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Extraction of Village - Wise Flood Persistence Derived from Multi Temporal Satellite Data a Case Study of Kerala Floods 2018

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Abstract— Kerala, an Indian state which is situated in the country's southwest is bordered by the Arabian Sea to the west, is geographically susceptible to floods, cyclones, and storm surges. The region's vulnerability arises from incessant rainfall, coupled with inadequate drainage systems and limited access to sea outlets, which are primary contributors to flooding and, in some cases, flash floods. In this study, the catastrophic floods that occurred in Kerala in 2018 are analysed. Using satellite-based analysis, flood persistence maps are generated, and the impact of persistent flooding on social vulnerability is examined. Social vulnerability parameters, including Total population and Total Female population (gender), are sourced from the Census of India, 2011. The flood persistence data, derived from multi-temporal satellite observations during Aug 11-27, 2018, reveal that three districts Alappuzha, Pathanamthitta, and Kottayam are the most severely affected. Approximately 461 villages experienced varying degrees of flood persistence, ranging from 0 days to more than 10 days. The analysis serves the purpose of identifying the most severely affected villages based on the duration of flood persistence. This information aids in prioritizing relief and rescue operations, particularly in the worst-affected districts and villages. The study further emphasizes the overall extent of flood-affected areas during the 2018 floods, contributing to a comprehensive assessment of flood risk and impact in Kerala.

Index Terms— Floods, Precipitation, Remote Sensing, Social vulnerability.

I. INTRODUCTION

In August 2018, the Indian state of Kerala saw catastrophic floods, affecting millions of people and killing over 400 people. Severe precipitation incidents and accompanying floods have increased as the climate has warmed, inflicting major losses in both human life and infrastructure. It reveals that Kerala encountered a 53% increase in rainfall above normal during the monsoon season up to August 21, 2018, specifically, the extreme rainfall events of 1, 2, and 3 days in August 2018. Prior to the extreme rainfall, on August 8, 2018, six of the seven main reservoirs were already operating at over 90% of their maximum capacity. The areas upstream of three significant reservoirs (Idukki, Kakki, and Periyar) experienced extreme rainfall with a return period exceeding 500 years for durations of 1-15 days in August 2018. The combination of above-normal seasonal rainfall before August 8, high reservoir storage, and unprecedented extreme rainfall in reservoir catchment areas exacerbated the flooding. (Mishra et al., 2018). The state of Kerala has recurrently faced a series of flooding incidents that have adversely impacted various sectors of its growth. The floods of 2018, among the most devastating in the state's history, significantly affected nearly all districts, including Trivandrum, Pathanamthitta, Idukki, Thrissur, Ernakulam, and Kottayam. The sub-region near the Karamana basin in Trivandrum, characterized by high urbanization and is susceptible to intense riverine flooding. The major rivers in this area, Karamana and Killi, along with their tributaries, contribute to the water dynamics. Extensive urbanization, coupled with river overflow during the monsoon seasons, has led to severe flooding. (Vijayachandran&Singh, 2023).

In recent years, flood mapping studies have become increasingly popular, thanks to the availability of high-resolution Synthetic Aperture Radar (SAR) imagery. Unlike visible spectrum satellite images, which are hindered by cloud cover during adverse weather conditions, radar images possess cloud-penetrating capabilities and can operate in all weather conditions. This makes radar images more suitable for flood mapping applications, particularly in disaster management. The 2018 Kerala floods were the most severe the state had faced in a century, causing widespread destruction and extensive damage. While some flood inundation studies have focused on Central Kerala, there is a deficiency in the comprehensive remote sensing-based flood mapping of Northern Kerala and South Kerala. The results show that the Malappuram district's low-lying areas are particularly hard hit; some villages saw catastrophic floods, with over 10% of the total area submerged during peak hours. (Chithra et al., 2022). In August 2018, Kerala, India faced prolonged heavy rainfall, leading to floods that claimed over 400 lives and displaced a million. While current climate changes may partly alleviate flood impacts, future climate change is likely to worsen consequences. (Hunt & Menon, 2020). Kerala is a state which is vulnerable to flood due to its geography and change in climatic conditions, during

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monsoon Kerala experiences a heavy rain fall. The state of Kerala is crisscrossed by 41 rivers, the water level in rivers rises because of heavy rain fall resulting in flooding of many rivers. Due to excessive rains, the hilly regions in Kerala are prone to landslides which adds more to the disaster.

Kerala is categorized as one of the densely populated states in India, with a significant portion of its population residing in areas prone to flooding. This demographic distribution contributes to a heightened risk of mortality during flood events. Notably, the state experienced a severe flood in August 2018, marking one of the most recent instances of extensive flooding. This event is regarded as one of the worst floods to have impacted Kerala since the significant flood of 1999. The vulnerability of the population due to their concentration in flood-prone regions underscores the challenges posed by such natural disasters in the state. The floods in Kerala during 2018 were exacerbated by a substantial 30% increase in rainfall compared to the average precipitation. The complex interplay of various factors contributed to this calamity. Among them, the discharge of water from the 36 dams in Kerala played a significant role. Excessive rainfall, deforestation, encroachment upon floodplains, congestion in drainage systems, and the limited reach of rivers to the Arabian Sea were identified as key contributors to the devastating floods. The release of water from the numerous dams, coupled with the heightened rainfall, created a situation where the capacity of the land to absorb water and the natural flow of rivers to the Arabian Sea were overwhelmed. Deforestation and urbanization further compounded the issue. In the pursuit of rapid urban development, the natural courses of many rivers in the Western Ghats were altered, diverting them from their original paths. This modification disrupted the natural drainage system, hindering the absorption of water into the ground and impeding its flow into the Arabian Sea. Consequently, these collective factors played a pivotal role in the inundation that characterized the 2018 floods in Kerala. Population density is one of the chief reasons for floods, Kerala stands third in the population density index right after Bihar and West Bengal, according to 2011 Census. Kerala recorded a population density of 859 per km², this figure is more than twice the overall population density of India, solidifying Kerala's status as one of the most densely populated states in the country. The catastrophic floods of 2018 were not a sudden or isolated event; rather, experts assert that they were the culmination of a series of sequential events that unfolded in the preceding years. Despite the significance of these events, they were unfortunately overlooked and ignored, underscoring the importance of acknowledging and addressing the underlying factors leading to such disasters. According to the report of Western Ghats Ecology Expert Panel (WGEEP), "the Western Ghats is divided into 'Three ecologically sensitive zones' and recommended 57 restrictions to preserve it." WGEEP also suggested not to construct any dams in these sensitive regions but dams were constructed in these sensitive regions which does not sound like the right fit.

II. STUDY AREA

Situated between the Western Ghats and the Lakshadweep Sea, the state of Kerala spans the region between 8°18' and 12°48' North latitudes and 74°52' and 77°22' East longitudes. Kerala experiences a tropical rainforest climate, occasionally encountering cyclones. In contrast to the eastern part, Kerala's western coastal strip is relatively flat. The state is intersected by the Kerala Backwaters, a network of interconnected brackish canals, lakes, estuaries, and rivers. Kerala's rivers, characterized by their compact size and absence of a delta, are especially vulnerable to environmental factors, confronting issues such as sand mining and pollution. The region is no stranger to natural disasters, with occurrences of landslides, floods, and droughts not uncommon. The prevailing climate in Kerala is predominantly tropical wet and marine, with a notable influence from the heavy rains brought by the monsoon. Adding to the geographical features, the Western Ghats, a series of Rocky Mountains, are situated in close proximity to Kerala's eastern boundary, attaining elevations of around 1,500 meters. This geographic setting contributes to the environmental dynamics and challenges faced by the state. Comprising 49 rain-fed river/lakes with numerous tributaries, these water bodies flow through the state. Kerala is home to 49 rivers, 46 flowing westward and the remaining 3 eastward, originating from the Western Ghats and emptying into the Arabian Sea. The state exhibits diverse soil types, including red soil, ferrous soil, sandy soil, black soil, peat soil, and loam soil, fostering various flora and plantation crops. Lower and middle regions feature tropical wet evergreen forests with dense undergrowth, while middle altitudes host deciduous forests. Mountainous areas showcase a blend of tropical damp and temperate forests, along with shola forests in the hills. Bordered by the Arabian Sea and the Western Ghats, this distinctive landscape boasts a temperate and tropical climate, providing pleasant weather throughout the year. The coastal state experiences hot and humid conditions in April-May, transitioning to mild, temperate weather in December-January. The warmest phase, featuring temperatures peaking at 33 degrees Celsius, unfolds between April and June. Following this, the South West Monsoon prevails from June to September, marking the transition from the summer season. As winter sets in, a subtle decrease in temperature accompanied by a refreshing breeze characterizes the climate. The winter season typically extends from November to January or, in some cases, February. The focus of the current study is on three specific districts – Alappuzha, Pathanamthitta, and Kottayam which were directly impacted by floods. **Fig. 1** visually represents the extent of the flood affected area during the 2018 Kerala floods.

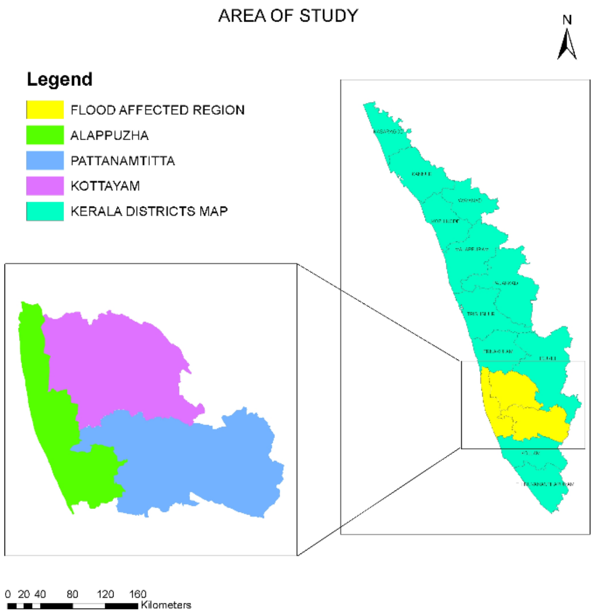

Fig. 1: Map showing Area of study

Objectives

- To generate maps representing total population affected and total female population affected in the 2018 Kerala floods using the Flood persistence layer generated from multi-temporal satellite data.
- To identify the villages, total population and female population affected during the 2018 floods based on the flood persistence derived from satellite data.

III. METHODOLOGY

Space applications have a big part to play in helping with flood disaster management, as long as the data can be shared with disaster management support organizations quickly. Remote sensing data from satellite provides continuous spatial flood extent information. Regular satellite observations may be used to monitor the status of the ground-level flood situation, including the extent, frequency, and duration of floods. Radar has several advantages over optical data, including the ability to collect data day and night and through cloud cover. At radar wavelengths, water surfaces are typically smooth and can be classified as specular reflectors which provide limited backscatter. At radar wavelengths, the surrounding environment is expected to exhibit diffuse scattering with a moderate degree of backscatter. Water is considered a low intensity area, while the land around it is considered a high-intensity area. Thresholding is a traditional way of determining the level of flooding in an open space. Pixels that have intensities higher than the threshold are regarded as dry land, in contrast to pixels with intensities lower than the threshold are regarded as floods or open water. The threshold value will vary depending on the degree of contrast between the ground and water classes, and typically needs to be established for each SAR profile. The intensity of the backscatter is determined by the frequency, angle of incidence, and polarization, and is sensitive to wind waves on the surface of the water. Preflood satellite information over flood prone areas is collected and analysed prior to the commencement of flood season. On-screen digitization techniques are used to capture bank lines, permanent bodies of water and active river channels. The layers and datasets will function as the master data sets for the analysis that follows. For location accuracy during floods, the raw satellite data will be geometrically co-registered with the pertinent state masters. For that specific year, these corrected data sets are regarded as master data sets. Water bodies are categorized to facilitate their extraction from images. In the case of optical data, unsupervised classification is employed with the maximum number of classifications specified. This process identifies the primary active river channel, tributaries, and permanent water bodies, converting them into vector format. Image enhancement techniques are applied to improve the contrast between image features. Digital river bank line delineation is achieved through on-screen digitization techniques within a GIS environment. Post-editing further refines the delineation, with the final layer stored in vector format. For microwave data, a backscattering image (sigma naught) is generated, and water bodies are extracted using a variable threshold technique model. Subsequently, stray water pixels are isolated through grouping and removal to enhance the precision of the extraction process.

Role of Space Technology

The applications of space technology in disaster management hinges on the imperative need to generate and promptly share data in real or near-real time. Space technology advancements provide important technological potential to fulfil crucial information requirements during the phases of mitigation, preparedness, and response/relief in the event of a disaster. Data from satellite-based remote sensing aids the provision of spatial flood extent and flood damage statistics, along with information vital for river engineering research, in an economical way, as detailed below. The methodology for pre-flood data preparation is illustrated in **Fig. 2**, while the methodology for flood delineation from satellite data is depicted in **Fig. 3**. (Flood mapping manual of NRSC).

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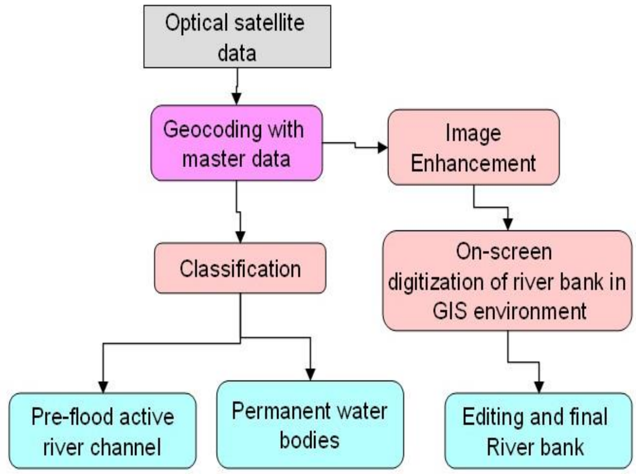

Fig. 2: Flow chart for pre-flood analysis of optical data (Source: NRSC)

Methodology for Flood Mapping and Monitoring

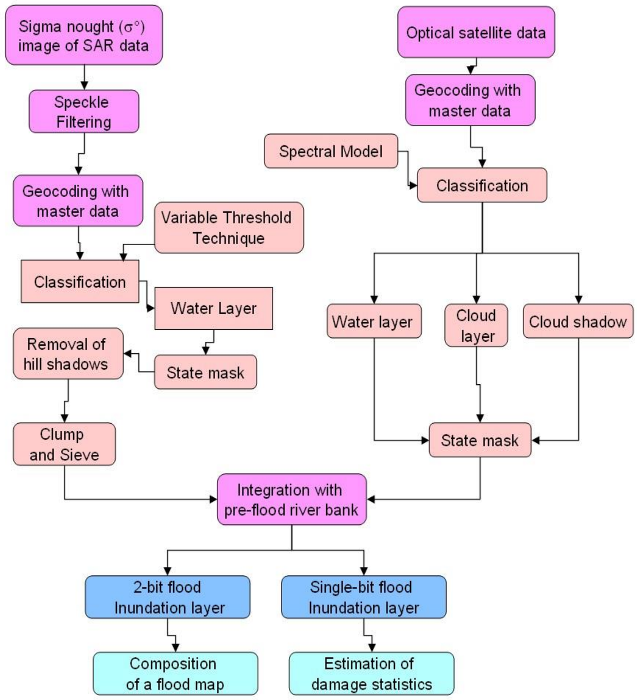

Fig. 3: Methodology for analysis of satellite data during floods (Source: NRSC)

A comprehensive database is established, comprising base layers such as administrative boundaries (state, district, taluk, mandal), roads, railways, settlements, airport locations, district headquarters, villages, and cover for each state. Flood map templates are meticulously crafted at scales of 1:1 million, 1:500,000, 1:250,000, and 1:50,000 utilizing the aforementioned layers. In preparation for the flood season, pre-flood riverbank and permanent water bodies layers are derived from satellite data, as previously discussed. As the flood season unfolds, the flood inundation layer, generated through satellite data analysis, is continually stored and updated in the database. **Table-1** explains the database layers used to generate flood inundation data. Leveraging flood templates and the inundation layer, flood maps are composed at the state/district level and, in select areas, at a detailed level.

IV. RESULTS AND DISCUSSION

The analysis was carried out with the aid of Arc Map, Version 10.8, and Microsoft Excel. This study offers a thorough examination of the villages affected by the 2018 Kerala floods, encompassing key demographic data such as the total population and the specific impact on the female population. The floods in 2018 directly impacted three districts within Kerala: Alappuzha, Pathanamthitta, and Kottayam. Within the scope of this investigation, we obtain a comprehensive count of the villages that experienced the repercussions of the floods in the aforementioned districts Moderate, High, and Very High, **Table-1** represents flood hazard severity, **Fig. 4** represents a pie chart showing flood Persistence.

Flood Persistence

The flood persistence layer was generated based on the flood inundation layers derived from the analysis of multi-temporal satellite data acquired during the floods of Kerala. During Aug 11-27, 2018, the satellite datasets were analysed and date-wise flood inundation layers were extracted. Subsequently, all these layers were integrated in Erdas Model Maker Module to generate a flood persistence layer. The flood persistence layers depict the inundation from the first day of event to the last observed inundation date. This is classified into four classes, namely 0-3 days, 4-6 days, 7-9 days and > 9 days to classify the severity of inundation. Based on the number of days of inundation and the corresponding villages and population affected are identified to assess the impact of floods. Based on the flood persistence in days, severity is categorized as Not Affected, Low, as per the findings of this study, 22% of the region was identified as susceptible to very high flood impact, with an additional 3% classified as a high flood-affected zone. Moreover, 9% of the area was deemed vulnerable to moderate flood impact, while 13% fell into the category of low flood risk. Notably, a substantial 53% of the area remained unaffected by the floods that occurred in Kerala in 2018.

Table-1: Flood Persistence

Category	Hazard Severity
0	Not Affected
1 (1-3 days)	Low
2(4-6 days)	Moderate
3(7-9 days)	High
4(> 9 days)	Very High

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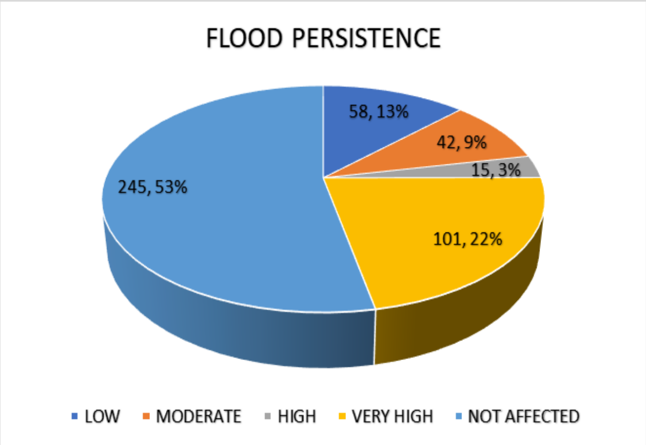

Fig. 4: Pie chart showing flood Persistence

Maps Generated

The present study produces two maps,

- Total population affected in the flood
- Total Female population affected in the flood

In Kerala, there are a total of 1018 villages according to the 2011 Census. Out of these, 216 villages, each covering an area of more than 25 hectares, have been affected. This study further illustrates the overall flood-affected areas during the 2018 floods, presenting a village-wise breakdown of flood impact. Additionally, it examines the vulnerability of villages to floods based on the duration of inundation. **Fig. 5** and **Fig. 6** visually represent the total population affected and the total female population affected, respectively the research offers a comprehensive overview of the total number of villages affected by floods, and the classification is based on the population residing in each affected village.

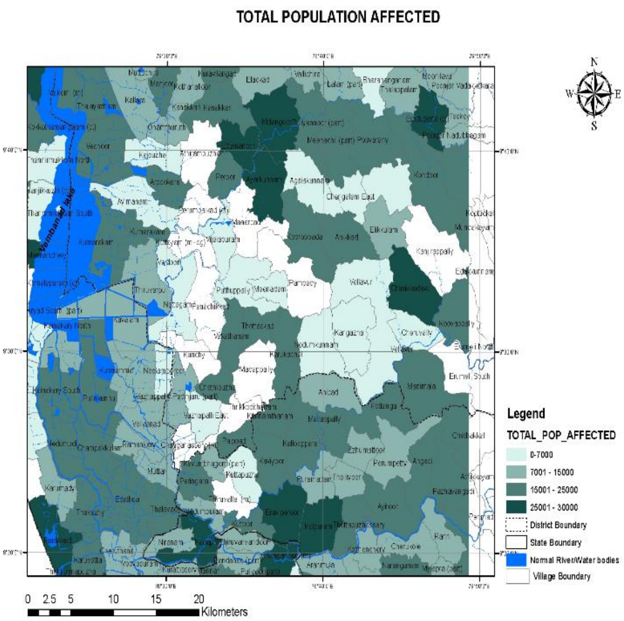

Fig. 5: Map showing Total Population affected in Kerala floods 2018

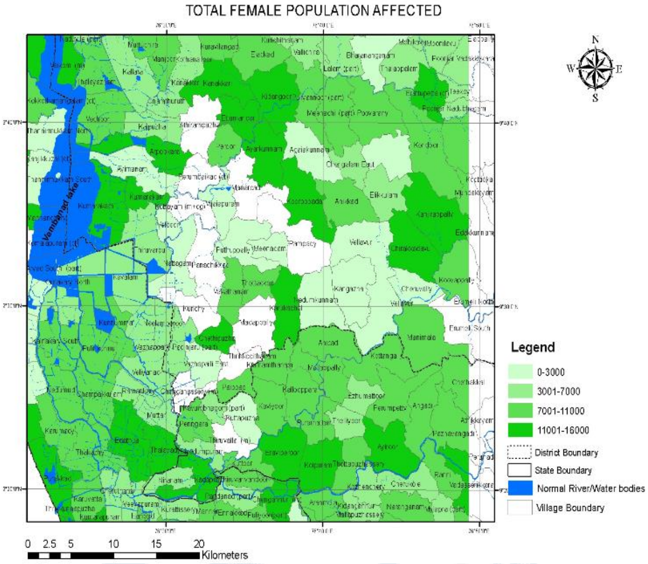

Fig. 6: Map showing Total Female Population affected in Kerala floods 2018

Total Flood Affected Population and Total Flood Area

The total population affected and the total Female population affected are calculated and classified according to the flood persistence. Considering the villages whose area is greater than 25 hectares, out of these 58 villages fall in low flood affected zone. About 42 villages are categorized into moderate flood affected zone. A total of 15 villages are classified in high flood affected zone. 101 villages lie in very high flood affected area. **Table-2** and **Table-3** gives a brief idea about the flood affected zones.

Table-2: Total population affected in the floods

S.NO.	Description	Total flood affected area (ha)	Total no. of villages	Total population affected
1	Not affected	324298	245	4507612
2	Low	2569	58	1044757
3	Moderate	2684	42	650313
4	High	447	15	250614
5	Very High	8551	101	1561854

Table-3: Total Female population affected in the floods

S.NO.	Description	Total flood affected area (ha)	Total no. of villages	Total Female population affected
1	Not affected	324298	245	2322277
2	Low	2569	58	541400
3	Moderate	2684	42	332127
4	High	447	15	129950
5	Very High	8551	101	798674

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Statistics

Bar graphs illustrate the total population affected and total female population affected in each village. The bar graphs are generated in accordance with the flood affected areas in various persistence severity zones. **Fig. 7, Fig. 9, Fig. 11, Fig. 13** depicts the total population affected, **while Fig. 8, Fig. 10, Fig. 12, Fig. 14** shows the total female population affected.

Bar graphs:

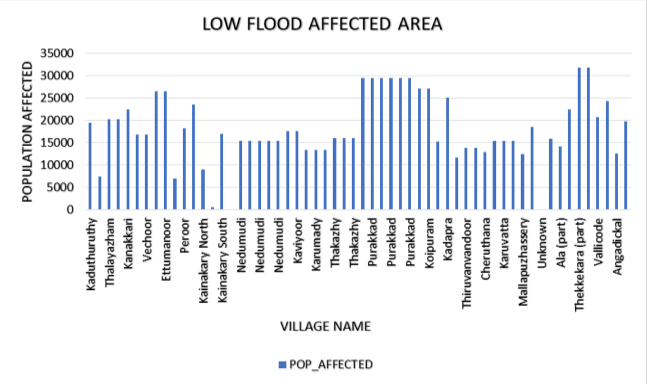

Fig. 7: Bar chart representing low flood hazard zone for population affected

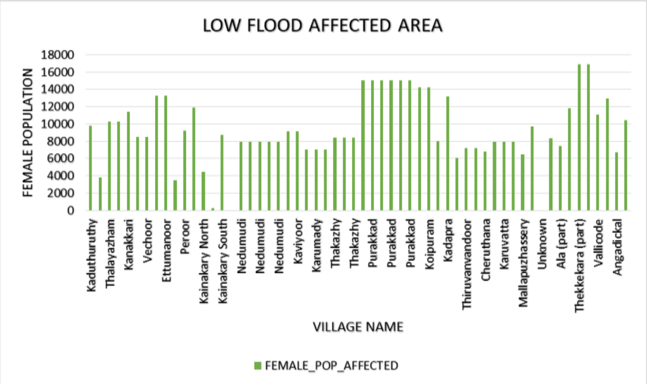

Fig. 8: Bar chart representing low flood hazard zone for female population affected

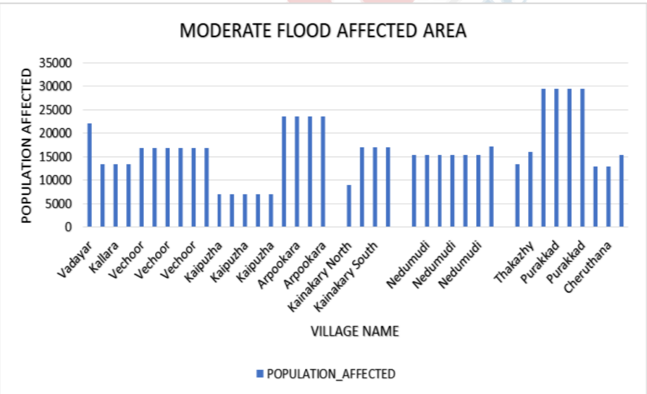

Fig. 9: Bar chart representing moderate flood hazard zone for population affected

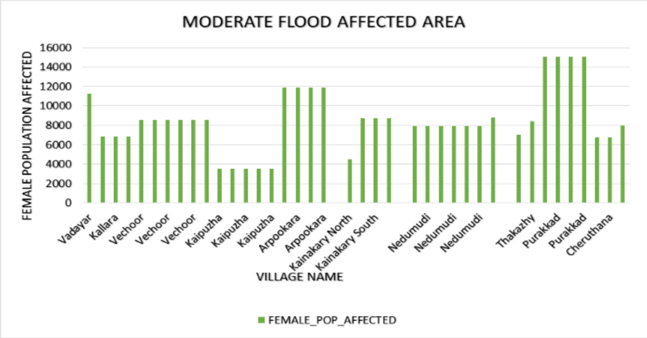

Fig. 10: Bar chart representing moderate flood hazard zone for female population affected

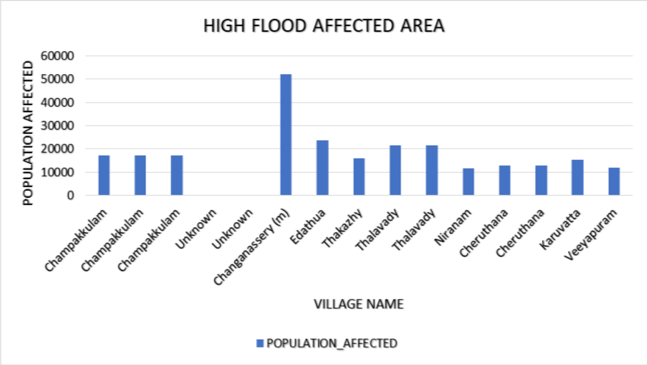

Fig. 11: Bar chart representing high flood hazard zone for population affected

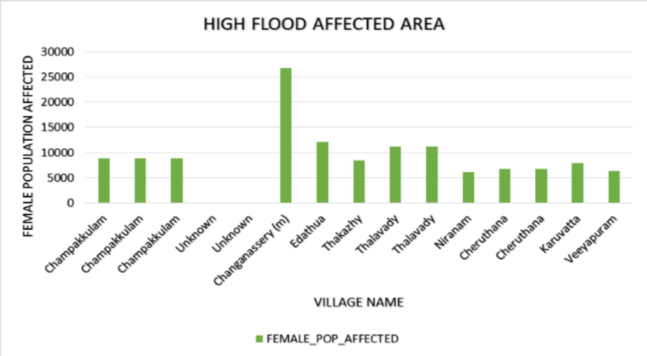

Fig. 12: Bar chart representing high flood hazard zone for female population affected

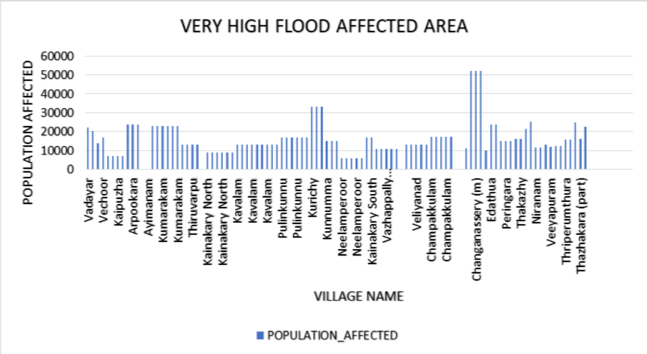

Fig. 13: Bar chart representing very high flood hazard zone for population affected

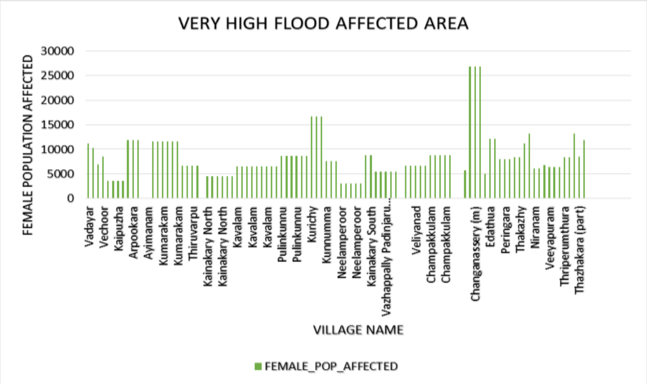

Fig. 14: Bar chart representing very high flood hazard zone for female population affected

V. CONCLUSION

This study presented the flood persistence areas in Kerala during Aug 11-27, 2018. It would be possible to use flood prediction, early warning, and management techniques on a regular and long-term basis. The flood persistence maps are a first step towards assessing the impact of flood persistence on society and its impact on various sections of the community. Flood persistence/duration maps helps us to identify the areas covered by water during prolonged flood events and can be used for prioritising the relief & rescue operations in areas with longer flood duration. It also helps in understanding the underlying conditions, terrain and physiography of the areas which have longer flood retention periods and the means as to how to utilised these areas for growing flood tolerant crops for effective utilisation of surplus water. The village-wise flood persistence map is a critical scientific input to find out the flood affected regions and flood affected population. The technology intervention, in conjunction with the ground validation, play a critical role in the development of effective flood mitigation, preparedness strategies.

Future and Scope of the Study

- The acceleration of flood risk caused by climate change and expanding development in flood-prone areas.
- Classify villages in terms of severity, weightage to the depth along with the frequency.

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