood danger. Connections are used to estimate experimental flood danger.

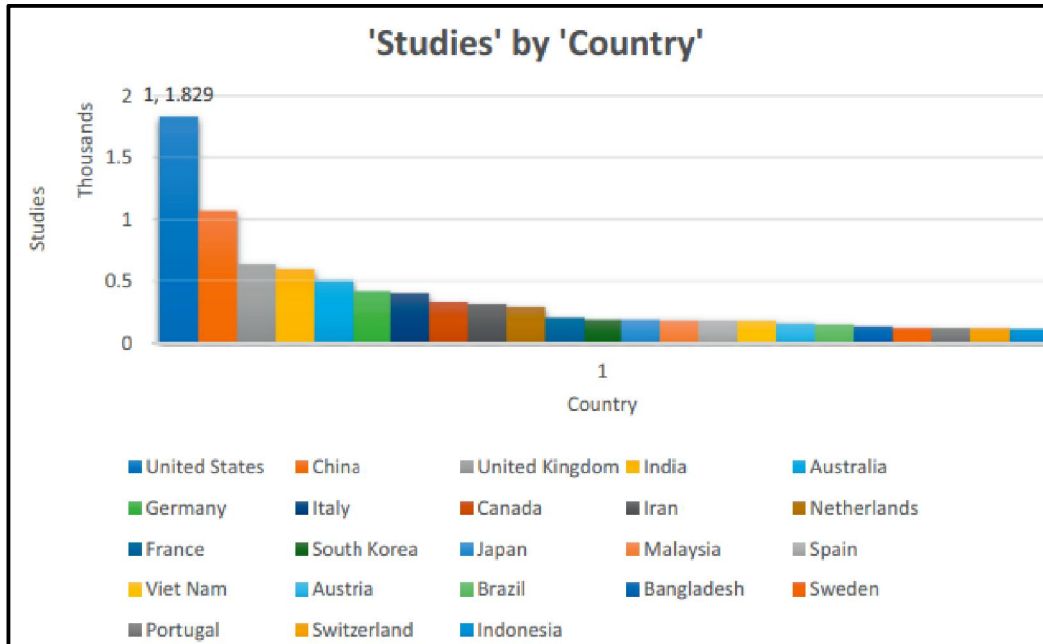
Lyu et al. (2018) recommend assessing flood risk worldwide using ecological and socioeconomic parameters. Flood risk is quantified as natural, economic, and societal. Poor settlements, age, population density, and social services impact flood risk. Tree reduction and soil erosion may signal environmental concerns. Poverty, land resource base, and infrastructure usefulness are social and economic factors (Ma et al., 2007). Evaluations should include gender, economy, and culture. Over 30 years, FVI vulnerability has altered (Mahato et al., 2021). The new definition includes exposure, vulnerability, and resilience (Mahmood et al., 2017). System adaptation uses it. Figure 3 illustrates 2010–2020 country-based study distribution.

Floods may devastate the environment, society, and economy. Geography predicts flood damage, increasing economic costs (Mohanty and Simonovic, 2021). Since Molloy et al. (2017), geography uses vulnerability. Risk, response, and poor population health may cause flood vulnerability, suffering, and inequality. Flood danger, reaction, and poverty are unrelated (Andrade and Szlafsztein, 2018).

### **C. Flood vulnerability in the context of underdeveloped countries**

Floods often devastate wealthy nations. For decades, monsoon-vulnerable 7000 islands between the Philippines and Vietnam have been inundated (Muqtada et al., 2014). Researchers have focused on addressing its consequences and vulnerabilities in industrialized nations. Many wealthy nations face flood danger from extreme weather and climate events like monsoon rains and cyclones. Numerous hydrodynamic systems have been developed in various countries to examine the intricate nature of flooding. Due to insufficient hydrological and physical information, fewer models are used to predict floods in developing countries like Asia, Africa, and Bangladesh (Islam et al., 2016). According to Mohanty and Simonovic (2021), the Lake Poyang area is at danger of flooding, with an estimated 55% of the region being vulnerable.

These cultures must recognize physical and social hardship due to poverty and inadequate resources. By merging physical, social, environmental, and economic vulnerability, Molloy et al. (2017) blurred science and humanities. They evaluated infrastructure, building design, and material composition for physical vulnerability and age, gender, health facilities, and emergency services for social vulnerability. Data envelopment analysis was used to study multi-dimensional flood risk in population, mortality, economy, and agriculture by Muqtada et al. (2014).



**Figure 3. Distribution of the studies published by country (201–2020).**

Social, environmental, physical, and economic vulnerabilities exist. These approaches rapidly, precisely, and comprehensively analyze flood risk. No firm data and difficulty identifying elements, especially social ones, make it challenging. This method's key drawback is monitoring complicated social processes and material repercussions to assess vulnerability. Therefore, decreasing exposure to one indication and quantifying it is challenging (Adger, 2006). Computer-based modeling accounts for local factors and predicts local susceptibility more sensitively than previous techniques, although it is limited in data scarcity.

#### D. Different types of flood vulnerability

In the past, floods devastated people, property, and the environment. Floods, storms, and climate change threatened Brooks et al. (2005). Ecological footprint is risky. They suggested assessing environmental risk using resilience, functionality, and adaptation. Climate change reduces adaptability, endangering social, economic, and environmental systems, warn Nasiri et al. (2016) Geography, population, species, and habitat form may affect ecological fragility. Tolerance, preservation, and function impact environmental vulnerability (Neumayer and Plumper, 2007). Fuzzy interval-stochastic programming (MIFISP) was used to analyze wetlands for flood prevention by Nguyen and Liou (2019). Topography and hydrology strongly impact wetland vulnerability.

Studies studied how environmental change destroyed civilization (Ma et al., 2007). (Nguyen, 2020). Individual and cultural responses to environmental change determine social adaptation. Needs money and wetlands. Economic vulnerability causes poverty for several socioeconomic groups (Ortiz et al., 2016) (Shivaparasad Sharma, 2018). Balica et al. (2013) define vulnerable populations as those confronting wage shortages, resource inaccessibility, and social and economic crises. Mahmood et al. (2017) link social vulnerability to good vulnerability. They controlled flood danger using technology, not hierarchy. Papatoma-Koehle et al. (2019) examined low-income flood risk.

These flood-damaged places need attention. Optic data simplifies flood mapping, identifies flood-vulnerable regions, and improves weather forecasts (Brooks et al., 2005). Topographic models and flood vulnerability maps assess flood depth and identify flood-prone areas (Percival and Teeuw, 2019) Researchers' confusion with hazardous waste and public health analytical methodologies was shown by Fatemi et al. (2017).

The study indicated greater psychiatric activity in women under 65. According to personal interviews, Paprotny et al. (2020) linked Pennsylvania workers' mental illness to flood risk and health. From 2000 to 2020, Percival and Teeuw

(2019) identified flood-related impairment in 2–9-year-old Bangladeshi children. Flood risk, exposure, and PTSD were evaluated.

## V. DISCUSSION

Past research explored flooding's impacts. Floods and hazards were researched separately academically. Previous studies indicated environmental catastrophe impair sensitivity. The five-database search found about 8000 flood-related scholarly publications (Tables 1 and 2). Research has explored psychological, environmental, and economic insecurity. Improved flood vulnerability assessment methods (Ma et al., 2007; Sulaiman, 2019; 2020a, b). To measure flood vulnerability across time and region, a generic collection was required. Floods are predicted using disaster modeling, hydraulic modeling, emergence inspection, and multi-criteria methods (Timmerman, 1981; Tobin and Montz, 2004). Predictors evaluate flood danger. A checked research suggests inventorying and investigating these factors. Fernandez et al. (2016) measured global social and water vulnerability. Remote sensing and GIS analysis aid (Rosales et al., 2021).

Review keywords indicate less geospatial flood risk assessment research. It suggests geographic information systems can predict flood risk. Global flood and civilization study is undertaken. Flood vulnerability relies on coping and resistance. After a complete flooding and susceptibility analysis, some flood predictions were decades outdated. Remote sensing and GIS have boosted flood analysis. Scholarly flood studies are hard.

Multiple vulnerabilities may be analyzed using one model. Social vulnerability emerges when parties or communities fail to manage event repercussions (Wahab and Muhamad Ludin, 2018). Wang et al., 2019; Vignesh, 2021. Poor people suffer more from flooding. Fatemi et al. (2017) studied social vulnerability using a location threat model, including biophysical causes, risk, and action. Using the movements paradigm, Sperotto et al. (2016) recommended adding environmental events to flood risk. Sayers Team (2018) Reshman et al. 2019

Water susceptibility study requires more methods (Sayers et al., 2018). Geospatial and statistical methods can assess flood susceptibility (Scheuer et al., 2011). Sharif, Hamidi, Sulaiman, and Abid (2019–2021). This strategy uses realistic resource evaluation for shortage-conscious people. The Global Flood Awareness System (GLFAS) collaborates with organizations to overcome political and societal barriers. Collaboration helps visualize floods and spot issues immediately. Previous study has explored urban flooding vulnerability as the globe urbanizes. Empirical storm wave, rainfall, and rural flood research needs parametric approaches.

## VI. CONCLUSION

After evaluating vulnerability assessment approaches, we find that research has explored several tactics and methods since the 2000s. Over 150 renowned expert articles were carefully examined to provide a consistent overview of various methodologies. Diagrams showed flood susceptibility evaluation behaviors using keywords, important datasets, and study documentation. The latest vulnerability assessment framework models and methods were explored. A database of common flood risk measurements, strategies, and approaches was examined. Researchers studied urban, tidal, and rainfall floods.

RSI photographs and GIS mapping evaluate flood hazard susceptibility. Flood risk might be expanded to eliminate method discrepancies. Indicators were crucial for vulnerability assessments. While indicator-based research is common, weighting, aggregation, and standardization are issues.

Many academics forecast flood risk using GIS, statistical research, remote sensing, and computer languages. We used old and new data, geographical variables, and indicator-based methods to map worldwide vulnerability. This research was hindered by its methodologies, vulnerability type, reference number, and flood emphasis. This research highlighted issues that a more comprehensive vulnerability assessment might solve. The globally applicable integrated approach should contain physical, social, environmental, and economic vulnerability indicators for all catastrophes.

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