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Delineation of Flood-Prone Areas in Alappuzha District Using Geospatial Technologies

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Abstract

Flooding is one of the most destructive natural disasters, capable of causing significant damage to infrastructure, ecosystems, and human lives. It is triggered by a variety of factors such as persistent rainfall, rapid snowmelt, rising sea levels, cloudbursts and anthropogenic activities. This study focuses on mapping flood-prone areas in the Alappuzha district of Kerala using the Weighted Overlay Method for flood risk mapping, the research integrates geospatial techniques such as Remote Sensing (RS) and Geographic Information Systems (GIS) to create a flood inundation map. Key parameters include physical factors like slope, drainage density, rainfall, geomorphology, soil, land use, NDVI, NDBI, MNDWI, and WRI, along with social factors such as population, households, building conditions, and access to information. The analysis reveals that low-lying areas near water bodies, including Cherthala, Ambalapuzha, and Kuttanad, are highly susceptible to flooding, intensified by poor drainage infrastructure. Kuttanad situated below sea level, faces frequent floods, severely impacting agriculture and livelihoods. Southern taluks like Karthikappally and Mavelikkara, although at higher altitudes, still face moderate flood risks due to proximity to minor rivers. This study underscores the importance of integrating geospatial data and hydrological models for effective flood risk assessment and sustainable flood management practices.

Keywords: Land use; NDVI; NDBI; MNDWI; WRI; Natural Disaster; Weighted Overlay Method; Key Parameters; Water Bodies; flood management

1 Introduction

Floods are one of the most damaging types of disasters, which can cause huge damage to infrastructure, ecosystems, and human lives (Jonkman S. N. 2005 [(1)]). It occurs when the water spills onto the catchment area due to persistent rainfall, excessive melting of snow, sea level rise, cloud burst, and also by anthropogenic activities (Paul, B. K. (Ed.). 2020 [(2)]). The natural causes of floods include torrential rain whose amount cannot be absorbed by the ground and exceed the holding capacity of rivers and reservoirs (Kondolf, G. M., Gao, Y., Annandale, G. W., Morris, G. L., Jiang, E., Zhang, J., ... & Yang, C. T. 2014 [(3)]). Intense short rain causes flash floods, while long rain saturates the soil causing riverine flooding (Schumacher, R. S. 2017 [(4)]).

Flooding in tropical regions is often driven by monsoons, tropical cyclones, and coastal storms (Rajeev, A., & Mishra, V. (2022 [(5)]), while spring snowmelt and ice jams intensify river flooding (Beltaos, S. 2002[6]). Hurricanes cause storm surges, breaching coastal defenses and topography influences flooding risks: low-lying floodplains face overflow, while steep slopes trigger flash floods (Colombo, A., Hervás, J., & Vetere Arellano, A. L. 2002[7]). Urbanization with impermeable surfaces and poor drainage worsens flooding as does deforestation which reduces soil stability. Climate change intensifies these risks through stronger storms, altered rainfall, and rising sea levels (Handmer, J., Honda, Y., Kundzewicz, Z. W., Arnell, N., Benito, G., Hatfield, J., ... & Yamano, H. 2012[8]).

India has experienced severe floods, including the 1987 Bihar flood, which killed over 1,400 people and affected 29 million, and the 2004 Assam floods, which displaced 12 million and caused over 200 deaths (https://en.wikipedia.org/wiki/Floods_in_India). In 2005, Mumbai's record rainfall of 944 mm in a day caused over 1,100 deaths. The 2013 Uttarakhand floods, driven by cloudbursts and glacier melts, killed 5,700, while Kerala's 2018 flood, its worst in a century, claimed over 400 lives, displaced a million, and caused ₹40,000 crores in damages, exacerbated by deforestation and poor dam management (https://www.drishtiias.com/).

This study focuses on mapping flood-prone areas in Kerala's Alappuzha district using geospatial techniques. Physical parameters like slope, drainage density, rainfall, and land use alongside social factors such as population, housing conditions, and literacy rates were analyzed (Nahin, K. T. K., Islam, S. B., Mahmud, S., & Hossain, I. 2023[9]). The study emphasizes flood inundation modeling to understand the extent, intensity, and frequency of flooding (Eagleson, P. S. 1972[10]). Integrating geospatial data and hydrological models is crucial for effective flood risk assessment and promoting sustainable flood management practices.

2 Study Area

Alappuzha district is the smallest district in Kerala lying between 9o 05′ and 9o 54′ N and 76o 17′ 30″ and 76o 40′ N latitudinal and 74° 52′ to 76° 07′ E longitudinal figures respectively, have been taken as the study area. It is bounded by the Kottayam and Pathanamthitta districts in the East, on its west the Lakshadweep Sea, to the south Kollam district, and to the north Ernakulam district. Alappuzha district is one of the districts in the Travancore area of the State, which is having two Revenue Divisions namely Alappuzha Division comprising Cherthala, Ambalappuzha, and Kuttanad Taluks covering 49 Villages, and Chengannur Division, comprising of Karthikappally, Chengannur and Mavelikkara Taluks covering 44 Villages. Under the Local Self-Government System, the district is divided into 6 Municipal Councils (Cherthala, Alappuzha, Kayamkulam, Harippad, Chengannur, Mavelikkara), 12 Development Blocks (Ambalapuzha, Aryad It comprises 8 Blocks: Bharanickavu, Chambakkulam, Chengannur, Kanjikuzhy, Haripad, Mavelikara, Muthukulam, Pattanakkad, Thycattussery and Veliyanad) and 72 Panchayats. The extent that contains Alappuzha city and its surroundings falls within the revenue limits of the district headquarters.

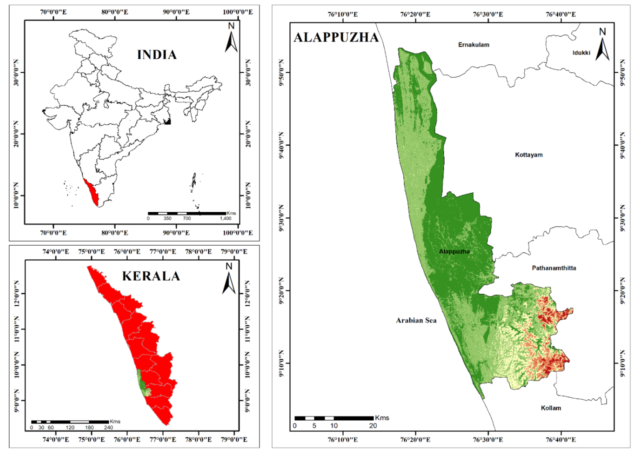

Fig. 1. Location Map of Study Area (Alappuzha District)

2.1 Physiography

Alappuzha district in Kerala is primarily divided into two physiographic divisions: lowland and midland. The lowland region, which covers about 80% of the district, includes the Taluks of Cherthala, Ambalappuzha, Kuttanad, and Karthikappally. The midland region occupies the remaining area. Notably, Alappuzha is the only district in Kerala without any highland or forested areas. The general elevation of the district is less than 6 meters above mean sea level, with certain parts, such as areas in Kuttanad, being below sea level (1-2 meters).

2.2 Climate

The coast is humid and warm, while the interior of the district is slightly cool and dry. The average monthly temperature is 250 C and the average rainfall in the district is 2,763 mm. There are 8 (eight) reporting rain gauge stations at Arookutty, Cherthala, Alappuzha, Ambalapuzha, Harippad, Mavelikkara, Chengannur, and Kayamkulam

2.3 Soils

The characteristics of different regional soil types and agricultural suitability vary. Peaty and Kari soils in the eastern parts of Cherthala and Ambalapuzha and western regions of Kuttanad are low in fertility with poor yields. Alluvial soils are found in the rest of Kuttanad, northeast Karthikappally, west Chengannur, north-west Mavelikkara, and the delta formed by the Pamba, Manimala and Achenkovil rivers near their confluence with Vembanad Lake. These soils are ideal for paddy and sugarcane. Laterite soils predominate Chengannur and Mavelikkara, which develop Coconut, Arecanut, and fruit trees. Sandy soils are common in Cherthala, Ambalapuzha, and Karthikappally which are suitable for coconut cultivation.

2.4 Rivers

Alappuzha is blessed by a network of rivers, backwaters, and canals formed part of the west coast canal system used as navigation. The important rivers draining mainly in the district are the Pamba River and its tributaries viz., Achankovil and Manimala Rivers. Apart from this, Vembanad Lake is the largest backwater in Kerala, lying in northeastern Alappuzha, bordering Kottayam district, where it takes rivers like Pamba, Achankovil, and Manimala. It has islands mainly Perumbalam and Pallippuram. Kayamkulam Lake lies between Panmana and Karthikappally and opens into the sea at Kayamkulam Barrage. Alappuzha is characterized by an elaborate network of canals that is a constituent of the West Coast Canal system which also constitutes a primary means of navigation. Important among the above canals are the Vadai Canal, and Commercial Canals, besides linking and connecting link canals. Moreover, there is a myriad of inland canals for passenger traffic and all kinds of trade operations.

2.5 Wetlands

Other than the estuarine portion of the rivers opening to the Lakshadweep Sea, other significant backwaters in the form of lagoons (Kayals), canals, and distributary systems of the rivers occupy a large part of the coastal plain of the Alappuzha district. Some of the remarkable backwater bodies are Vembanad Kayal, Karthikappally Kayal, Vayalar Kayal, and Vatta Kayal. In addition, there is an obviously depressed region which is below sea level (0.5 to 1 m below MSL) and always water-logged due to which some parts remain always submergible. This depressed region is the Kuttanad area south of Vembanad Lake. All these water bodies are brackish in summer.

2.6 Demography

According to the 2011 Census, Alappuzha District has a population of 2,127,789, whereas 1,013,142 male and 1,114,647 female population. The density of the Population is about 1504 persons per sq.km and the sex Ratio is about 1,100.

3 Methodology

This study employs satellite imagery conventional data and secondary sources, processed using ArcGIS to identify flood-prone areas in the study area. A total of 18 parameters 10 physical and 8 socio-economic were considered. Physical parameters include rainfall, slope, geomorphology, drainage density, soil land use land cover (LULC), NDVI, NDBI, MNDWI, and WRI. Socio-economic parameters such as population, household count, household size, literacy rate, building roof and wall types, child population, and access to information were sourced from the Census of India.

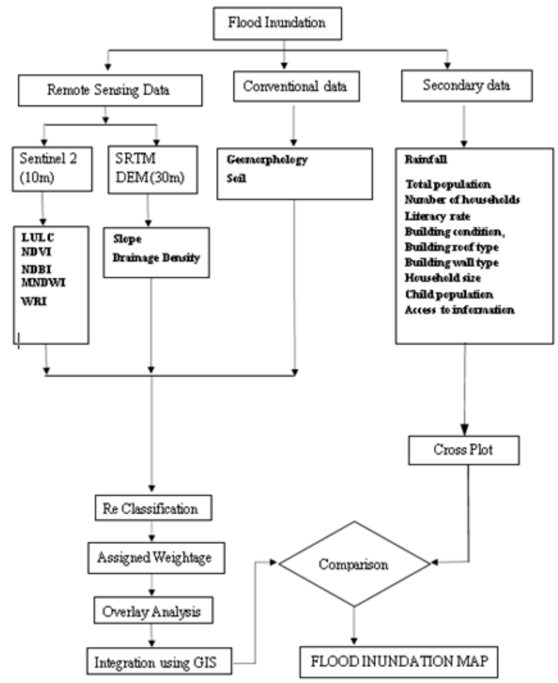

Fig. 2. Methodology Flow chart of the study

Topographic data including slope and drainage density were generated from the SRTM DEM (30m) using ArcGIS's Spatial Analyst tool. The soil map was digitized from the Kerala Soil Map, while geomorphology maps were obtained from the Kerala Geomorphology Map. Rainfall data came from NASA. The LULC, NDVI, NDBI, MNDWI, and WRI indices were derived from Sentinel-2 data acquired on December 10, 2019, through Copernicus. The Maximum Likelihood Classification method was used for LULC classification, while other indices were calculated using appropriate formulas.

Each factor considered in the flood risk assessment needs to be converted into a raster format. All the information gathered is then reclassified into classes using a standardized scale such that every category ranges from 1 to 5 where 1 indicates low flood risk while 5 indicates high flood risk. This helps to standardize the various units of measurement of each layer to enable comparison and combination. After reclassifying, every parameter is assigned a weight based on how important it is relatively. The total of all the weights of the parameters will amount to 100%. Weighted Overlay Analysis using Raster Calculator in Arc GIS 10.8 Software preparation Flood Inundation Map. Every pixel in the output flood inundation map will have a computed score on the weighted sum of all factors that influence flood risk.

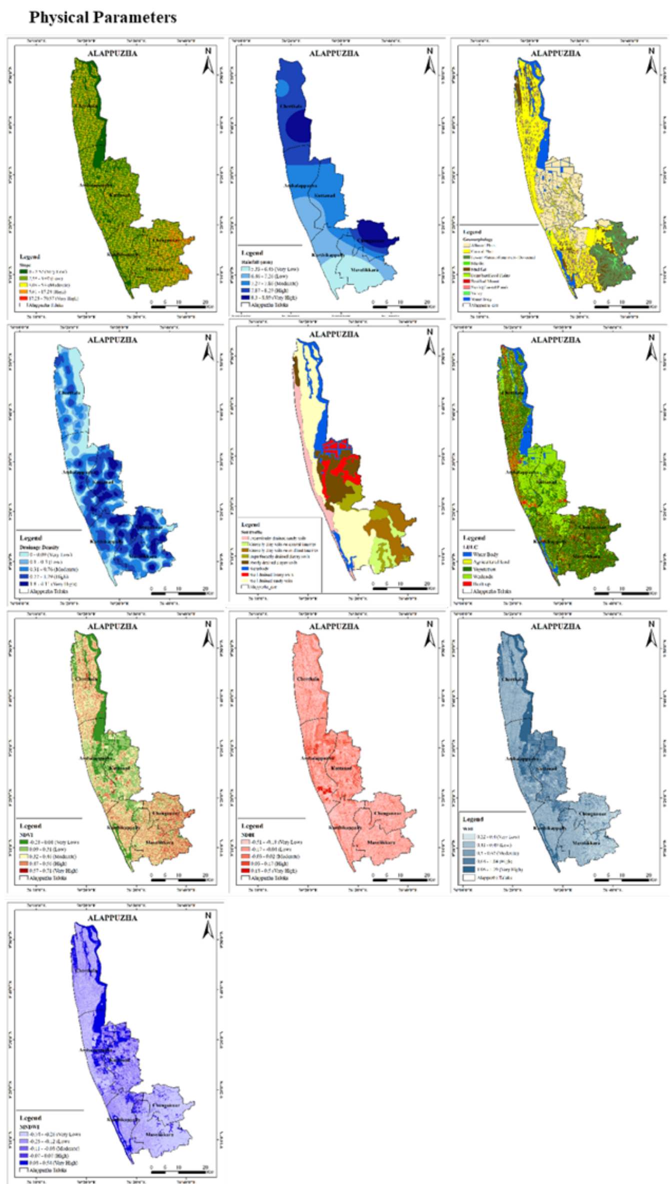

Fig. 3. Maps showing all physical parameters

4 Results and Discussions

4.1 Physical Parameters

One of the major determining flood-prone areas is the slope. The map classified the slope into five ranges, namely: Very Low, Low, Moderate, High, and Very High. Areas which have lower slopes have a higher probability of being flood-prone (Very Low and Low).

This rainfall map of the Alappuzha district depicts spatial variation in the intensity of rainfall across different taluks. Cherthala and Chengannur taluks are deep red in color, portraying regions with very high rainfall values (>8.109 mm). High rainfall (7.537– 8.108 mm) is also observed at some places in the Ambalappuzha and Kuttanad regions.

The geomorphic divisions of the study area include the alluvial plain, coastal plain, lower lateritic plateau, marshy lands, mud flat, flood plain, residual mount, swale, valley, and waterbody. Coastal plains and alluvial plains in the low-elevated regions (Cherthala, Ambalappuzha, and Kuttanad) are more prone to inundation as the topography is flat, favoring the flood.

Regions with very high and high drainage densities, such as Cherthala, Ambalappuzha, and Kuttanad, are highly prone to flooding because the dense drainage network gets saturated during heavy rainfall events thereby causing waterlogging and even submergence. Conversely, low and very low drainage density areas have less vulnerability due to the reduced capacity of the drainage network to hold surplus water.

Soil texture determines the rate of flooding. Impermeable soils with poorly drained, such as clay, enhance runoff rates, increasing the risk of flooding, especially in the lower elevated areas such as Ambalapuzha, Kuttanad, and northern parts of Chengannur.

The LULC of the district includes water bodies, wetlands, vegetation, built-up land, and agricultural land. The presence of wetlands and water bodies makes the northern and central parts highly vulnerable to floods. The majority of the built-up and agricultural lands can be found along these regions. Some of the vegetative areas is also seen in these low-lying areas whereas a major portion is predominant in the southern portion of the district which is at lower risk of flood.

NDVI value ranges from -1.0 to 1.0 and indicates the amount of vegetation within the land surface. NDVI values are between -0.285 and 0.705, which are categorized into five classes as -0.285 - 0.049 (very low), 0.05 - 0.212 (low), 0.213 - 0.348 (moderate), 0.349 - 0.457 (high), and 0.458 - 0.705 (very high). Dense vegetation indicated by high NDVI values can interrupt rainfall water and reduce the speed at which it reaches rivers or streams thus increasing infiltration into the soil.

The NDBI indices vary from -1 to 1 with a high value signifying built-up areas while the low value signifies other regions. The value of NDBI varies between -0.514 and 0.503 with five classes classification, that is, -0.514 - -0.223 (very low), -0.222 - -0.151 (low), -0.15 - -0.08 (moderate), - 0.079 - 0.016 (high), and 0.017 - 0.503 (very high). High NDBI-value built-up areas are dominated by impervious surfaces like roads and buildings, etc. cannot soak up rainwater; hence increased runoff and flooding are being experienced.

The WRI values range from 0.219 to 1.792 which are categorized into five classes as 0.219 - 0.491 (very low), 0.492 - 0.639 (low), 0.64 - 0.843 (moderate), 0.844 - 1.083 (high), and 1.084 - 1.793 (very high). WRI values greater than 1 usually represent the areas that contain waterbodies, which prove high in water-retention capacity.

MNDWI values of the study area are categorized into five classes such as -0.736 - -0.285 (very low), -0.284 - -0.205 (low), - 0.204 - -0.084 (moderate), -0.083 - 0.061 (high), and 0.062 - 0.542 (very high).

4.2 Socio-economic Parameters

The socio-economic data of the study area were obtained from the Census of India. The parameters include total population, number of households, household size, literacy rate, building roof type, building condition, building wall type, child population, and access to information. The data obtained is then performed normalization which makes it easier for further processing.

The total population of the district ranges between the normalized values of -1.26 to 1.46 in which a value between -1.26 to -1.228 indicates a very low population that is experienced in the Kuttanad region due to its geographical factors. Moderate population (-1.227 - - 0.172) is found along the is observed along the elevated portion of Chengannur. High (-0.171 - 0.777) is observed along the southern portions (Karthikappally and Mavelikara) which is less prone to flooding. A very High population (0.778 - 1.46) belongs to the highly flood-vulnerable areas such as Cherthala and Ambalappuzha.

The child population ranges between the normalized values of -1.33 to 1.36 in which value between -1.33 to -1.119 indicates a very low population that is experienced in Chengannur. A moderate Population (-1.118 - -0.296) is found along the observed along Kuttanad and Mavelikkara. High (-0.295 - 0.432) is observed in Karthikappally which is less prone to flooding. Very High population (0.433 - 1.36) belongs to the highly flood-vulnerable areas such as Cherthala and Ambalappuzha.

Both maps show the highest number of households with larger household sizes (0.666 - 1.42) found in Cherthala taluk whereas Ambalappuzha, Karthikappally, and Mavelikara regions experience higher households with greater sizes (-0.023 - 0.665). Chengannur region observed moderate households (-1.194 - -0.024) as its an elevated portion of the district. Households and it is very low in the Kuttanad region (-1.37 to – 1.195).

The map depicts the building conditions of settlements in the district. A number of households with the condition of Census House are classified as good, livable, and dilapidated. Building condition is categorised into categorized into five classes such as < -0.96 (very low), -0.959 - -0.841 (low), -0.84 - -0.75 (moderate), - 0.749 - -0.192 (high), and -0.191 - 1.37 (very high). Only around 50-60% of settlements in the highly and very highly vulnerable regions are in good condition, 25-30% as livable, and the rest as dilapidated which is highly prone to flooding. These are evident in Cherthala, Ambalappuzha, and Kuttanad.

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Wall condition is categorized into five classes such as < -2.18 (very low), - 2.17 - 0.0186 (low), -2.17 - 0.0186

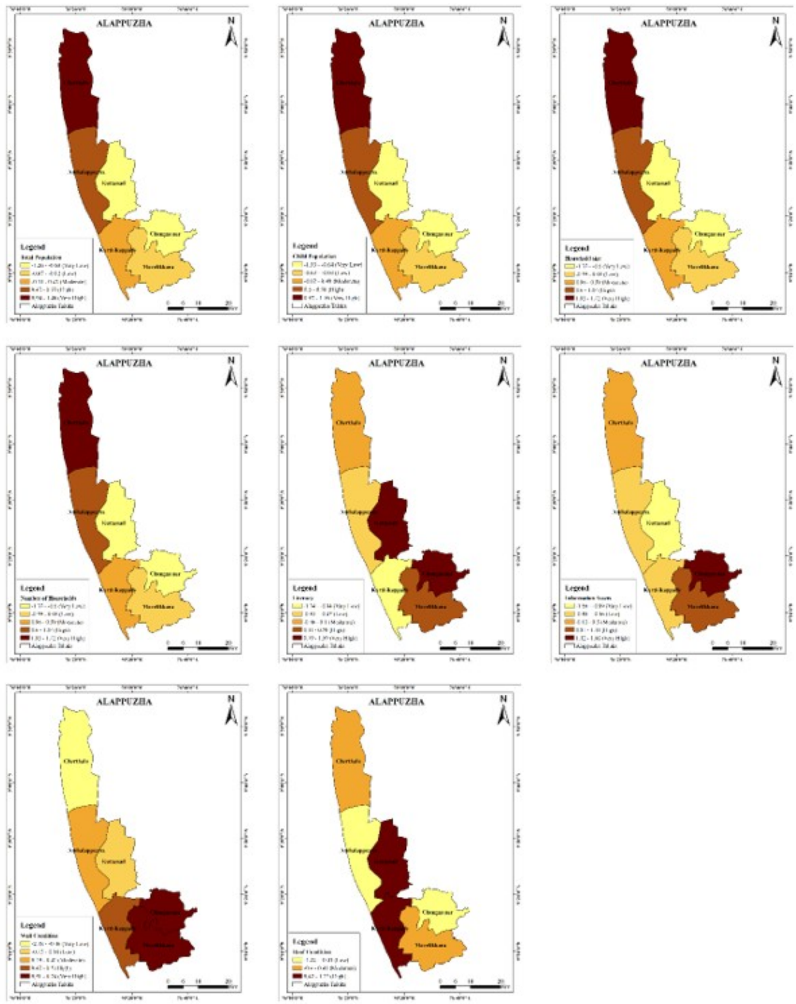

Fig. 4. Maps showing all Socio-Economic parameters

(moderate), 0.329 - 0.603 (high), and 0.604 - 0.74 (very high). According to census type, wall condition is divided into several types such as Grass/ Thatch/ Bamboo. Plastic/ Polythene, Mud/Unburnt brick, Wood Stone not packed with mortar, Stone packed with mortar, G.I./ Metal/ Asbestos sheets, Burnt brick, Concrete, and any other material. The majority of the houses in the study area have walls made of burnt bricks and concrete type.

Roof condition is categorized into three classes such as < -1.22 (low), -1.219 - 0.005 (moderate), and 0.006 - 1.22 (high). Roof condition is divided into several types such as Grass/ Thatch/ Bamboo. Plastic/ Polythene, Mud/Unburnt brick, Wood Stone not packed with mortar, Stone packed with mortar, G.I./ Metal/ Asbestos sheets, Burnt brick, Concrete, and any other material. Houses with tiles and concrete are less prone to flooding. Other roof types are less resistant to flooding.

Literacy plays an indirect role in mitigating the rate of the flood as it enables one to gain knowledge about the pre and post-flood events. Chengannur, Kuttanad, and Mavelikkara taluk have higher literacy rates with 88.87%, 88.21%, and 87.47% respectively. Cherthala has a moderate literacy rate with 86.95%. Ambalappuzha accounts for about 86.57% with low literacy. A very low literacy rate is found in Karthikappally with 86.08%.

Information assets per census type include radio/transistor, television, computer /laptop, and telephone/mobile phone. High flood-prone areas such as Ambalappuzha and Kuttanad have lower access to these assets, making them more vulnerable to population. Cherthala and Mavelikara have moderate access to information. Chengannur has accounted for the highest information assets.

The flood risk map of Alappuzha district in Kerala highlights major taluks such as Cherthala, Ambalapuzha, Kuttanad, Karthikappally, Chengannur, and Mavelikkara,

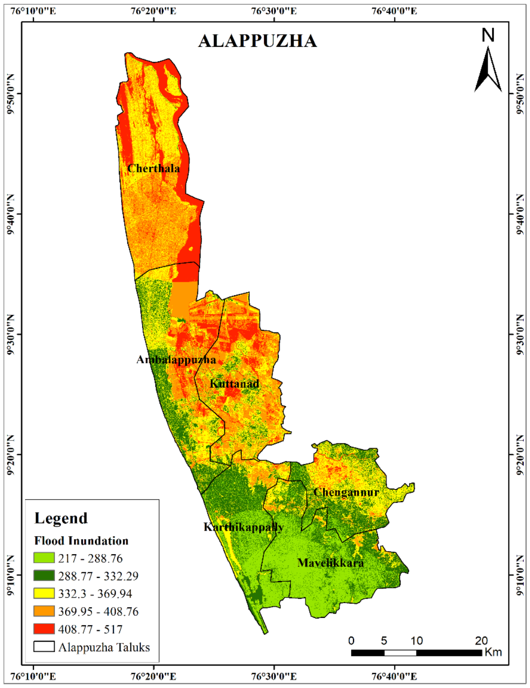

Fig. 5. Flood-prone areas of Alappuzha district

showing varying levels of flood susceptibility. Low-lying coastal and riverine areas are especially prone to flooding, as indicated by the Weighted Overlay Method. The district is predominantly agricultural, with 80% of it in coastal areas and a long 82 km coastline. Taluks like Cherthala, Ambalapuzha, and Kuttanad, located in lowland regions, are categorized under very high to high flood-risk zones. These areas experience heavy precipitation and are close to major rivers, backwaters, and Vembanad Lake, exacerbating flood risks. The alluvial plains of Kuttanad, known as the "Rice Bowl of Kerala," are particularly vulnerable as they lie below sea level, with sloping topography contributing to flooding during the monsoon season.

The proximity to rivers like Pamba, Manimala, and Achankovil further increases flood susceptibility. This has a significant impact on local agriculture with farmers losing crops annually. Ambalapuzha, on the periphery of Kuttanad, faces moderate to high flood risks, affecting the agricultural livelihoods of farm households. Cherthala, a coastal plain near the lake is highly prone to flooding, especially during the monsoons when water from lakes and rivers swells the area.

While the southern regions of Karthikappally, Chengannur, and Mavelikkara are at higher altitudes, they still face moderate flooding due to nearby rivers. In highly vulnerable areas, 50-60% of settlements are in good condition, with the rest in poor or dilapidated states. Literacy rates are low and the area faces challenges in reducing disaster vulnerability.

5 Conclusion

The integration of RS and GIS in the study has enabled susceptible areas to flood to be mapped by taking into account some basic factors such as topography, drainage networks, land use patterns, and historical flood data. Research analysis shows that low-lying areas, areas near water bodies, and poor drainage infrastructure have a high susceptibility to flooding. The most affected areas were low-lying regions like Cherthala, Ambalapuzha, and Kuttanad along with other flood-prone areas of the Alappuzha district due to distance proximity to the rivers, coastal plains, and Vembanad Lake. Areas like Kuttanad flood frequently since it is below mean sea level and the flooding really badly affects agriculture and the livelihoods of farmers. Consequently, settlements in these high-risk areas usually fall into poor infrastructure communities, where most houses do not have structures to minimize flooding. Southern taluks like Karthikappally, Chengannur, and Mavelikkara lie at higher altitudes but still are exposed to moderate flood risks due to being close to minor rivers. Generally, the report findings outline that the district is prone to flooding and thus poses an even greater challenge to both its agricultural economy and its population, implying the imperative for particular flood management and mitigation strategies.

5.1 Acknowledgement

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