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Flood Risk Assessment, Mapping and Planning by GIS-Decision Support Systems: A Case Study in Kerala State, India

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Abstract : Flood is one of the serious, common, and dangerous natural disasters that many countries are facing. Floods can be local, impacting a neighborhood or a community, or even as large as affecting regions, plains, and valleys. This extreme climatic event has the potential to cause a serious impact on human health, security, livelihood, and poverty. When such events hit developed countries, human loss could be minimized as they have better warning systems and technology to reduce flood risk. But in developing countries, as they lack in many aspects of flood risk management, the impact of floods could have more harmful effects than that of developed countries. India which is vulnerable to many disasters has around 12 percent of its land prone to floods and river erosions. And even the precipitation trend seen in the country over the past years shows an alarming need for flood risk studies and management. Keeping the above facts and knowledge in mind, Pathanamthitta District, Kerala State, India, has been chosen for a detailed investigation. Analytical Hierarchy Process (AHP) has been employed, which is a multi-criteria decision-making approach for ranking and giving weightage to the hazard and vulnerability parameters. Further, the researcher employed the GIS software for the spatial mapping of precipitation levels, elevation, slope, land use land cover (LULC), normalized difference moisture index (NDMI), flood inundation levels, buffer analysis, and mapping of other non-spatial data variables to generate flood hazard and flood vulnerability. By employing GIS, through overlay analysis the risk map is generated which reflects the high, moderate, and low-risk zones of the study region. Based on the findings, the study concludes with various structural and non-structural measures, along with spatial recommendations through zoning of the flood plains of the study region.

Keywords *:* GIS;Flood Hazard; NDMI; LULC; Flood Vulnerability; Integrated Planning

Introduction

Floods are overflows of water that submerge typically dryland areas. Floods originating from oceans and seas, or water bodies such as lakes or rivers damaging homes, businesses, infrastructure and causing human casualties. Floods can be local, impacting a neighborhood or community, or very large, affecting entire regions, plains, valleys, or deltas. Floods result in both direct and indirect impacts. Direct impacts include structural and property damage caused by the impact of floodwaters, erosion, or submersion. Assets that may be damaged as a result of floods include buildings, transportation infrastructure, utilities, irrigation systems, and farmlands. Vehicles, equipment, and goods may also be damaged by floods. Floods may also result in the loss of life. Indirect damages include loss of crops and livestock, a temporary decline in economic activities including tourism, restricted access to food and other critical supplies including medicine, disruption of transportation systems hindering recovery and relief efforts, and the longer-term economic impacts associated with the cost of recovery (USAID, 2015). According to the IPCC report 2013, extreme precipitation events over most of the mid-latitude land masses and wet tropical regions will very likely become more intense and more frequent by the end of this century, as global mean surface temperature increases. Globally, it is likely that the area encompassed by monsoon systems will increase over the 21st century. While monsoon winds are likely to weaken, monsoon precipitation is likely to intensify due to the increase in atmospheric moisture. Monsoon onset dates are likely to become earlier or not to change much. Monsoon retreat dates will likely be delayed, resulting in the lengthening of the monsoon season in many regions (IPCC, 2013).

The Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (Seneviratne et al, 2012) recognized that projected increases in temperature and heavy precipitation imply regional-scale changes in flood frequency and intensity. Projections of increased flood hazard are consistent for parts of south and Southeast Asia, tropical Africa, northeast Eurasia, and South America, while decreases are projected in parts of northern and Eastern Europe, Anatolia, central Asia, central North America, and southern South America (Wang et al. 2019). The frequency of floods in small river basins is very likely to increase, but that may not be true of larger watersheds because intense rain is usually confined to more limited areas (IPCC, 2014). Extreme climate events will have an increasing impact on human health, security, livelihoods, and poverty, with the type and magnitude of impact varying across Asia. Increases in floods and droughts will exacerbate rural poverty in parts of Asia as a result of negative impacts on the rice crop and resulting increases in food prices and the cost of living (IPCC, 2014). In South Asia, seasonal mean rainfall shows inter-decadal variability, noticeably a declining trend with more frequent deficit monsoons under regional inhomogeneities. Over India, the increase in the number of monsoon break days and the decline in the number of monsoon depressions are consistent with the overall decrease in seasonal mean rainfall. In South Asia, the frequency of heavy precipitation events is increasing, while light rain events are decreasing (IPCC, 2014).

About 560 million people along India’s 7,500-km long coastline are at risk of inundation. The monsoon will become more uncertain. Stronger cyclones may strike the western coast. These are some of the predictions made for India by experts interpreting the findings of the latest climate-change report, released on September 25, 2019, by the Intergovernmental Panel on climate change (IPCC), the United Nations (UN) body that assesses the science related to global warming (Shetty, 2019). As per the India Meteorological Department (IMD) report of 2019, the number of rainy days in different parts of the country is decreasing while intense rainfall events of 10-15 centimeters per day are increasing. These alarming trends show the need for a flood risk assessment study and coping strategies. Proper flood management measures have to be taken to reduce the impacts of such unexpected but devastating natural events.

Flood vulnerability scenario of developed countries

Developed countries were affected by severe floods, but with less life loss. The developed countries will have better flood warning systems, a better system of data management, and better technology to reduce the risk. Several floods hit Australia during the years 2011 and 2012, the floods swept across Queensland, New South Wales, and Victoria. In 2011, the floods forced the evacuation of thousands of people from towns and cities, the damage was more than $A15 billion, over 200,000 people were affected and 35 people died.

Flood vulnerability scenario of developing countries

Assessments show that after 2000, flooding events affected nearly 949 million people all over the world. Generally, many of these people, 900 million, lived in countries of medium human development. Reports that the anticipated consequences of flooding are estimated to affect mostly developing countries (IPCC, 2001). In developing countries, the flooding impacts have been more harmful than in developed countries for the same severity of the flood. Several factors contribute to these losses such as the data collection process, the flood warning channels, and an inappropriate technology adaptation. In countries prone to floodings, such as the Philippines, India, and Vietnam, these natural disasters often cause extensive damage and displace thousands of families. In the Philippines, located between the Philippine and South China seas, the more than 7,000 islands that comprise the Philippines are particularly vulnerable to flooding, especially in the monsoon season. Tropical rains often cause rivers to burst their banks, resulting in entire communities being swept away. More than one-quarter of the Philippines' 34 million children live below the poverty line, and it is often these children who are most seriously affected by flooding and other natural disasters. The 2010 Pakistan floods began in late July 2010, as a result of heavy monsoon rain; the floods directly affected about 20 million people via destruction of property, livelihood, and infrastructure. About 2,000 people died and the total economic impact was $US40 billion.

Flood vulnerability scenario of least developed countries

The countries classified as the ‘least developed’ are growing at such a rate that their population will double in less than 30 years. Many LDCs, home to 80 percent of the world’s population, are also among the world’s most disaster-prone, such as Bangladesh, Cambodia, Ethiopia, Haiti. Considering that the poor in these countries are often the most exposed to disasters, the numbers of people affected are likely to double in the next 30 years unless serious measures are taken to protect them. With the likelihood that these people will have increasingly limited access and entitlement to resources, disaster vulnerability will, in turn, increase. For example, in case of Afghanistan, is an extremely poor, landlocked country, highly dependent on farming and livestock. Economic considerations have been of secondary importance to humanitarian requirements as a result of political and military upheavals during two decades of war. Damaging earthquakes, flooding, dust storms as well as drought, and food shortage, linked to complex emergencies and warfare, are common threats. Many disasters which occurred in remote areas have either not been recorded or, if so, the data available are not reliable. The increased vulnerability of the population due to the consequences of extended conflict magnifies the impact of disasters on the already weakened population (UNDP, 2001)

Flood vulnerability scenario of India

India is vulnerable, in varying degrees, to a large number of disasters. More than 58.6 percent of the landmass is prone to earthquakes of moderate to very high intensity; over 40 million hectares (12%) of its land is prone to floods and river erosion; close to 5,700 km, out of the 7,516 km long coastline is prone to cyclones and tsunamis; 68% of its cultivable area is vulnerable to droughts; and, its hilly areas are at risk from landslides and avalanches (NDMA, 2000). Flooding in India has been devastating in recent years, with the country experiencing several floods. More than 2 million people across 19 districts of Orissa, located on India's east coast, were affected by heavy flooding in 2011, and more than 5,700 people were missing and presumed dead in the wake of floods in the northern province of Uttarakhand. The Bihar, Odisha, Kerala, Maharashtra, and Karnataka floods of 2019 are some of the recent devastating floods that occurred in India.

Flood vulnerability scenario of Pathanamthitta District, Kerala State

A preliminary report on the flood destructions indicated large-scale destruction in the Pathanamthitta district. There were extensive landslides in these regions. Degradation of ecosystems as a result of heavy rain and landslides can severely alter the ecosystem dynamics. During heavy floods, there is severe soil disturbance. Heavy floods resulted in the loss of soil nutrients. The region was severely flooded during the 2018 floods. It caused disturbance to livelihood, bio-diversity, physical structures, and economy of the district and the state. This study assessed the flood hazard, flood vulnerability, levels of vulnerability, determinates of vulnerability, overall flood risk, and coping strategies to reduce the impacts of future flood events. A flood vulnerability index was used to measure the extent of flood vulnerability.

Concept of Hazard, Exposure, Sensitivity, and Adaptive Capacity

The following definitions are adopted in this study. i. Hazard: Hazard is the probability of occurrence of a potentially damaging phenomenon. (IPCC, 2007) Whereas vulnerability is the degree of loss resulting from the occurrence of the phenomenon. The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. ii. Exposure: Exposure is the nature and degree to which a system is exposed to significant climatic variations (IPCC, 2007). The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected (IPCC, 2014). iii. Sensitivity: Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. iv. Adaptive Capacity: Adaptive capacity is the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, take advantage of opportunities, or cope with the consequences (Makondo et al, 2020).

Concept of Flood Risk

Flood risk is defined as a function and a product of the hazard and vulnerability. (Ologunorisa, 2001). The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as the probability of occurrence of hazardous events or trends multiplied by the impacts of these events or trends that occur.

Risk = Hazard (H) x Vulnerability (V),

Where, hazard defines the magnitude of the phenomenon, the probability of its occurrence, and the extent of its impact; vulnerability includes the probability of loss or damage of any physical, structural, or socio-economic element to a natural hazard. Thus, flood risk combines both natural as well as anthropogenic factors, and therefore, it requires precise information about the spatial extent of flooding areas (Sinha, 2019).

Case Area Profile and Data Analysis

Case Area Profile

The state received an excess of about 8% of excess rainfall in 2018. However, the intra-state variability of rainfall in Kerala is very high; instantaneous rainfall at 1000 m above mean sea level can be 150% higher than at 40 m above MSL (State Relief Commissioner, 2018). In a span of 30 days, 339 human lives were lost, thousands of houses were damaged, over a million and a half people were moved to relief camps, large stretches of major roads got washed away and many bridges got damaged. Cochin International Airport which is one of the busiest International airports in the country got flooded and suspended its operations from 15th to 29th of August 2018. Uninterrupted rains lashed most areas of the State from 8th to 18th of August 2018 which resulted in widespread destruction in all the major sectors of the state. The floods of the Southwest season can be comprehended as an evident example of global climate change impact with very heavy rainfall in a short period as indicated and predicted by the Fifth Assessment Report published by the Intergovernmental Panel for Climate Change (IPCC) in 2014 (KSDMA, 2018). The State received an excess of 96% during the period from 1st to 30th August 2018, and 33% during the entire monsoon period till the end of August. Note that in the 2nd stage forecast issued on 30th May 2018, the prediction was only 95% of LPA (5% less than long-period average) during the month of August, while the state received 96% excess rainfall.

While comparing the available district-wise daily rainfall forecast with actually realized rainfall, it can be ascertained that there is a wide disparity between the predicted amount of rainfall and the actual received. Thus, it is evident that the actual rainfall received significantly exceeded the expectation. This unforeseen exceedance and high intensity of rainfall resulted in tremendous overland flow leading to complete saturation of topsoil, caused deep-seated landslides, debris flows, and substantial sheet erosion resulting in the rivers exceeding the levee areas and causing destruction to life and property. It can be seen that the 2-day and 3-day rainfall depths of 15-17, August 2018 rainfall in Pamba, Periyar, and Bharathapuzha sub-basins are most comparable to the Devikulam storm of 16-18, July 1924. For entire Kerala, the depth of rainfall realized during 15-17, August 2018 is 414 mm, while the same during 16-18, July 1924 was 443 mm (CWC, 2018). The severity of the flood was increased by high tide due to perigean spring tides for the period of 11th to 15th, August 2018. The Spring Tides raised the low tide water levels substantially and thus, the outflow of floodwater into the sea was substantially impeded. According to the satellite image analysis-based flood-affected area maps provided by the National Remote Sensing Centre (NRSC), between 16-07-2018 to 28th August 2018, 65,188 hectares of the land area was inundated. Many areas were underwater for more than 2 weeks.

The district of Pathanamthitta was chosen based on the intensity of damage caused in the district by the floods that occurred in Kerala. Pathanamthitta received an access amount of rainfall compared to its normal rainfall and most of the regions of the district were isolated from the rest of the world for many days due to the sudden floods and lack of preparedness to it. Even though the district received normal rainfall in the first phase of the monsoon 2018 i.e. 29th May to 31st July, the rainfall received during the second phase of the monsoon i.e. 1st to 30th of August was of large excess i.e. 117% more than the normal rainfall. Taking into consideration of the human fatalities, agriculture damage, housing, and other infrastructure damage, and the damages that occurred in the eco-sensitive like forest and other natural resources, Pathanamthitta was one of the majorly affected districts in the state. Pathanamthitta is suitable for a district-level study of floods as the urban-rural characteristics of the district are comparable. The district also has shown diversity in land use with a larger portion of the district being covered by the forest area.

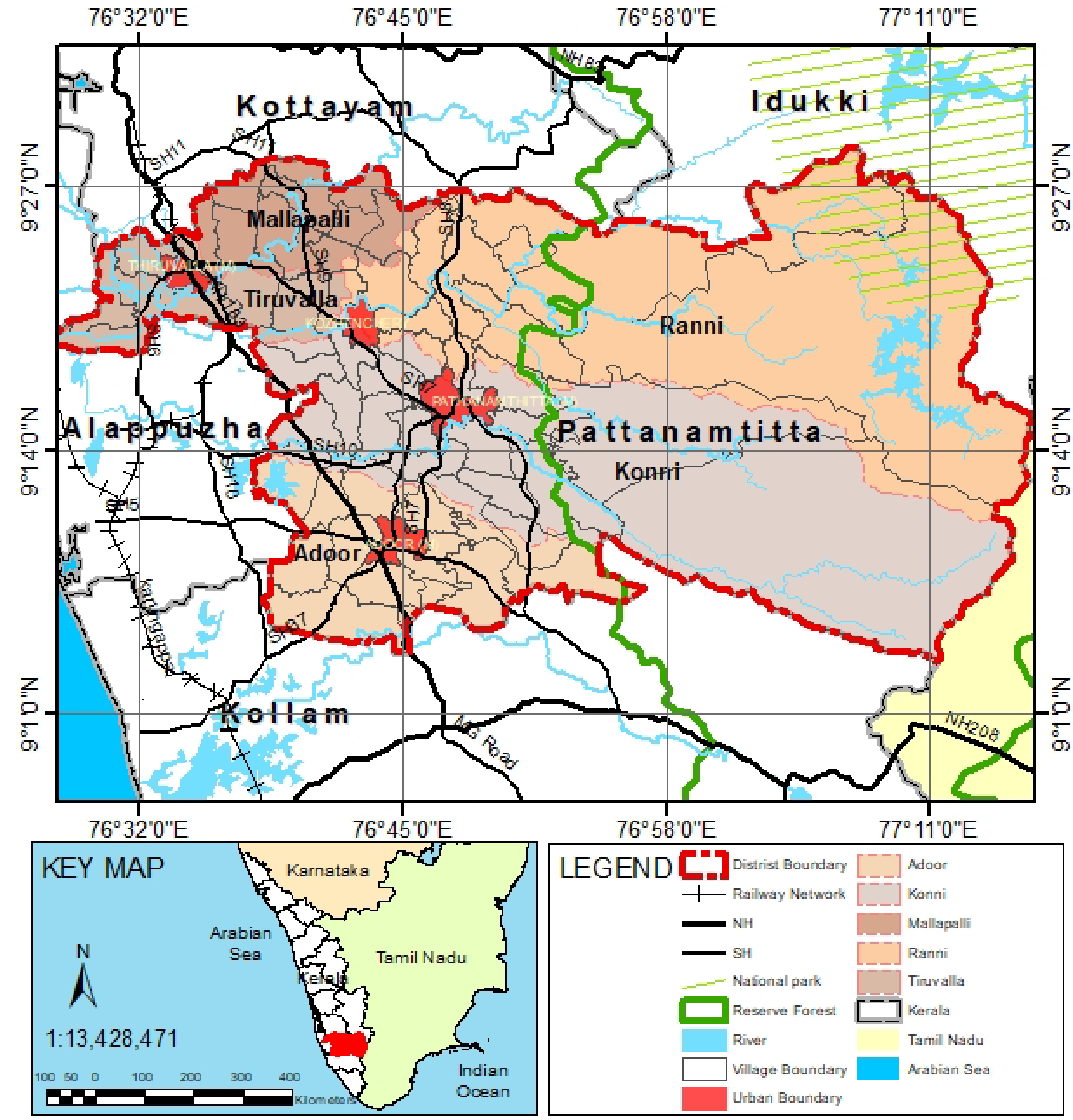

Figure 1 Base map of the Pathanamthitta District, 2020.

Source: Generated by the researcher in ArcGIS from the topographic map of the district, 2020

Data Collection and Analysis

Primary Survey

Primary data collection is the process of gathering data through surveys, interviews, or experiments. A typical example of primary data is household surveys. In this form of data collection, researchers can personally ensure that primary data meets the standards of quality, availability, statistical power, and sampling required for a particular research question (The World Bank, 2019). Field surveys are one of the most effective mediums for primary data collection. Depending on the research question, these interviews may take the form of household surveys, business (firm) surveys, or agricultural (farm) surveys. No primary data collection was done for this study considering the scale and requirement of the research. According to the need of the study, all the data collected are from secondary sources. But various stakeholder meetings were carried out with the heads of the planning institutions and the heads of some local planning bodies. These stallholder meetings were helpful for the process of AHP used in the study for weighting the parameters of risk assessment.

Criteria for selection of personnel for stakeholder meeting:

i. Personnel involved in the decision making and planning of the overall district.

ii. Personnel who are involved in the decision making and planning of the municipalities and other local self-government institutions.

iii. Personnel involved in the disaster risk management of the district.

iv. Personnel having expertise in various factors influencing the disaster risk of the district.

v. Personnel having expertise in flood studies and flood risk management measures.

The inputs and suggestions gained during these interviews were used by the researcher in various stages of the study which includes the parameter selection stage, AHP analysis stage and in the recommendation stage. In order to experience the socio-cultural characteristics of the district reconnaissance survey was carried out in various parts of the district.

Secondary Survey

Within social development, when somebody collects data for their purposes it is called primary data. Sometimes, however, information is used for planning, monitoring, or evaluation that has previously been collected by other people or organisations for their purposes. This is known as secondary data. There are many potential sources of secondary data. Secondary data can be used at any stage of a project or programme cycle (Intrac, 2019). Literature reviews account for many varieties of classification for secondary data, including those that seek to distinguish between raw data and compiled data. Regarding the former type (raw data), there has been little if any processing. In the case of the latter type (compiled data), there has been some form of selection or summarizing (Allen, 2017). The parameters for flood vulnerability assessment for the Pathanamthitta district were selected based on the literature reviewed and taking into consideration the opinion of the specialist of the district. The parameters selected for the study are compiled and presented in Table 1.

Table 1.Control parameters for the study

SI. No	**Control Parameters**	**Source**
1	Precipitation (mm/ year)	Indian Meteorological Department
2	Hydrogeology	Central Ground Water Board
3	Elevation (m)	ASTER Global DEM
4	Slope (%)	ASTER Global DEM
5	Land Use Land Cover	Landsat- 8 USGS
6	Normalized Difference Moisture Index	Landsat- 8 USGS
7	Distance to Active Channel (m)	Topographic map ArcGIS
8	Flood Prone Areas (From inundation maps)	Generated through ArcGIS using ASTER Global DEM
9	Population Density (per hectare)	Census of India 2011
10	Female Population (%)	Census of India 2011
11	SC and ST population (%)	Census of India 2011

12	Dependent Population- Children <06 (%)	Census of India 2011
13	Low Quality Houses (%)	Census of India 2011
14	Households with No Sanitation (%)	Census of India 2011
15	Households with No Safe Water Source (%)	Census of India 2011
16	Unemployment (%)	Census of India 2011
17	Agriculture Dependent Population (%)	Census of India 2011
18	Road River Intersections (Within buffers)	Generated through ArcGIS using Topographic map
19	Literacy Rate (%)	Census of India 2011
20	Access to Hospitals (No: of health centres and hospitals)	Census of India 2011
21	Access to Schools (No: of schools and colleges)	Census of India 2011
22	Access to Internet (%)	Census of India 2011
23	Forest Area (%)	Census of India 2011
24	Total Income (average per person)	Directorate of Economies and Statistics
25	Female Work Participation Rate (%)	Census of India 2011

A total of 25 parameters were selected by the researcher for the flood risk study of the district. These parameters include various topographic factors, demographic factors, social factors, economic factors, infrastructure elements, and other geographic factors. The sources of these data include various sectoral secondary data sources and satellite data sources.

Classifying the parameters for Flood Risk Assessment

For carrying out the flood risk assessment, the IPCC method of flood risk assessment has been followed. As a part of this, parameters were selected based on the exposure deciding indicators, sensitivity deciding indicators, and adaptive capacity deciding indicators of Pathanamthitta. The parameters mentioned in Table 1 contain the Exposure, Sensitivity, and Adaptive Capacity parameters selected for the district.

Table 2.Exposure, Sensitivity and Adaptive Capacity Componets and Associated Indicators

Component	**Criteria**
	Hydrogeology
	Elevation (m)
	Slope (%)
	Land Use Land Cover

	Normalized Difference Moisture Index
	Distance to Active Channel (m)
	Flood Prone Areas (From inundation maps)
Sensitivity	Population Density (per hectare)
	Female Population (%)
	SC and ST population (%)
	Dependent Population- Children <06 (%)
	Low Quality Houses (%)
	Households with No Sanitation (%)
	Households with No Safe Water Source (%)
	Unemployment (%)
	Agriculture Dependent Population (%)
	Road River Intersections (Within buffers)
Adaptive Capacity	Literacy Rate (%)
	Access to Hospitals (No: of health centres and hospitals)
	Access to Schools (No: of schools and colleges)
	Access to Internet (%)
	Forest Area (%)
	Total Income (average per person)
	Female Work Participation Rate (%)

These indicators will help to generate the Hazard map and Vulnerability map for Pathanamthitta. According to IPCC 2014 report, the exposure indicators will give the hazard level of the district. They are the natural factors leading to the high chances of occurrence of the disaster in the region. Sensitivity and adaptive capacity will give the vulnerability level of the district. They are the adding factors deciding the impact of the disaster. While increasing sensitivity increases the vulnerability, increasing adaptive capacity decreases the vulnerability. Managing the vulnerability parameters wisely can reduce the impact of the disaster in the region. Later on, the hazard level and the vulnerability level together give the risk level of various parts of the district.

Analytical hierarchy process principles

Generally, AHP consists of three main principles, including hierarchy framework, priority analysis, and consistency verification. (Saaty, 2008) Formulating the decision problem in the form of a hierarchy framework is the first step of AHP, with the top-level representing the overall objectives or goal, the middle levels representing criteria and sub-criteria, and the decision alternatives being at the lowest level. Once a hierarchy framework has been constructed, users are requested to set up a pairwise comparison matrix at each hierarchy and compare options by using a scale pairwise comparison as in Table 3. Finally, in the priority stage synthesis, each comparison matrix is solved by an eigenvector method to determine the importance of the criteria and the performance of alternatives (R. Velmurugan, 2011).

Hierarchy framework

First, the objective, or the overall goal of the decision, is presented at the top level of the hierarchy. Specifically, the overall goal of this application is to “prepare the risk map”. The second level represents the main criteria that help to reach the goal. i.e. preparation of hazard and vulnerability map. The sub-criteria are represented at the third level of the hierarchy which includes the mapping of various parameters.

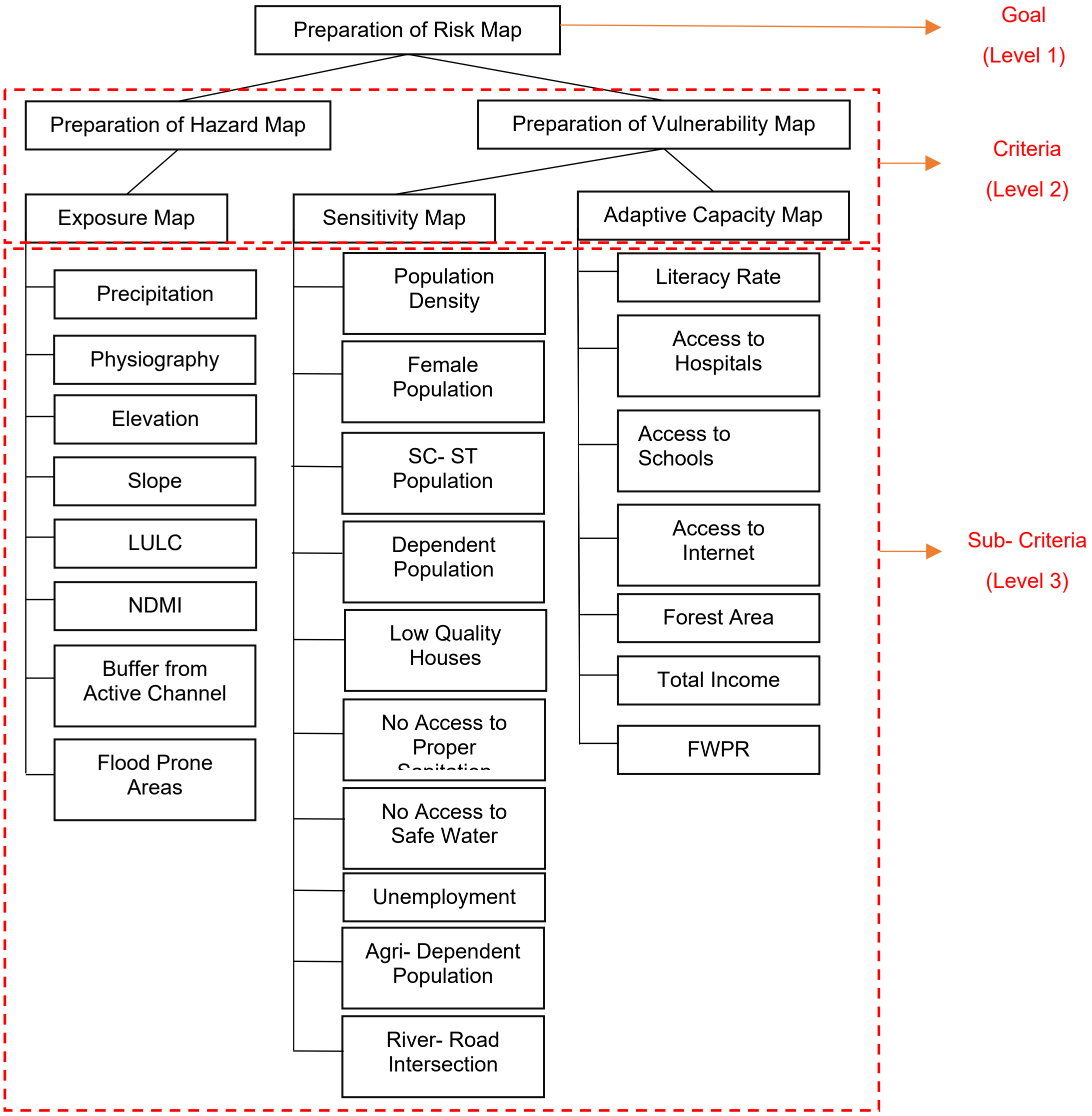

Figure 2 AHP hierarchical framework adopted in the study.

Vulnerability Analysis

For the flood vulnerability study of the region, overlay analysis was carried out to estimate the sensitivity and adaptive capacity based on the weights arrived through AHP. As the third step, the vulnerability formula (vulnerability= sensitivity- adaptive capacity) was applied to estimate the vulnerability.

Results and Discussions

Hazard Analysis

Precipitation levels have a direct impact on the hazard levels of the district. As the amount of precipitation in a region increases, the region becomes more hazardous to flood events. Also, the low-lying regions without many slopes accumulate the runoff coming from high altitude regions with a slope leading to high chances of flooding in the low-lying regions. These regions will have excess surface water because of the precipitation in the region. Therefore, the low-lying areas especially the regions within the floodplain buffer of the rivers are showing higher hazard levels. The moisture content in the air and the vegetation also influences the precipitation levels. The geology and land use of the region determines the amount of penetration into the ground which also influences the hazard level of the region.

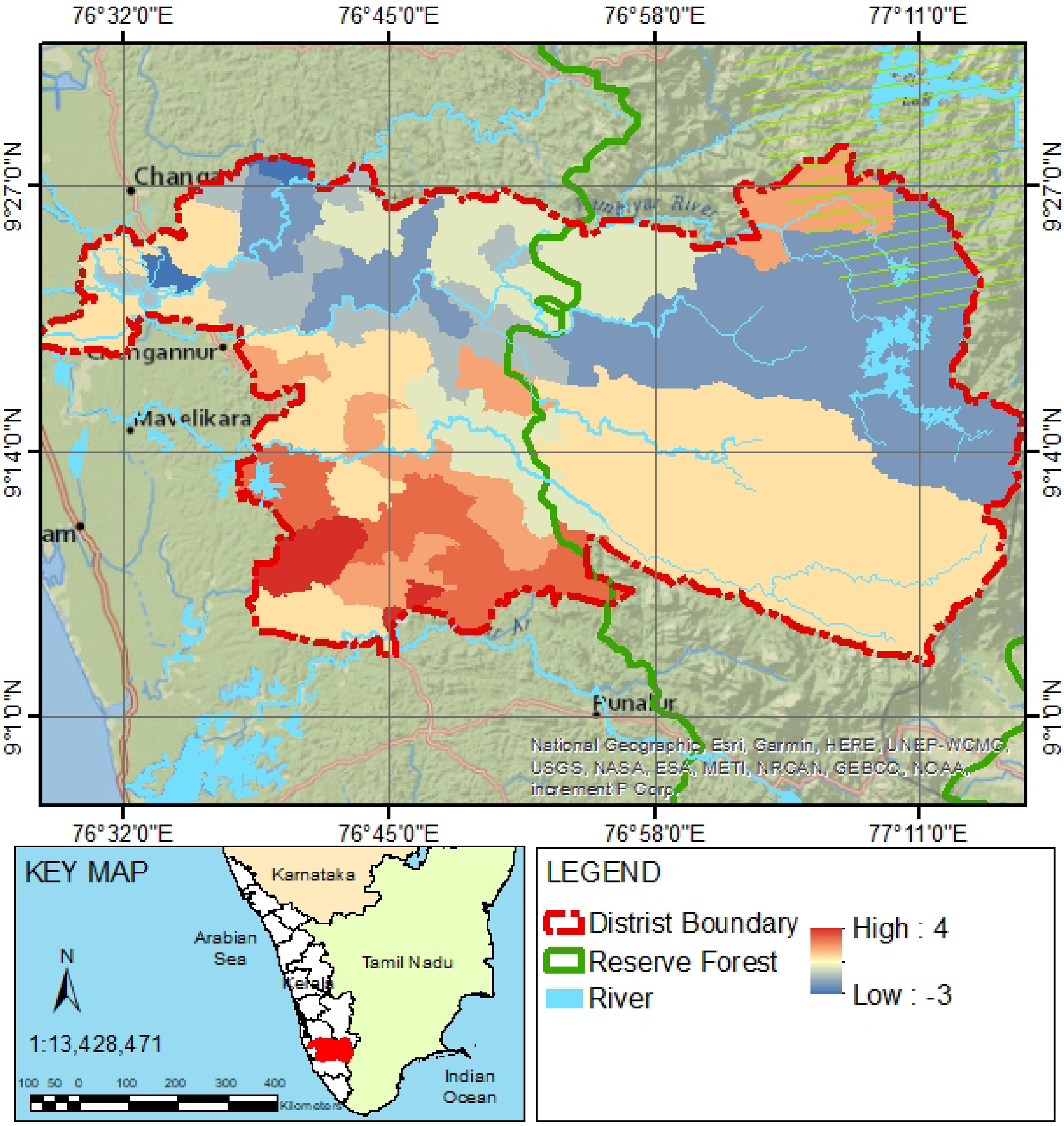

Figure 3 Vulnerability Level Map of the Pathanamthitta District, 2020

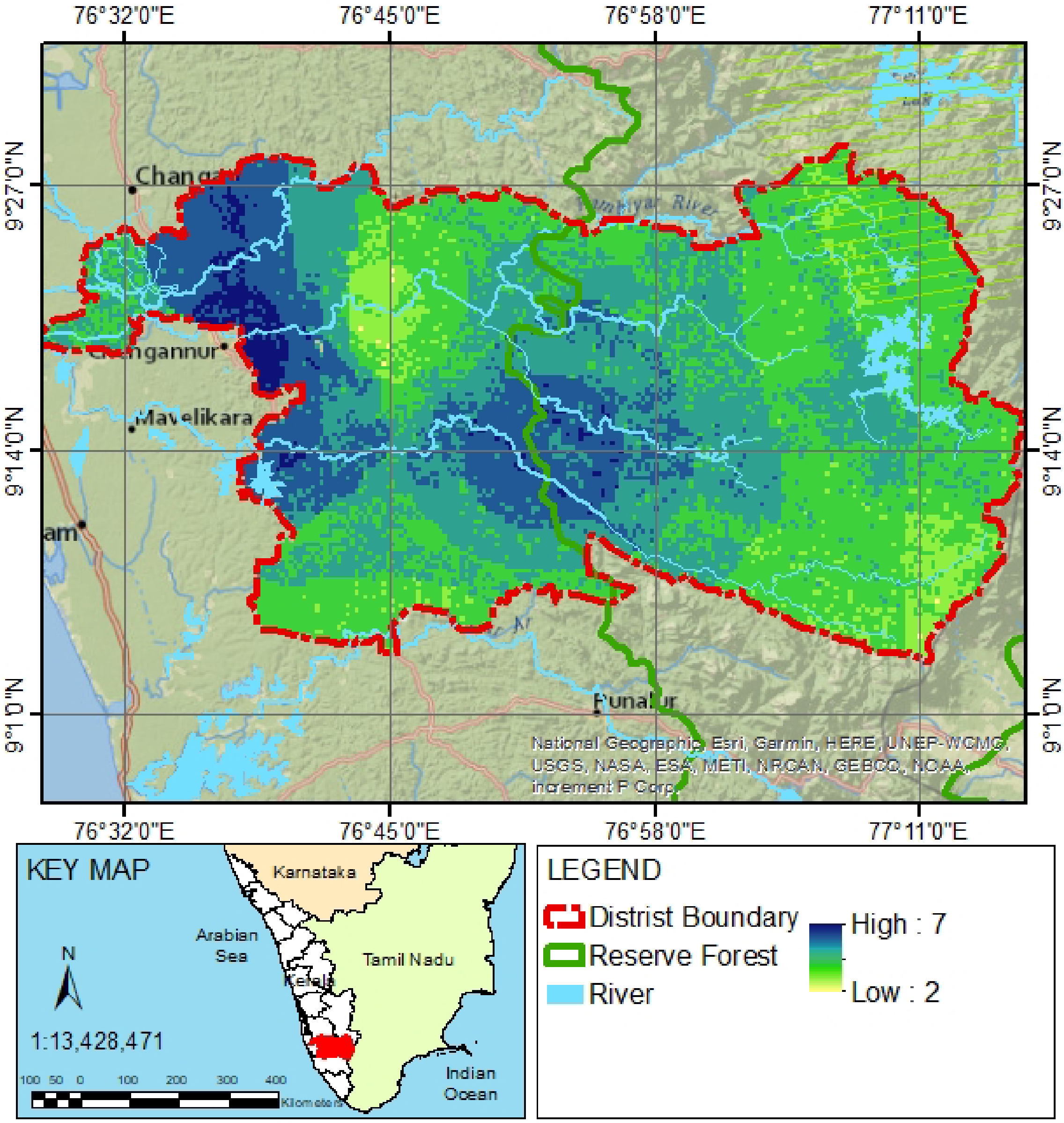

Figure 4 Hazard Map of the District Pathanamthitta, 2020

The factors leading to hazard in a region are mainly natural. There is a limitation in intervening in these factors and thus reducing the risk of a region. Even though these events can't be stopped or controlled, their impacts can be reduced through various mitigation processes. In some cases, the land topography can be altered through various structural measures reducing the risk and impacts of natural events. Even land management through land zoning can limit the risk related to such events. Otherwise, there is no way to stop these events rather than reducing the extent of the impact.

Vulnerability Analysis

The sensitivity of the region to floods and its adaptivity to floods both equally decides the sensitivity of the region. The highly vulnerable regions of the district seem to have high sensitivity and less adaptivity to floods. In the regions where the adaptive capacity outstands its sensitivity, the overall vulnerability is seeming to have reduced. The regions with higher population density, higher female population, higher dependent population, higher agriculture-dependent population, higher SC-ST population, a higher proportion of low-quality houses, less access to safe and proper drinking water, less access to proper sanitation, higher unemployment, and settlements near the road- river intersections are highly vulnerable to floods. Having said that the regions with factors like higher literacy, better access to hospitals and schools, better internet and communication facilities, population with higher income, more vegetations zones, and population where more females are independent, are less vulnerable to floods. They possess more chances of escape from tremendous damages.

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Risk Analysis

The risk of a region to floods is directly dependent on the hazard level and the vulnerability level of the region. It can be observed from the flood risk map that regions with higher hazards and higher vulnerability become the high-risk zone during floods. It is also observed that in some regions although having high hazard levels, because of a decrease in the vulnerability level, has become fewer risk zones during floods. This shows how reducing the vulnerability of a region can reduce its risk even if they have a high hazard characteristic. Reducing flood risk can be accomplished by reducing the probability of flooding (through “structural” man-made alterations) or by reducing the consequences/impacts that will result when a flood does occur. Disaster preparedness on a local community level could include a combination of indigenous coping strategies, early-warning systems, and adaptive measures. Defining adequate community property rights, reducing income disparity, exploring market-based and off-farm livelihood options, moving from production-based approaches to productivity and efficiency decision-making-based approaches, and promoting integrated decision-making is to be explored. Livelihood diversification, including livelihood assets and skills, has been suggested as an important adaptation option for buffering climate change impacts on certain kinds of livelihoods. Ecosystem-based adaptation has been suggested to secure livelihoods in the face of climate change. Some of the golden rules of strategic flood risk management are:

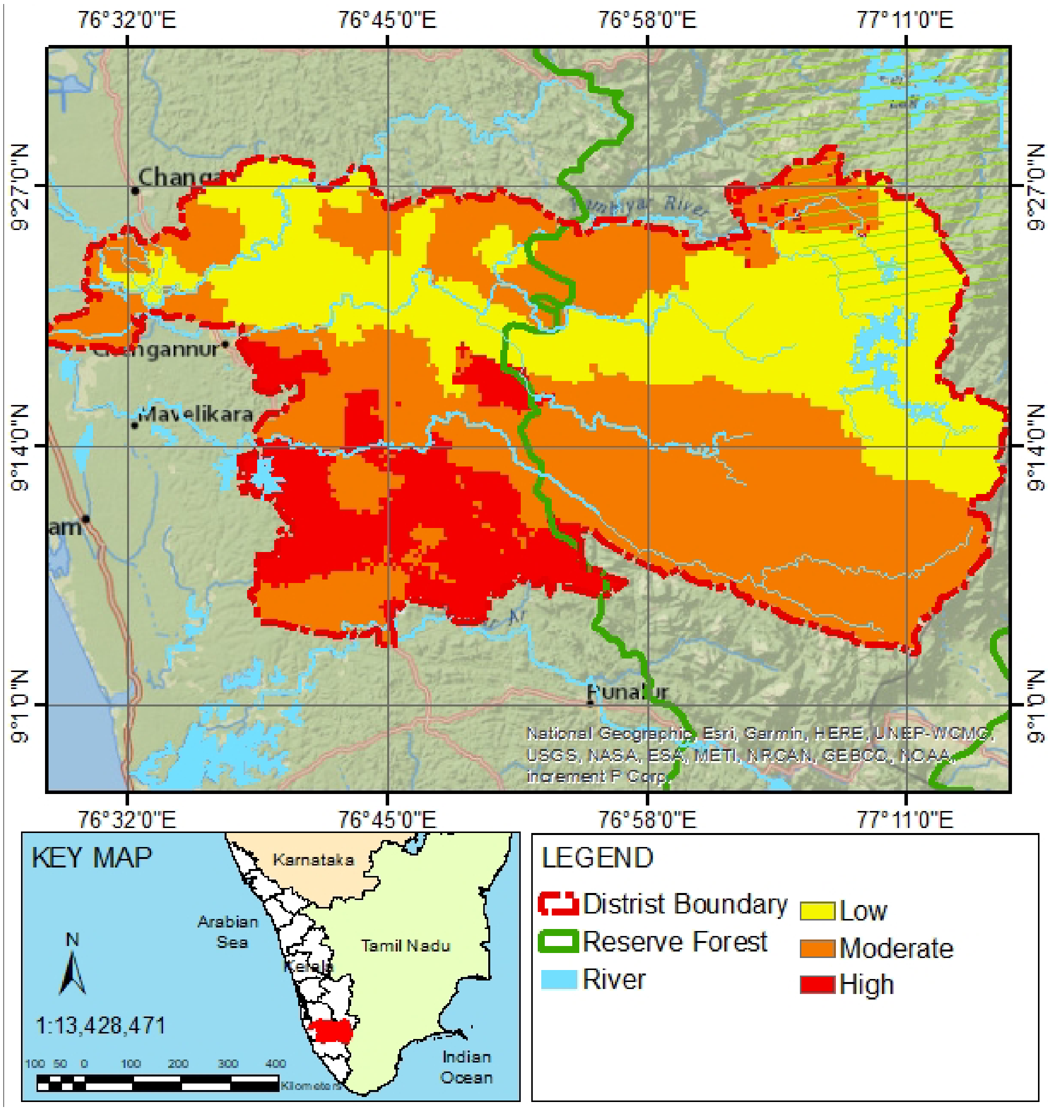

Figure 5 Flood Risk Level Map of the district, 2020.

I. Accept that absolute protection is not possible and plan for accidents.
II. Design standards, however high they are set, will be exceeded. Structures may fail (breach, fail to close, and so on), and early warning systems or evacuation plans may not work as expected. Accepting that some degree of failure is almost inevitable, and this places a focus on enhancing resilience.
III. Promote some flooding as desirable.
IV. Floods and floodplains provide fertile agricultural land and promote a variety of ecosystem services. Making room for water maintains vital ecosystems and reduces the chance of flooding elsewhere.
V. Base decisions on an understanding of risk and uncertainty.
VI. An explicit trade-off between the risks reduced, opportunities promoted and the resources required to achieve them is central to FRM. The uncertainty within the data and models must be explicitly acknowledged.
VII. Utilize limited resources efficiently and fairly to reduce risk.
VIII. The resources used must be related to the risk reduced and the ecosystem, economic and social opportunities promoted.
IX. Be clear on responsibilities for governance and action.

Governments, businesses, communities, and individuals must be active participants – all sharing responsibility and contributing fiscal support within a clear framework of collaboration (Paul Sayers, 2013).

Recommendations

A. IPCC Risk Management Measures

According to IPCC the three important coping strategies are:

B. Emergency Assistance and Disaster Relief

The emergency actors or the first actors who provide assistance during and after the disasters are the members of the effected community through local charities, kinship networks, or local governments. Other than that, the emergency assistance and disaster relief come from the national and state level governments to these areas. The disaster relief includes food provision, water and sanitation, medical assistance and health services, household goods, temporary shelter, transport etc. (Bynander, 2005) (IPCC, 2012)

C. Population Movements

Population movements is the second coping strategy. (Hunter, 2005) It includes evacuations before, during, and after some disaster events, longer-term relocation of affected communities which can be temporary or permanent. These different types of population movements will have different social, psychological, health, and financial effects on the communities (IPCC, 2012)

D. Recovery and Reconstruction

Recovery and reconstruction include actions that are taken to bring back the everyday life of the locality after the disaster. Often reconstruction leads communities to return to the same conditions that existed before the disaster, and doing this will create the potential for further similar losses, thus recreating the same exposure that resulted in disaster in the first place. (Jha, 2010). IPCC also talks about how local places anticipate future risks and how they respond to them (IPCC, 2012)

E. Communicating Risk

Effective communication is important in the cycle of disaster management. Climate communications addresses how information can be designed, and what are the mechanisms and timing of its distribution (Lata et. al 2021).

F. Message Design

The term risk communication refers to intentional efforts from various sources to provide information about hazards through various ways for different audience segments. Since this is very important the information quality (specificity, consistency, and source certainty), information reinforcement (number of warnings and repetition), and the ways in which information is designed matter (IPCC, 2012)

G. Warnings and Warning Systems

The warnings of potential hazards should include the information on the risks caused by the hazards as well as the potential strategies and pathways to mitigate the damage (Drabek, 1999) (IPCC, 2012).

H. Structural Measures

Structural measures are used to reduce the effects of floods. This often employ engineering works to provide protection from flooding such as dikes, embankments, seawalls, river channel modification, flood gates, and reservoirs. However, structural measures also include those that strengthen buildings (during construction and retrofitting). Embankments, dikes, levees, and floodwalls are all designed to protect areas from flooding by confining the water to a river channel, thus protecting the areas immediately behind them. Building dikes is one of the most economical means of flood control (Centre, 2005). It also includes building codes which has different engineering and architectural structural approaches to reduce the risk. This is accompanied by the elevation of buildings and ground floor standards in the case of flooding. (IPCC, 2012).

I. Land Use and Ecosystem Protection

Local land use planning embedded in zoning, local comprehensive plans, and retreat and relocation policies is a useful approach to disaster risk management to keep people and property away from locations exposed to risk (Burby, 1998). The most effective measures include land acquisition, density reduction, clustering of development, building codes for new construction, and mandatory retrofit of existing structures (Lata et. al 2021).. Ecosystem conservation offers long-term protection from climate extremes (Sudmeier-Rieux, 2006) (IPCC, 2012).

Options for delivering flood risk reduction and promoting ecosystem services

A. River Wetland and Wash land Storage

Floodplain wetlands can play an important role in flood mitigation, acting as ‘natural sponges’ for floodwater storage and regulating flow. This flood attenuation function occurs both on large floodplains in the lower parts of the river where large hollows and depressions can store excess water, and in upland areas where the rivers begin. Due to the multiple ecosystem services derived from wetlands, restoring, protecting or creating wetlands will provide other benefits, such as erosion control, improved water quality, aquifer recharge, stabilization of micro-climate and recreational value.

B. Blue Corridors

The term ‘blue corridors’ relates to the use of strategically designed urban flood routes that direct flood flows through urban areas to temporary storage areas (parks and other green spaces within the floodplain but remote from the river course). Typical interventions range from major re-engineering of the urban environment to direct flow waters, through to more subtle modification of existing infrastructure to modify the path of flood flows and create preferential flow routes – for example the use of ‘flood bumps’ to direct flood flows along specific highways/roadways away from higher-impact areas to areas of low impact.

C. Catchment-Scale Runoff Management

The way in which land is used and managed interacts with hydrological processes in the river basin, presenting opportunities for reducing flood risk through catchment management. Catchment-scale management addresses the cause of flooding at source. It requires a detailed understanding of the natural processes that influence the generation and conveyance of floodwaters. Land use and management is then strategically planned to facilitate natural flood regulation services. For example, upland forestry is well recognized for its role in reducing flood flows; it intercepts rainfall, increases infiltration, reduces soil erosion and increases evapotranspiration. Further downstream, vegetation along a river bank increases the roughness of the channel, which slows the flow of floodwaters.

D. Structural Measures

Embankments/Banks, Flood Walls, Flood Levees. The embankment system in the river restricts the river to its existing course and prevents it from overflowing the banks. Embankments are constructed generally with earth easily available from nearby areas. In developed areas where adequate space is not available or land is very expensive, concrete or masonry floodwalls are constructed. Levees normally run along or parallel to a body of water such as a river or a sea. It has water only on one side. Its main purpose is protecting the land behind it from flooding (closing dike). Levees are embankments constructed to prevent flooding. It may be formed naturally or artificially. They prevent the water from overflowing and flooding surrounding areas.

E. Infrastructure

Linear assets (above ground): Raised defence (Levees or Dykes). Linear assets (below ground): Urban Drainage Networks/ Systems (UDS). Interface assets (linking above and below ground systems): Culverts, gulley’s and manholes. Point assets: Pumps, gates and culvert trash screens. Watercourse and channels: Include the vegetation and sediment within a flood plain and channel.

F. Reservoirs and other Water Storages

Lakes, low lying depressions, tanks, dams and reservoirs store significant proportions of flood water and the stored water can be released subsequently when the flood has receded. The stored water can also be used subsequently for irrigation, power generation, and meeting industrial and drinking water needs. In the case of large multipurpose reservoirs, a proper reservoir regulation schedule can be worked out for optimum benefit from the project as a whole. Such structures should be provided in the high- risk zones of the region.

G. Channel Improvement

A channel can be made to carry flood discharge at levels lower than its prevailing high flood level by improving its discharge carrying capacity. Channel improvement aims at increasing the area of flow or the velocity of flow (or both) to increase its carrying capacity.

H. Catchment Area Treatment/Afforestation

Watershed management measures such as developing the vegetative cover i.e. afforestation and conservation of soil cover in conjunction with structural works like check dams, detention basins, etc. serve as an effective measure in reducing flood peaks and controlling the suddenness of the runoff.

I. Sustainable Urban Drainage Systems (SUDS)

Urban areas face particular challenges for FRM because of the extensive transformation of natural land surfaces into impervious surfaces, and the limited space available. SUDS are designed to mimic natural drainage processes, and examples include retention ponds, detentions basins, filter strips on vegetated land, green roofs, swales, and infiltration trenches. Structures are being built with below-ground temporary detention areas with nearby storage ponds such that new development does not cause an increase in the runoff in the downstream flows. At the same time, these detained waters provide ecosystem goods and services in various ways to the local environment.

Flood Plain Zoning

Floodplain zoning is widely used to divide the floodplain into areas where the flood hazard is different and define the types of development and land use that are suitable in each zone. The purpose of flood zoning is to prevent inappropriate development by only allowing certain types of development and land use in areas where the flood hazard is highest (Paul Sayers, 2013). It, therefore, envisages laying down limitations on the development of both the unprotected as well as protected areas (National Disaster Management Authority, 2008). Details about each zone are given below.

Zone 1
Flood plains of the rivers that are expected to flood as soon as the precipitation level increases (the area likely to be affected by floods up to a 10-year frequency). These areas are kept as natural recharge and water storage places reserved only for gardens, parks, playgrounds, etc. Residential or public buildings or any commercial buildings, industries, and public utilities will be prohibited in this zone. Also, the hights of the embankments in this region needs to be elevated using the appropriate structural measure to prevent the floodwater from entering the other sides of the river.

Zone 2
These are the regions having the chance of getting flooded when the water level rises even more (area liable to flooding in a 25-year frequency flood). Here residential buildings could be permitted with the certain stipulation of construction on stilts (columns), minimum plinth levels, prohibition for construction of basements and minimum levels of approach roads, etc. In urban areas, there should be double-storeyed buildings. Ground floors could be utilized for schools and other non-residential purposes. All the emergency infrastructure like defense installations, industries, public utilities like hospitals, electricity installations, water supply, telephone exchanges, aerodromes, railway stations, commercial centers, etc. should be placed even beyond this zone (where they are above the levels corresponding to a 100- year frequency).

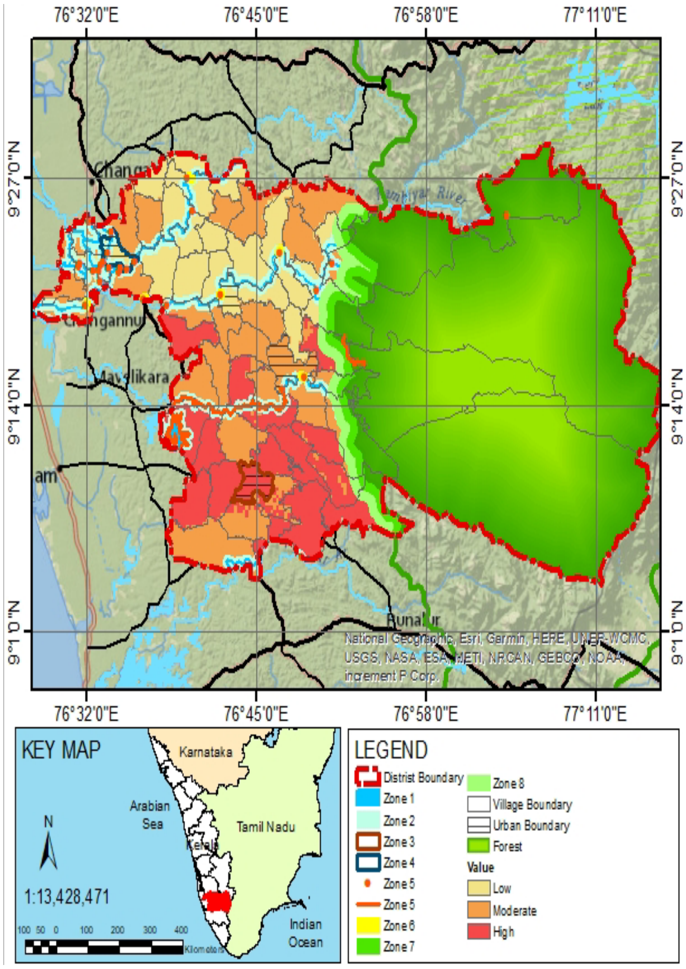

Figure 7 Flood Plain Zoning Map recommended for the study region.

Zone 3

These are the urban areas situated at the high-risk zones. These regions will follow the building bye-laws for the flood-prone regions. Vulnerable buildings should be floodproofed. People living in flood-prone areas of this zone should be relocated. Unhealthy constructions should be demolished. Also, after locating the low-lying areas in this zone, green buffers should be given for both storing the water and safeguarding the adjacent areas. Sustainable urban drainage systems (SUDS) should be implemented as a means to manage runoff and increase storage.

Zone 4

These are the urban areas situated at the moderate-risk zones. The buildings in this region should be upgraded to flood-proof buildings. The unhealthy buildings should be demolished and the residents should be rehabilitated to high altitude regions. Green buffers should be given to flood-prone areas.

Zone 5

These are zones where river intersections are there. It includes river- river intersection, river- road intersections, and river- urban area intersections. Structural mitigation measures like embankments and infrastructure need to be provided in the low-lying, flood-prone areas of these zones.

Zone 6

These are the zones having major road-river intersections. Such regions must be provided with green buffers to safeguard infrastructure and human life residing near it. Also, all the necessary facilities like hospitals and schools should be restricted. Existing such facilities should be relocated to much safer regions.

Zone 7

These are the regions which are next to the forest area and are having a slope in their terrain. This buffer should have trees and vegetation which can hold the soil and resist the heavy run-off during heavy precipitations. Trees with strong root systems grow well on hillsides, stabilizing the slopes (Carter, 2019). Development activities will be prohibited in this zone. Residential or public buildings or any commercial buildings, industries, and public utilities should be prohibited in this zone. This zone will be the recharge and storage zone which will act as a water buffer.

Zone 8

This zone also has restrictions on development activities. Here residential buildings could be permitted with certain stipulations of construction. Even commercial buildings and necessary infrastructure buildings shall be permitted to an extent. This zone will be mainly dedicated to agriculture and agriculture-related activities providing enough amount of green buffer. It should have water storage places to contain the water coming from the hilly areas. Wetlands and other natural recharge units should be preserved in this zone.

Conclusion

In this research, the researcher has adopted IPCC’s definition of vulnerability and risk and carried out an integrative risk assessment by including biophysical and social domains of risk for the district of Pathanamthitta. To assess the dimensions causing spatial risk, the researcher used AHP and GIS as tools to further assess the hazard, sensitivity, and adaptive capacity of the districts. The selection of AHP helped in assessing the parameters with the help of experts related to various aspects of the study. The research gives an important finding that the natural hazard feature of the land alone cannot increase the risk of the land towards floods. The vulnerability factor of the land plays a major role in increasing and decreasing the risk of the area. Even in assessing the vulnerability of land both sensitivity and adaptivity play a major role. When sensitivity increases the vulnerability of a land, adaptivity reduces the vulnerability. Another important finding is that the southern part of the district is risk-prone to floods, mostly attributed to high hazard levels and high vulnerability levels. Based on the results and findings the researcher has tried to recommend some structural measures, land use zoning measures, and other non-structural measures to reduce the risk. Many of the recommendations are adopted from the coping strategies recommended by Intergovernmental Panel on Climate Change, National Disaster Management Authority Guidelines, and Flood Risk Management Approach by Asian Development Bank. But it is to be noted that these measures can only reduce the impact/ extent of damage due to floods. These measures cannot eliminate flood as it’s a natural phenomenon. Though the study has followed a step-wise systematic procedure, the study does suffer from some limitations due to the lack of required data. For the flood hazard study, flood frequency study for decades is the best way. In this case, procuring 30 years annual flood maps was not possible. Also, for flood-related studies, it is preferable to carry out the watershed boundaries rather than the administrative boundaries. But due to the lack of data about such a boundary and for the feasibility of the researcher, the researcher has limited the spatial analysis to the village boundaries of the district. Despite these data-driven limitations, the study provides important direction for future downscaled city-level or household-level fieldwork research.

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