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Flood Inundation Mapping(FIM) and Climate Change Impacts(CCI) using Simulation Models and GIS: A Review

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Abstract - *Floods happening frequently necessitated a thorough analysis of the problem and the development of a solution. Floodplain mapping was one of these strategies. The mapping of the floodplain is one of the crucial jobs that must be finished in order to assess, make a decision, and take action for flood risk management due to the significance and severity of flood effects. To find areas that are often inundated by nearby rivers, lakes, rivers, and bodies of water as well as to understand how flood levels are dispersed spatially, a technique known as "floodplain mapping" can be utilized. For many years, researchers have been looking into floodplain mapping. It has recently been utilized in conjunction with tools like ArcGIS as well as HEC-RAS to do more in-depth analysis on the subject. However, a user can be unsure about which technique to employ and how to apply it when beginning a study in the field for the first time. Over the past 20 years, a lot of academic studies have been written about mapping floodplains. However, the subject and its research have improved through time, and the use of software has made the study of floodplain mapping simpler. However, a new user learning the material for the first time may find things challenging and hard to understand. Given the variety of floodplain mapping techniques available, it could be challenging for a novice user to select the right one for his purpose. This paper reviews flood inundation mapping by grouping the studies that have already been examined (2000-2023) into the following categories: input data for flood inundation mapping (FIM), digital elevation model (DEM), coupling of HEC–HMS and HEC–RAS, calibration, validation, and sensitivity; flood frequency analysis; impact of land use; risk assessment and mitigation; and climate change impacts.*

Key Words: flood hazard; flood inundation mapping (FIM); South Pennar river basin; climate change impacts (CCI); HEC-HMS; HEC-RAS; CMIP6; SWAT; GIS; rainfall runoff modelling; rainfall-runoff-inundation (RRI) model; RCP; shared socioeconomic pathways

1.INTRODUCTION

Over time, floods have been shown to be a severe global catastrophe. India has endured a long history of natural disasters. On the other side, flooding has increased in frequency recently. The lives and property of individuals have been severely damaged by these floods[1,2]. 2010 Guwahati and Delhi floods, 2013 Kedarnath flood, 2014 Srinagar flood, 2015 Gujarat, Chennai floods, 2016 Assam, Hyderabad floods, 2017 Gujarat flood, 2018 Kerala flood, 2019 Kerala, Madhya Pradesh, Karnataka, Maharashtra, Gujarat floods, 2020 Assam, Hyderabad floods and 2021 floods of Uttarakhand and Maharashtra- Mahad and Chiplun were the one of devastating floods in the recent two decades.

The frequent occurrence of floods called for a careful examination of the issue and the creation of a remedy. One such remedy was floodplain mapping. Given the importance and severity of the effects of floods, mapping the floodplain is one of such essential tasks that has to be completed to evaluate, make a decision, and implement the proper flood mitigation measures. A method called "floodplain mapping" can be used to locate regions that are frequently flooded by neighboring rivers, lakes, streams, and bodies of water as well as to learn more about how flood construction levels are distributed spatially[3].

Numerous scholars have been investigating floodplain mapping for many years. Recently, it has been used in conjunction with programs like ArcGIS and HEC-RAS to carry out more in-depth research on the issue. However, when starting a study in the field for the first time, a user could be unclear about which technique to use and how to apply it. The subject of mapping floodplains has been covered extensively in academic articles during the previous two decades. The topic and its study, however, improved through time, and the study of floodplain mapping was made easier by the use of software.

Flood Inundation Mapping (FIM) uses GIS tools like ArcGIS, Quantum Geographic Information System (QGIS) and hydrological model Hydrological Engineering Center-Hydraulic Modeling System (HEC-HMS) and hydraulic model like Hydrological Engineering Center-River Analysis System (HEC-RAS). This subject has been studied extensively by academics, and there is an abundance of content available[4]. A new user taking in the material for the very first time, may sometimes find things difficult and confusing. Given the variety of floodplain mapping techniques available, it could be challenging for a novice user to select the right one for his purpose. Software like ArcGIS, QGIS, HEC-HMS, HEC-RAS, and others were used in the various methods put to the test. The research articles that have been examined can go in this area.

The studies that have already been looked at (2000–2023) are categorized into the following groups in this paper to explore flood inundation mapping.

- Input Data for Flood Inundation Mapping(FIM)
- Digital Elevation Model(DEM)
- Coupling HEC-HMS and HEC-RAS
- Calibration, Validation & Sensitivity
- Flood Frequency Analysis
- Impact of Land use
- Risk Assessment & Mitigation
- Climate Change Impacts

2. Input Data for Flood Inundation Mapping (FIM)

Pai et al., (2014) developed a data of daily gridded rainfall (IMD4) with high degree of spatial resolution of (0.25° x 0.25°, latitude x longitude) for 110 years from 1901-to 2010 across main land of India using records of daily rainfall from 6955 rain gauge observatories. The climatological and variability characteristics of rainfall across India in IMD4 are comparable with those from different gridded daily rainfall data sets, when compared to various data sets. In IMD4, the spatial rainfall distribution is more accurate and well-represented, when used to the west coast windward side of the Western Ghats due to increased geographic resolution and a larger number of rainfall stations[5].

Ross et al., (2018) developed the Global Hydrologic Soil Groups (HYSOGs250m) for runoff modeling based on curve number[6]. The hydrologic soil groups (HSGs) in this dataset, referred to as HYSOGs250m, have a predicted resolution of about 250 m and 1/480 degree decimal spatial resolution. These were produced to aid in local, national, and international curve-number runoff modeling using the USDA's data. HSGs were categorized using the depth to bedrock and texture of the soil classifications offered by the Food and Agriculture Organization's Soil Grids 250m methodology. This dataset is open for use by anybody in accordance with the data use policy of Earth Observing System Data and Information System (EOSDIS).

Jaafar et al., (2019) constituted GCN250, a brand-new global gridded curve number (CN) for hydrologic analysis and design[7]. To build a globally consistent, gridded dataset describing CNs of 250 m spatial level, a worldwide land cover dataset (300 m) and soil data (250 m) were integrated. The resultant data product, GCN250, reflects runoff for an amalgamation of 2018 release of hydrologic soil group global data product (HYSOGs250m) and resampled 2015 world wide land cover dataset of European Space Agency (ESA CCI-LC). There are three conditions for which this GCN250 is suitable: dry, wet, and average. These data can be applied to modeling groundwater recharge, land management, assessing flood risk, and hydrologic design.

3. Digital Elevation Model (DEM)

A 3D computer graphic representation of elevation information called a digital elevation model (DEM) is used to represent the landscape on a planet, moon, or asteroids. The term "global DEM" refers to a discrete global grid. In GIS, DEMs are the most used substrate for the digitally created relief maps. DEM is one of the most important elements of a flood inundation model.

Surabhi Bhatt et al., (2014) mentioned that in their study, modern technologies like remote sensing and GIS were used to obtain drainage networks using Cartosat DEM for the Upper Krishna basin in order to evaluate the morphometric analysis[8]. A quantitative and mathematical study of landforms is called morphometric analysis. Krishna River's catchments have a higher propensity for rapid peak discharge. The research's conclusions indicate that GIS can provide valuable information about watershed features for flood management.

Aziz Shaikh et al., (2023) used HEC-RAS v6 for two dimensional hydrodynamic modeling with GIS to evaluate 2006 flood and to determine inundation in the low-lying areas of Surat. 30 m DEM of the Shuttle Radar Topography Mission (SRTM) was used, along with flood data from that year unsteady flow condition, for unsteady flow condition[9]. The West and North Zones of Surat City have been shown to be the most flood-prone due to their low lying topography, which results in larger flood extents, deeper water levels, and prolonged flood durations. The simulation findings can be used to make the appropriate choices at appropriate time to lessen the number of fatalities and damages. Planning and executing effective flood control measures can help study to lessen the flood hazards in sensitive locations.

4. Coupling HEC-HMS and HEC-RAS

Knebl et al., (2005) the chose river basin of San Antonio River Basin in USA, which frequently sees substantial flash floods[10]. 2002 summer flood was modeled. On the basis of hydrographs supplied by the rainfall-runoff model HEC-HMS, which transformed excess precipitation to runoff, the hydraulic model (HEC-RAS) offered an approximate representation of the unsteady state flow across the river channel network. Future modelling efforts will be aided by the results of this work, which offer an instrument for regional hydrologic forecasts of floods. Despite being created for the river San Antonio, this regional scale model, according to the research, might be used as a template in other regions of the nation.

According to ***Ackerman et al.***, (2009) HEC-RAS is frequently used to calculate levels of water surface, and flood extent and depth are determined using GIS analysis of the data[11]. Utilizing data from a ground surface model and water surface profile information, new floodplain delineation tools in HEC-RAS produce inundation maps. With the use of this demarcation tool, the modeler can quickly refine the hydraulic model inside of HEC-RAS while still seeing the resulting floodplain. Using the established floodplain boundaries and flood depths, further modeling software can subsequently be utilized to examine the effects of floodplains.

Astite et al., (2015) assessed the reduction of flood risk by means of mapping the hazards of flood brought on by overflowing rivers. This map was produced using the GIS (ArcGIS) and the hydraulic model (HEC-RAS), both of which are contemporary simulation technologies[12]. The study focused on the region surrounding Oued El Harrach in Northern Algeria, that experienced numerous floods that significantly damaged both people and property. For decision-makers in flood risk reduction, protection, and management, the research's cartography was an essential tool.

Romali et al., (2017) performed simulation of a risk-based strategy for flood mitigation that, in terms of reducing flood impacts, has garnered more attention than the conventional flood control strategy[13]. This research reports on the usage of HEC-RAS model to create FIM for an urban area in Malaysia. The Kolmogorov-Smirnov (KS) test is used to demonstrate that the Generalized Pareto is the most advantageous distribution for the Segamat River. Floodplain maps for various return dates were produced in ArcGIS using outcomes HEC-RAS model.

Neeraj Kumar et al., (2017) studied to predict the Yamuna River's water surface elevation (WSE) using the Global Flood Monitoring System (GFMS), that prvides virtually real-time flow observations for several rivers in the world[14]. For this study's calibration of the model, three sites were selected; these stations are used by several Indian Government Agencies for river stage monitoring as well as for 1D water surface modelling using the GFMS and HEC-RAS. Using flow data from 2001 to 2014, the HEC-RAS model-based research suggested that any structure on the Yamuna river for the next century should be planned to be at least 90 m above sea level.

In a case study including the city of Ain Sefra in the region of Ksour Mountain of southwest Algeria, by ***Derdour Abdessamed et al.***, (2019) investigated the coupling of HEC-RAS and HEC-HMS for runoff modelling and for FIM[15]. City of Ain Sefra is located in the downstream half of the Ain Sefra basin, which is of 1957 km^2 in Algeria's southwest and is where the Wadi Breidj and Tirkount converge. Population growth and the city's encroachment on this wadi's natural space have caused catastrophic economic as well as human losses at this confluence, which passes through entirely urbanized areas and has been repeatedly flooded.

Hydrologic modeling using the HEC-HMS in conjunction of hydraulic modeling with the HEC-RAS, which connected watershed modelling and GIS, were the main focuses of this study's methodological approach. This study examined the process of flooding in Ain Sefra with as well as without the help of concrete retaining walls of concrete by the local government.

The storms of 10, 100, and 1000 years return period had peak discharges of 425.8, 904.3, and 1328.3 m^3/s, respectively. According to studies, GIS and watershed modeling are particularly useful for mapping, investigating, and modeling runoff in dry locations where scarcity of good hydrometeorological data. Three main concepts—hydrological, hydrodynamic, and cartographic—are used to synthesize flood threats. Important tool for managing food control and simulating flooding in real time. Studies recommended more investigation into sediment transport by means of numerical models using input from water depths and velocity. The study's conclusions led to a protective proposal for improving Ain Sefra's flood passage, lowering risk, and protecting the city from flooding.

Neeraj Kumar et al., (2020) claim that HEC-RAS model as well as global flood monitoring system (GFMS), two GIS and remote sensing tools, enable the study of flood assessment and its potential. This study's goal was to forecast the Yamuna River's water surface elevation (WSE) using GFMS, which gives data on stream discharge around the world almost instantly[16]. Gumbel's distribution technique was used to calculate the WSE level over the next 100, 500, and 1000 years. HEC-RAS second modeling was used to compute the WSE or High Flood Level(HFL) for year 1978 and 2001 to 2014.

In study region during the flood that happened on August 26, 2013, Figure 1 shows the area that was under water. The research's conclusions were presented in four sections, and the carefully crafted and decided knowledge closely agreed, demonstrating that HEC-RAS as well as GFMS data/tools were effectively applied.

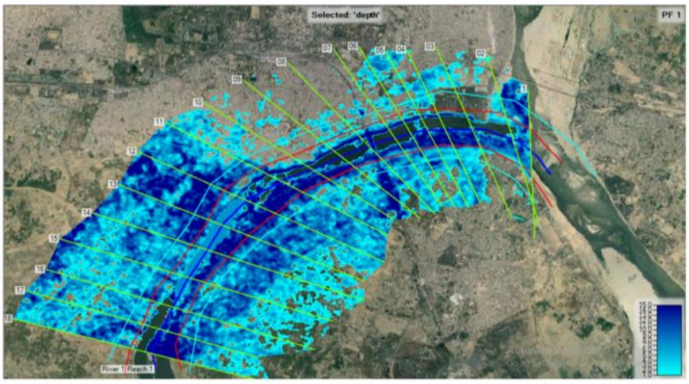

Fig -1: Flood map of the study area using HEC-RAS (Source: Neeraj Kumar et al., (2020))

HEC-HMS was employed by ***Niharika et al.***, (2020) to simulate runoff in respect of Baitarani river using composite and dispersed curve number techniques. HEC-HMS runoff modeling was studied for the Baitarani basin in Odisha up to the Anandapur gauging station using two methods: composite and distributed curve number (CN) approaches. In the simulation of runoff, it is discovered that the distributed CN approach is more precise than the composite CN approach[17].

According to ***Hafnaoui et al.***, (2020) the increasing frequency in respect of flash floods for Algeria has driven search for effective and doable solutions[18]. One such solution is the use of mapping to demarcate floodplain zones. El Bayadh experienced a significant flood on October 1, 2011, which significantly damaged both lives and property. This study's objective was to map El Bayadh's flood risk using rainfall data. Four flood-prone areas and four precipitation values of 40 m, 60 m, 80 m, and 100 m were combined to create a map of the flood threat.

Abdella et al., (2021) claim in many parts of Ethiopia, one of the worst natural calamities is flooding. Causes of floods include deforestation, increased cultivation, urbanization, wetland drainage, changes in the climate, siltation in river bed, etc[19]. This project evaluated, analyzed, and developed appropriate works of river training for lower Kulfo. Using a 1D hydrodynamic model of HEC-RAS with interface of HEC-GeoRAS, a field research comprising secondary data collection was done to forecast flood extent for the required 6 km reach. The sizes of many river training structures could be determined with the use of estimates of flood depth and area. The results of the modeling indicated that the peak of flood depth was 2.3 m in plains, and the peak of flood depth was 4.3 m in channel bed.

According to ***Joshi et al.***, (2021) flood mapping gives communities more knowledge for better flood risk management and could help with damage reduction by alerting the appropriate authorities[20]. The Shipra River basin frequently experienced flooding. In this study, a GIS-based hydrodynamic model had been used to compute submergence zone to be discovered from flood events for varied return durations. The process is shown in detail in Figure 2. Outcomes of steady flow model carried out in HEC-RAS were reviewed in relation to the discharge in cubic meters and the area under inundation in square kilometers.

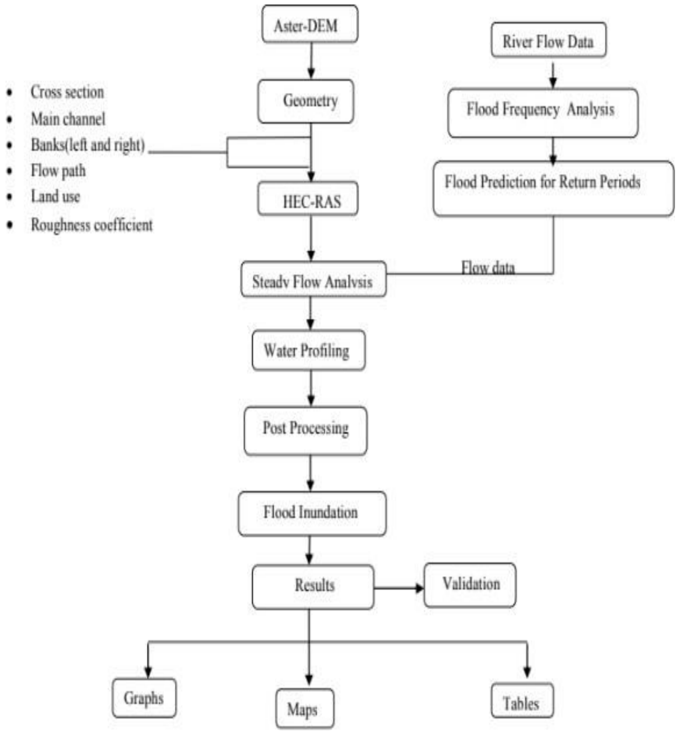

Fig -2: Methodology used for the Flood Map of Shipra River Basin. (Source: Joshi et al., (2021))

Sathya et al., (2023) combined HEC-HMS and HEC-RAS model to sand audit Chaliyar basin of India. HEC-HMS was employed to model rainfall-runoff, sediment routing and erosion of soil. Sediment transport and hydraulic modeling had been perfomed by HEC-RAS[21]. HEC-RAS and HEC-HMS models both performed well and sand audit report and sand volume map were produced. The ensuing sand audit, bed profile plots, and sand volume maps will be valuable tool to support sand mining policies and for prevention of adverse effects on environment.

In their study, ***Ashokan, Krishna and Saravanan*** (2023) constituted flood inundation mapping (FIM) for a stretch of South Pennar River of South India, from Vazhavachanur (near Moongilthuraipattu) to Cuddalore, river mouth at Bay of Bengal[22]. They used hydrological model HEC-HMS for rainfall-runoff modelling and hydraulic model HEC-RAS for flood inundation. Output of the HEC-HMS was given as input to the HEC-RAS. Coupling HEC-HMS and HEC-RAS proved to be an effective way of flood inundation mapping for selected scenarios.

5. Calibration, Validation & Sensitivity Analysis

Thakur et al., (2017) combined HEC-RAS and HEC-HMS to evaluate the flood inundation using established precipitation and land use for Copper Slough basin in Champaign, Illinois[23]. HEC-HMS model had been calibrated by adjusting the Manning's n, or CN. Compared to Manning's n, the sensitivity of the model to CN is considerable. Flood plain mapping by means of HEC-RAS employed transformed runoff from HEC-HMS. According to studies, peak flood and corresponding inundation maps can be produced using estimates of future precipitation. No model is full and final; there is always room for improvement.

Matej Vojtek et al., (2019) used the Event-Based Approach for Small and Ungauged Basins (EBA4SUB) as well as HEC-RAS modeling to study FIM in small ungauged basins with an emphasis on sensitivity analysis[24]. Small and ungauged, the study area is the Korytárka basin. It was investigated how the combined EBA4SUB hydrologic and 1D HEC-RAS hydraulic models responded to various combinations of input parameters in terms of the resulting flooded areas (FA) and flood volumes (FV). It was discovered that roughness parameter's sensitivity was about 1.5–2 times more than that of cross-section. It was discovered that the sensitivity to the CN parameter was significantly higher than that of Tc. Two most pressing problems with hydrologic modeling are how difficult it is to accurately estimate the CN parameter, which is used to calculate excess rainfall, and how important it is to accurately estimate Tc, which affects both flow routing and the response of the basin to rainfall.

Cowles et al., (2019) combined HEC-RAS and HEC-HMS to examine the way land use change during 1938–2018 affected runoff as well as flooding in the river Amite of Louisiana in USA[25]. According to studies, between 1938 and 2018, CN for the Basin as a whole decreased from 86 to 79. Reforestation caused CN to decline from 82 to 70 in rural regions, and urbanization caused it to rise from 86 to 90 in southern part of the Basin. Peak discharge was attained 49.3 minutes quicker on average across all subbasins under urbanized settings due to decreased time of concentration (T_c) and storage coefficient (R) of surface runoff.

For study of the Sangam in Prayagraj of India, ***Kumar et al., (2020)*** investigated the usefulness of HEC-RAS and GFMS to map flood extent. It was discovered that the predicted flood at several locations for the year of 2013 coincided with the actual discharge[16]. According to the return duration of flood for this region, after 100 years, the area will be in the most critical and critical stages for about 14.4 sq km & 6.95 sq km, respectively. A greater collection of observed data for this location may also be required by the study's model. A effective implementation of HEC-RAS in the research area was indicated by close agreement between simulated and actual data.

With a focus on topographic resolution sensitivity and Manning's n, ***Praskievicz et al.***, (2020) investigated flood-inundation modeling in an operational setting[26]. With the aid of AutoRoute, recent two flooding events in a forested Florida and urbanised Texs, were simulated. The floodplains in both states were of varying topographic resolutions and Manning's n values. Results were compared to those from the HEC-RAS. Fit for HEC-RAS is 58-74% 1D, compared to 48–66% for AutoRoute, and the difference between the two is 5–10%.

Adeel Afzal et al., (2022) employed HEC-RAS and satellite photos to undertake flood inundation modeling for Indus river basin[27]. According to the study, flooded area is less for higher increase in n values for plains, where as it is high, even for lower increase of n in channel. In situ observations may not be possible on occurrence of significant event of floods in order to fully calibrate and validate HEC-RAS inundation models.

Global sensitivity study for flood inundation mapping and hydrodynamic modeling was carried out by ***Alipour et al.***, (2022) for San Jacinto for Hurricane Harvey of 2017[28]. During the substantial flooding caused by Hurricane Harvey in 2017. The performance of two dimensional HEC-RAS model was assessed 4600 model configurations. While computational time interval has no influence on model correctness, finer resolution of mesh increases accuracy, but decreases the model efficiency. When the primary objective of simulations is the prediction of the maximum water level, HEC-RAS shows higher sensitive to roughness, resoultion of mesh and DEM. Modelers should carefully order the input variables in accordance with the desired results of their final model.

Goswami et al., (2023) investigated flood simulation for Dikrong River of India, using HEC-RAS. When velocity profiles from the Total Station (TS) and DEM simulations were compared with, simulation patterns, the correlation coefficients in the range 92 to 94 percent were evident[29]. Water Surface Elevation (WSE) correlation coefficients for various return times range from 96 to 98 percent. Flood inundation and the depth of flow in channel both rise as return periods increase, according to the study. Flash floods are considered to be especially dangerous in Banderdewa and Harmutty. Recent DEM may provide accurate inundation maps and aid in real-time preventative and mitigation operations.

In their study, ***Ashokan, Krishna, and Saravanan*** (2023) for flood inundation mapping (FIM) for South Pennar River of South India, they claim that curve numbers (CN) play a vital role in calibration and validation of hydrological model, HEC-HMS and Manning's n in hyadrulic model, HEC-RAS[22].

6. Flood Frequency Analysis

Up to 150 years, stream flow can be predicted using Normal Distribution; Log Pearson Type III; Gumbel Distribution; and Extreme Distribution approaches.

According to ***Gerardo Benito et al.***, (2003) the years 1160-1210 (3%), 1540-1640 (11%) (Peak 1590-1610), 1730-1760 (5%), 1780-1810 (4%), 1870-1900 (19%), 1930-1950 (17%), and 1960-1980 (12%) had the highest flood frequency[30]. Number of floods in the research area over the last 1000 years together with its temporal variability and seasonal distribution. The flood magnitudes of those documented episodes were examined in Aranjuez, Talavera, Toledo and Alcántara of Tagus River.

Although there are many different weather patterns that Iberian Peninsula are tied to, there is usually a strong connection. This shows that during the previous millennium, climate variability caused a change (positive or negative) in hydrological extremes, independent of the mechanism that causes floods.

According to ***Saini et al.***, (2016) urban floods are more expensive and difficult to compared to rural floods due to disparities of land use and functional organization[31]. Severe flooding has a long history in Ambala city of Haryana. Their study attempted to look into both natural and manmade factors of flooding on a watershed and municipal scale. HEC-RAS software was employed to predict flood extent on the basis of historical 20 year maximal discharge for Tangri River. Weibull method gives maximum discharge of 500, 1000, 1200, and 1500 m^3 for return periods of 2, 5, 10 and 20 years.

Salman et al., (2021) investigated on the Narai Drain in Peshawar used HEC-RAS and GIS-based FIM[32]. According to studies, the higher stretch of the Narai Drain, which is near to the flood zone and is where the Hayat Abad Ring Road is located, is safe from flooding for 100 years. Even during a 10-year return time, the lower reach area of the Narai Drain is susceptible to flooding. Due to the combination of the two streams, Regi and upper Narai Drain, in lower reach, a larger flow is created that could result in a significant flood.

Log-Pearson type III distribution method was advised to predict maximum rainfall of one day. Channel redesigning, which entails excavating and enlarging the main channel, as well as building retaining walls along the drain's banks at its most susceptible points, such as the lower Narai Drain, are important actions to be implemented. At Narai Drain Lower, the right bank should have a retaining wall that is 9 m high.

For Fetam River of Ethiopia, ***Hunegnaw Desalegn et al.***, (2021) conducted mapping of flood inundation zones using GIS and HEC-RAS[33]. To evaluate size of the river's floods, investigations of flood frequency on the Fetam River were done. Using Gumbel method, peak discharge was calculated for various return periods. It is advised to refrain areas flooded by 100-year flood for agriculture and other developments

Namara et al., (2022) looked at the use of HEC-GeoRAS and HEC-RAS for flood study of the Awash Bello basin of Ethiopia[34]. HEC-HMS model's output is just barely higher than the peak flood value of Gumbel and Log Pearson method. The areas that saw largest yearly recurrence intervals of 2 years and 100 years, respectively, were 71 km^2 and 109 km^2. The flood from the two recurrence times is more extensive on of left than right side of river.

In their study, ***Ashokan, Krishna and Saravanan*** (2023) used Gumbel and Weibull's method for flood flow frequency analysis based on available historical data (of about 50 years) of Central Water Commission for South Pennar River of South India[18]. This was used for flood inundation mapping for various return periods[22].

7. Impact of Land Use

Cowles et al., (2019) investigated effects of changes in land use from 1938 to 2018using HEC-HMS in conjuction with HEC-RAS on runoff as well as flooding for Amite river of USA[25]. According to studies, between 1938 and 2018, CN for the Basin as a whole decreased from 86 to 79. Reforestation caused CN to decline from 82 to 70 in rural regions, and urbanization caused it to rise from 86 to 90 in the southern part of the Basin. Peak discharge was attained 49.3 minutes quicker on average across every subbasins under urbanized settings due to decreased time of concentration (Tc) as well as storage coefficient (R) of surface runoff.

According to their study, increasing the amount of impermeable surfaces might make flooding risk worse, especially if residential neighborhoods are constructed carelessly in floodplains that already exist. Higher and earlier flood peaks occur from faster water flow and less infiltration caused by increased imperviousness. Meanders, vegetation, and natural stream flow can all be restored to help reduce damage and attenuate flood peaks. It is possible to reduce the risk of flooding, particularly for storms with brief return periods.

Using HEC-RAS 2D, ***Niraula and Shakya*** (2020) conducted research on FIM for the Ratuwa River watershed, focusing in particular on how flooding affects different land uses in the basin[35]. Inundation area increases by 36% over a 25-year return duration compared to a 2-year return time. The time series results for the specified flow condition are determined to be best represented by a 2D unsteady flow analysis. 1-D modeling has been replaced with 2-D HEC-RAS modeling, which has been shown to be a useful tool for flood simulation.

In their investigations, ***Saravanan and Abijith*** (2022) evaluated flood susceptibility in the coastal districts in Tamil Nadu, India, as well as LULC using CA Markov and remote sensing[36]. Studies revealed that main problems of flood are unplanned development and encroachment, ruining of water bodies, clogged drainage systems. Hydrological modeling was not carried out and the key restriction was that the thematic maps were created using a 30 m resolution DEM that was readily accessible; greater resolution would have improved the model's predictions. Their future research may involve developing models based on machine learning

8. Risk Assessment & Mitigation

In their study of social vulnerability, ***Fernandez et al.***, (2015) employed a GIS based multicriteria decision analysis (GIS-MCDA) to better understand and track social vulnerability over time as well as identify "hot spots" that call for adaptation policies[37]. The paper's primary study goals, according to the author, were to offer a method for evaluating social vulnerability into flood risk by employing GIS-MCDA that combined several goals to include Social Vulnerability Assessment(SVA).

Using HECRAS and GIS, ***Yilmaz İcaga et al.***, (2016) developed flood inundation maps for the Akarcay Bolvadin Subbasin in Turkey[38]. The maximum flow depths for floods occurring every 100 and 500 years are 184 cm and 202 cm, respectively. When maximum flow rates are taken into account, they pose a risk to flood damage potential because floods, particularly those with especially adrift objects (trees, rocks, vehicles, dirt, etc.), can result in significant losses. Flow areas also range between 116 and 160 km^2 for return durations of 100 and 500 years. Flood risk (hazard) maps can be created by deriving and overlaying maps of inundation time, depth, velocity. Hazard assessments based on flow depth and velocity can also be carried out. Vulnerability maps can be qualitatively and quantitatively created by taking into account land use, population, flood risk factors.

Cowles et al., (2019) combined HEC-RAS & HEC-HMS to examine how changing land use from 1938 to 2018 affected flooding in Amite river of USA[25]. According to the study, increasing the amount of impermeable surfaces might make flooding risk worse, particularly if residential neighborhoods are constructed carelessly in floodplains that already exist. Higher and earlier flood peaks occur from faster water flow and less infiltration caused by increased imperviousness. Meanders, vegetation, and natural stream flow can all be restored to help reduce damage and attenuate flood peaks. It is possible to reduce the risk of flooding, particularly for storms with brief return periods.

The application of HEC-RAS along with HEC-LifeSim in flood risk assessment was examined by ***Ali El Bilali et al.***, (2021). The flood area, overflow hydrograph, arrival time, depth, velocity, and product depth*velocity are among the outcomes [39]. In accordance with the RESCDAM2000 stability requirements, the results indicated that the velocity is 1 to 2 m/s and the depth is above 2 m in the city, implying that the Malleh dam rupture puts people's life in danger. It has been found that simulation findings will be of great assistance to decision-makers in reducing flood vulnerability by increasing the capacity of the road network. By simulating human life loss, the HEC-LifeSim model is an effective tool for quickly and cheaply assessing flood risk.

9. Climate Change Impacts

Millions of people who live in South Asia are projected to face huge challenges as a result of climate change in the areas of the agricultural sector, water resources, infrastructures and daily life.

Vimal Mishra et al., (2020) developed daily bias-corrected data for South Asia and 18 river basins in the Indian subcontinent, with a spatial resolution of 0.25° [40]. The bias-corrected dataset for the historic (1951–2014) as well as projected (2015–2100) climates for the 4 scenarios (SSP126, SSP245, SSP370, and SSP585) is constructed using the output of 13 General Circulation Models (GCMs) of CMIP6. The bias-corrected dataset was compared to the observations for maximum and lowest temperatures, as well as for mean and exceptional precipitation. South Asia's climate is predicted to warm (3-5°C) and become more humid (13-30%) in the 21st century, according to bias-corrected estimates. Assessments of the hydrologic and climatic change impacts on South Asia's river basins may be done using bias-corrected estimates from CMIP6-GCMs.

Yamamoto et al., (2021) investigated how climate change affected flood inundation in an Indonesian tropical river basin of Batanghari using rainfall-runoff-inundation (RRI) model[41]. The findings suggested that flooding in this region would increase; for example, the amount of flood inundation associated with a 20-year return period would increase by 3.3 times. Under this study, the levels of enhanced flood depth and area under a future climatic scenario were presented. As a result, these elements should be taken into account when developing river basin management plans such as land use regulations for plantations and wetlands conservation.

Desai et al., (2021) looked into how hydrology of Betwa river in India may be affected by possible and speculative climate change scenarios using SWAT.In the 2050s and 2080s, respectively, simulation findings showed a rise in mean annual surface runoff of 3.8-29% and 12-48%. The development of suitable solutions for the river basin's adaptability to climate change could be influenced by these findings[42].

Visweshwaran et al., (2022) studied impact of climate change on Western Ghats, India. Bharathapuzha river basin

(BRB) was taken into consideration for this study's climate change impact(CCI) assessment[43]. Two representative concentration pathway (RCP) scenarios, with RCP 8.5 representing the worst case scenario for anticipated carbon and greenhouse gas concentrations in the lower atmosphere and RCP 4.5 reflecting the normal situation. Study used SWAT model to simulation of hydrological data. The findings indicated that evapotranspiration, soil moisture, and rainfall pattern will all increase at moderate to considerable rates in the coming years. This is particularly evident in the distant future (i.e., 2071 to 2100). Surface runoff had similar results. For instance, relative to the average historical situation (1981-2010), surface runoff will rise by up to 19.2% (RCP 4.5) and 36% (RCP 8.5) throughout 2100. Future management and adaptation strategies for water resources will benefit from the study's findings, and similar regions can employ the methods.

In their study, ***Anup Dahal et al.***, (2022) modeled Babai River using the HEC HMS and HEC-RAS[44]. For the hydrologic analysis, HEC-HMS was employed, and for the hydraulic modeling, HEC-RAS. The flood warning system can be helped by driving the model with anticipated precipitation and producing flood inundation maps. Future precipitation data for extreme climatic conditions were generated using the CMIP6 climate projection. In order to comprehend severity in the years to come, this study also analyzed the scenarios for current and future flooding. In this study, the projected future flooding due to a changing global climate was compared to the historical flooding extent. The level of risk in the research region was measured using the expected flood risk as well as assessments of vulnerability and hazards. Finally, the risk zones were mapped using the anticipated design discharges.

Thus, their study was able to anticipate the extent of a future floodplain which will be inundated. It also assessed the likelihood of future floods in order to determine how much urban and agricultural areas would be impacted by rising flood levels. The SSP5-8.5 scenario of the CMIP6 climate model's future extreme climatic data was utilized to analyze 100 years' worth of return floods for the near, mid, and long term futures. There will be 1.24 times as much flooding in the far future, according to the results. Risk evaluation involved reclassifying and mapping hazards, vulnerabilities, exposure, and risks using the SSP5-8.5 scenario.

Houngue et al., (2023) investigated the effects of climate and changes in land use over flood in Benin and Togo's Mono River Catchment[45]. The study evaluated how future climate & land-use changes might affect the likelihood of flooding in Benin and Togo's Mono River catchment basin using SWAT for runoff and TELEMAC-2D for inundation for RCP 4.5 and RCP 8.5. Both satellite observation and active participation from regional stakeholders helped TELEMAC-2D to be validated.

According to the climate and land-use change scenarios taken into consideration, events with 10-year return periods between 1987 and 2010 are predicted to become events with 2-year return periods. Extreme-peak and flood-extent mitigation opportunities were demonstrated by the proposed Adjarala dam. The discharge of the river at times of low flow, however, may also be decreased if the Adjarala dam is commissioned, according to flow-duration curves. To lessen the effects of the anticipated changes, adaptation methods besides sustainable land-use as well as dam-management approaches should be considered.

In their study, ***Ashokan, Krishna, and Saravanan*** (2023) examined how climate change has affected flooding in the South Pennar River (SPR) basin of South India[22]. They adopted data of EC-Earth3-Veg model for their study. They considered Coupled Model Intercomparison Project Phase6 (CMIP6)'s Shared Socio-economic Pathways, SSP2-4.5 and SSP5-8.5 for near future, mid future and far future with a goal of ascertaining increase in flood inundation due to climate change.

10. CONCLUSION AND RECOMMENDATIONS

Usage of GIS tools ArcGIS, QGIS and simulation tools like coupled HEC-RAS & HEC- HMS or SWAT prove to be effective for flood inundation mapping and prediction of climate change and changes in land use and land cover. Development of physical models are costly, time consuming and tedious. Hence the use of simulation models integrated with GIS, are economical and reliable.

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