ADVANCEMENTS IN

SUSTAINABLE GEOGRAPHY:

EMERGING RESEARCH PERSPECTIVES

ABOUT THE BOOK

'Advancements in Sustainable Geography: Emerging Research Perspectives' presents an in-depth exploration of India's contemporary geographical challenges. The examination of 'Indian Cities as Sponge City' encapsulates the intricate equilibrium required between urban development and water resource management, emblematic of a broader paradigm shift towards sustainable urbanization. The thematic discourse on 'Geography and Geospatial Science' accentuates the indispensable role played by sophisticated technologies in tracing out spatial intricacies. Chapters dedicated to the 'Coastal Plains of Tamil Nadu' meticulously focuses on assessments of drought risks and employ cutting-edge remote sensing for the intricate 'Land Use Dynamics and Flood Inundation Mapping of Chennai City.' The anthology transcends geographical confines, probing into the 'socio-cultural and economic impacts of responsible tourism.' Insightful chapters addressing data collection and migration studies contribute to a holistic understanding of the intricate tapestry of India's evolving geographic landscape. The book culminates by mapping the dynamic environmental factors in the 'Coastal Region of Cauvery Delta' and enquiring into the urban-ecological interface in 'Salem City,' providing an erudite and comprehensive exploration of sustainable development in contemporary India.

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Dr. Balasubramani is a Fulbright Fellow at North Carolina Central University (USA) and currently working as Associate Professor in Geography, Central University of Tamil Nadu. He has over 15+ years of experience in exploring geospatial technologies for different applications, including integrated risk assessments, watershed modelling, fluvial dynamics and public health and environmental datasets. He served as a Spatial Data Engineer in a software company (2006-2009), Guest Faculty at Madurai Kamaraj University (2009-2011) and Assistant Professor at Bharathidasan University (2011-2017). Dr Balasubramani's doctoral research was on land and water resources evaluation for sustainable development, awarded by the Madurai Kamaraj University (2016). He has conducted post-doctoral research at the Indian Institute of Space Science and Technology (Dept. of Space). His research is usually inter-disciplinary in nature and adopting geospatial technologies extensively. He has published 50+ research articles in journals, including publications in reputed remote sensing, earth science, and public health journals. Currently, he is serving as Assistant Editor of the Indian Geographical Journal. He has operated research grants worth of Rs.10 million funded by DST, SERB, ICMR, ICSSR, UGC and others. He is a recipient of Young Geographer Award by the National Association of Geographers, India (NAGI) and Young Scientist Fellowship by TNSCST (Govt. of Tamil Nadu). He has received international travel grants from IGU, SERB, ICSSR, DST and visited USA, Sri Lanka and Thailand for research presentations. He has won Best Paper Awards and delivered 100+ invited talks in conferences/workshops/training programmes. He has also extended contributions to Professional Societies such as ISRS, IGS and GSI and coordinated their programmes.

Dr. E. Venkatesham is an Assistant Professor in the Department of Geography at the School of Earth Science, Central University of Tamil Nadu since August 2017. He has a total of 12+ years of teaching experience. Prior to joining CUTN, he held the position of Assistant Professor (Contractual) in the Department of Geography in the University College for Women (Autonomous), OU, Hyderabad (2014-2017), Academic Consultant in the Department of Geoinformatics at Telangana University (2010-2014). Dr. Venkatesham completed his Ph.D. in Geography from Osmania University in 2015, following his PGDGC (2010) and M.Sc. (2007) from the same University. He qualified the UGC-NET in Geography in 2013. His research ardor spans Urban, Environmental, and Regional Development and sustainable development geographics, reflecting his dedication to shaping sustainable futures. He published 4 books, 3 book chapter and 7 research papers on critical aspects of contemporary society; Analysing the nexus between tourism and regional development, urbanization landscapes, and offer insights into responding to disasters like severe cyclonic storms. Additionally, they also focus on urban primacy, pollution dynamics, and the dynamics of green spaces. These studies address pressing challenges and provide valuable knowledge for informed policies and sustainable urban planning in the present context.

Dr. Arun Prasad Kumar is working as an Assistant Professor in the Department of Geography, Central University of Tamil Nadu, Thiruvarur, India since March 2020. Prior to that, he was a contractual faculty from June 2018 to March 2020 at CUTN. He obtained the prestigious Alexander von Humboldt International Climate Protection Fellowship funded by the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB), Government of Germany. Under the fellowship, he worked as the Post-doctoral Researcher in Land Surface Dynamics Group, German Remote Sensing Data Center (DFD), German Aerospace Center (DLR), Oberpfaffenhofen, Wessling, Munich from April 2017 to March 2018. In 2015, he was conferred with Green Talents Young Researcher Award for Sustainability Research by the Federal Ministry of Education and Research (BMBF), Government of Germany and did three months research internship between July 2016 and September 2016 at DFD-DLR, Oberpfaffenhofen, Wessling, Munich. He completed his Ph.D. in 2016 from Indian Institute of Space

Science and Technology with a research focus on the application of contemporary hyperspectral remote sensing to identify mangrove species in Indian east coast at species level for framing effective monitoring and conservation strategies. His research interests include remote sensing time series analysis, estuarine environment, wetlands, and microplastics pollution.

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Indian Cities as Sponge City: Challenges in the Way

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Abstract

The rapid process of urbanization has triggered climate change. Cities are under the stress of numerous problems. Dramatic climate changes accompanied by rampant increasing population lead to water insufficiency. Irregularity in the frequency and volume of rainfall is resulting in pluvial flooding in Indian cities. Other than this, the age-old poor drainage network in India is a problem that can't be ignored which leads to urban floods. Across the world, different water management strategies are adapted in the form of green infrastructure and Low Impact Development (LIDs). It is high time that India also learns from these practices and works on them. The practices should be adopted that instead of considering urban floods as a problem, rethinks it as a potential resource and opportunity to solve the city's water supply issues during the dry months. India also falls victim to urban floods due to plenty of reasons and may continue to be a victim unless smart strategies are adopted and implemented. This paper presents the Integrated urban water management strategy- of Sponge City. The idea and understanding of LIDs infrastructure are summarized. Followed by pointing out the challenges that Indian cities face while going for new idea adoption to get a better understanding of where we stand and the scope for continuing in the future; along with the benefits that could be milked from the concept.

Keywords: Sponge City, Urban floods, LID, Green Infrastructure, Indian Cities, Challenges.

1. Introduction

Water management is critical to the long-term growth of metropolitan areas. Urban water related issues have sparked worries among scientists everywhere. Urban flooding is on the rise, groundwater is being over-exploited, water is scarce, rainwater is wasted,and there is water contamination because of fast urbanization and extreme weather phenomena (Nguyen et al., 2019). The rate of occurrence of short-duration, but destructive, urban floods has grown globally in recent years (Pour et al., 2020). In the quick process of urbanization, a major transition can be seen from the natural landscape to urban built-up areas i.e., the early forests, green spaces, and vegetation areas are converted into residential, commercial, and industrial areas. Former semi-rural spaces are now introduced to numerous urban infrastructures including the synthesis of roads, commercial buildings, more paved surfaces, and many more (Chan et al., 2018). Urban areas are experiencing flooding resulting from excessive runoff brought on by a dramatic rise in impermeability, explained by over usage of "grey construction," such as concrete and asphalt, which has resulted in impermeable surfacesthat are unable to absorb water in urban areas (Jia et al., 2013; Nguyen et al., 2019). A decrease in pervious surfaces and rainfall penetration has resulted in decreased stormwater absorption in urban centers and far less recharging of subsurface groundwater, along with this the receiving water bodies are experiencing deterioration in water quality (Chan et al., 2018; Jia et al., 2013). Urban floods are a distinct sort of flood caused due to the problem of inadequate and inefficient urban drainage systems in metropolitan areas. When the intensity of the downpour and the volume of water exceeds the area's drainage capability, it results in floods. Urban floods obstruct roadways, inundate low-lying dwellings, and disturb the daily lives of urban dwellers (Nguyen et al., 2019; Pour et al., 2020). The goal is to make water systems resilient which means that they can successfully handle several potential futures along with this it should have the virtue of livability which means everything that makes an urban region a good place to live, and is thus tied to what certain community values. To achieve livable communities, water utilities must provide services including water supply, sewage disposal, and efficient drainage (Furlong et al., 2017). Taking into account the responsibilities and interactions of the numerous institutions engaged in the management of the urban water cycle, IUWM is a strategy for urban water management that includes groundwater augmentation, water supply, sewage management, and stormwater retention in cities (Wang et al., 2018). Numerous ideas and hypotheses have been put forth by scientists and decision-makers regarding urban water planning. Among these, the best management practices (BMPs), are the Low Impact Developments (LID) approach in the United States, the Sustainable urban drainage system (SuDS) and the Blue-Green Cities (BGCs) approach in the United Kingdom, Water Sensitive Urban Design (WSUD) in Australia, Low Impact Developments Urban Design (LIDUD) in New Zealand and, Sponge City (SC) in China to make communities more sustainable, habitable, and resilient. This paper deals with adopting the ideas of Sponge City. The "Sponge City" Concept, originally presented at a central urbanization work conference in December 2013, intends to address growing flood risk resulting from rampant urbanization and formulate a concept with the amalgamation of critical components of sustainable development, urban planning, and urban water resource management, such as maintenance and preservation of urban water bodies, stormwater retention, and water quality enhancement (Chan et al., 2018; Nguyen et al., 2019).

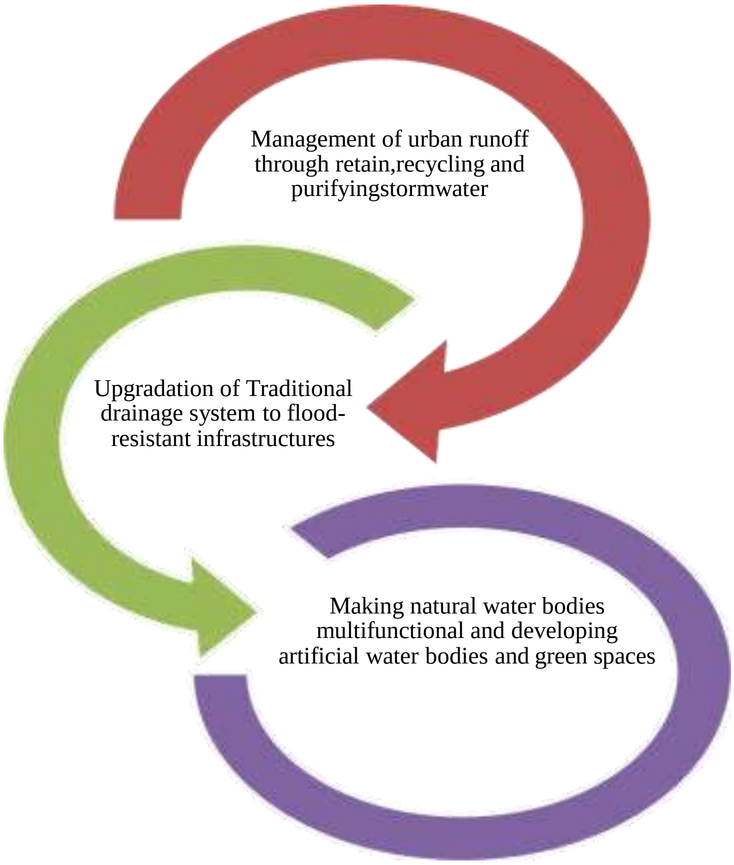


Fig. 1: Aims of Sponge City

The Chinese National Government is pushing the "Sponge City" concept and sponsoring demonstration projects in 30 pilot locations around the country. The initiative was launched in 2013-14 to tackle and surpass water-related difficulties by providing several benefits to urban communities to enhance water runoff reduction, water quality improvement, improved water storage, and greenhouse gas emission reduction. The Chinese government makes claims regarding improving permeation, retention, storage, purification, and drainage systems, and around 70% of stormwater will be recycled. The goal of Sponge City initiatives is to alleviate the consequences of urban growth on natural ecosystems while also solving urban water-related concerns (Chan et al., 2018; Nguyen et al., 2019). According to Xia et al. (2017), the "Sponge City" idea represents a breakthrough in Chinese urban planning since it has the potential to strengthen the sustainability principle by addressing ecological and socioeconomic elements and promote greater integration among urban planning and designing practice with urban water resource and flood risk management. Sponge City Plan encourages the implementation of LID infrastructures as it allows rainfall penetration, promotes the use of more porous materials for roads and permeable pavements, uses drainage ditches, swales, and infiltration channels, and creates urban parks with artificial wetlands.

2. Infrastructure

The urban and suburban areas are expanding, and parallel to these problems related to stormwater runoff is surging. A major reboot is what the present urban infrastructure needs. To attain the best community results, water infrastructure planning which forms an important division of water management is necessary as it focuses on choosing, locating, and evaluating the best possible infrastructure solutions. There is a set of essential actions that form the planning framework, these rational actions include- a description of the problem, potential alternative identification, choosing an optimal solution, and creation of an implementation strategy followed by execution of the same. Sponge City concept encourages the installment of stormwater management infrastructures aka LID infrastructures such as green roofs, Bio-swales, green zones, pervious pavements, infiltration or sediment ponds, rain gardens, biological retention tanks, and artificial wetlands. These infrastructures make urban water planning more effective by reusing stormwater that cities are losing to urbanization, through infiltration, retention, and purifying, avoiding to low away as they try to mimic the natural hydrological cycle as closely as possible. They also have the potential to boost overall urban green spaces which will, in turn, enriches the urban ecosystem by offering new niches for a wider variety of creatures (Chan et al., 2018; Furlong et al., 2017; Nguyen et al., 2019).

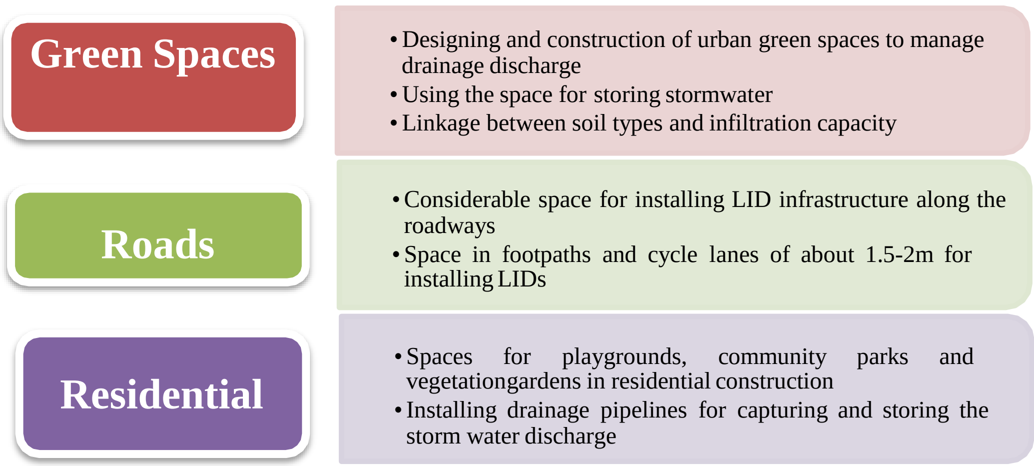


Fig. 2: Ideas incorporated in urban planning policies

The Ministries involved for the above-stated areas (fig2) are the Ministry of Environment, Forest and Climate Change (MoEFC) which will undertake issues like urban water pollution, managing green spaces, vegetation and deforestation issues along with soil aspects, the Ministry of Housing and Urban Affairs for all the land-use planning, be it road or residential infrastructures. The Ministry of Water Resources, River Development, and Ganga Rejuvenation is the glue that will be holding all these together. Sponge City as a concept can act as a major tool that will effectively synchronize and integrate these ministries to elevate the existing urban water management systems.

3. Low Impact Development (LID)

LIDs are a sustainable way of managing urban stormwater and have the capacity to lessen the effect of climate change-induced floods. Incorporating unconventional and sustainable water management practices along with traditional methods will prove successful in mitigation. However, many times they frequently fail because of the sites and climatic conditions are not optimized. The main problems are finding an ideal LID technique that suits the area and, considerable attention to the technical efficiency of the LID for the target area. Intense rainfall effects are seen more severely in paved surface regions contrary to the unpaved surface regions. All the projects that focus on urban development and planning generally put less emphasis on natural spaces (vegetation areas) and more stress on impermeable surfaces, which dramatically reduces the ability of the land surface to absorb rainwater and thus, increases surface runoff. The effect of continuous change in land use on the peak and volume of runoff is often overlooked by urban drainage system plans which results in catastrophic floods in urban areas. The present-day urban drainage system is designed to take climatic conditions to be fixed without incorporating the constantly changing characteristics of rainfall over time (Pour et al., 2020). The issues posed by the escalating frequency and intensity of these urban flood occurrences have drawn considerable attention to sustainable urban stormwater management. A growing amount of attention has been paid to adopting low-impact development (LID) buildings to increase water penetration into the subsurface. LID refers to a strategy and methodology for regulating stormwater runoff and boosting infiltration to decrease surface runoff. Natural features are utilized to minimize and reduce the peak runoffs and hence, mitigate the flooding effects. LID approaches are suggested and implemented in diverse ways for managing urban stormwater and are often observed as near-nature concepts; these approaches and practices include rain gardens, rain barrels, porous pavements, green roofs, and other retention systems such as bio-retention swales and ponds. LIDs have established their ability to reduce peak and volumetric runoff and effectively mitigate the negative effects of climate change on urban floods. However, fewer studies have examined the potential of LIDs to minimize the amount of area inundated by flooding or the usefulness of LIDs in lowering inundation depth and area impacted. The majority of LID research has been focused on the reduction of flood peaks and volume.

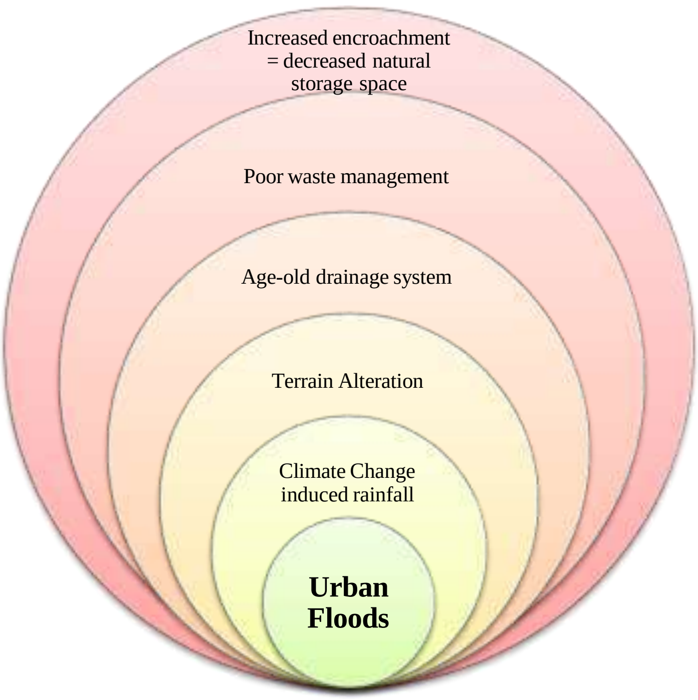
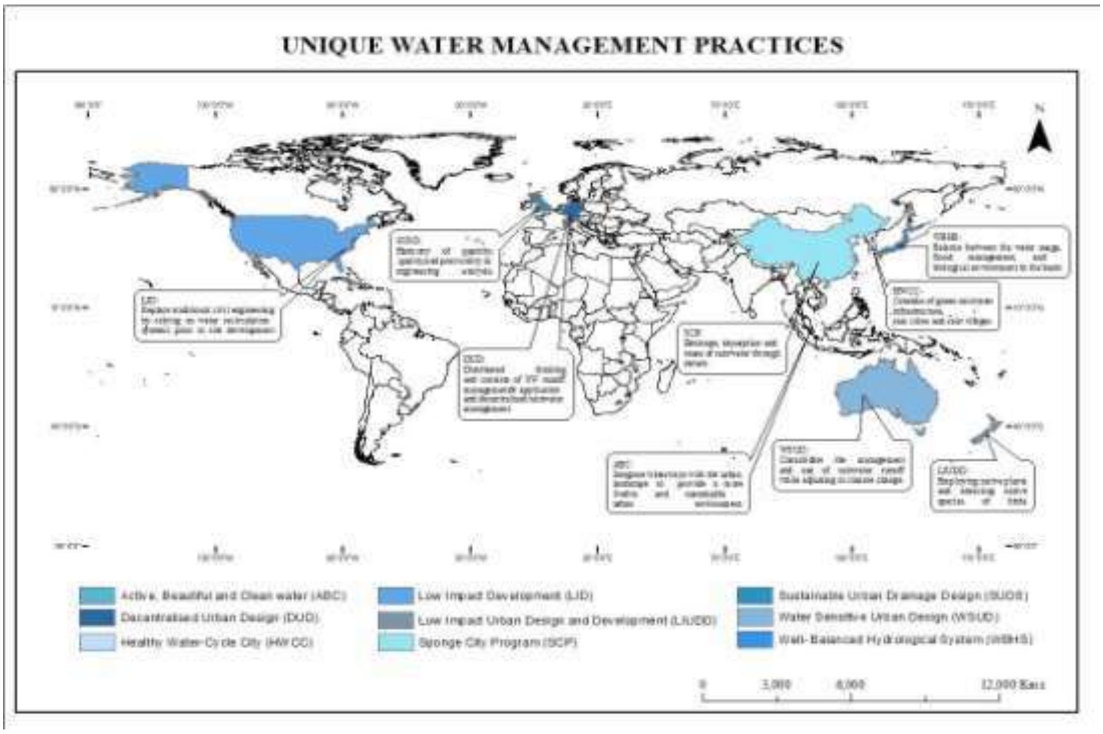


Fig. 3: Causes of Urban Floods

4. Status of Indian Cities

India as a developing nation has shown a tremendous demographic transformation shift from rural to urban (Hoelscher, 2016; Smith et al., 2019). This surge in urban population is reflected in the census data, i.e., the urban population increased from 27.8% to 31.2% from 2001 to 2011 respectively. The projections show that this surge will continue to 40% and 50% by 2030 and 2050 respectively (Gupta & Hall, 2017; Hoelscher, 2016; Prakash, 2019). With growing urbanization, the problems associated with the process are also growing. Cities faces problem like overcrowding, poverty, housing problems, traffic congestion, poor environmental quality, sanitation issues, increased crime, high unemployment rates, and many other more. Poor water management is another urban problem to be focused on. Developing countries like India lack infrastructure and planning aspects (Rietveld et al., 2016). Rapid and consistent rise in population and urbanization with poor urban planning and policies have led to water-related problems such as increased water demand i.e., with the urban population of 377 million in 2011, the domestic water demand was 50,895 MLD when the water supply stands at 135 liters per capita per day (Teri 2018), urban flash floods, storage issues, depleting groundwater levels, water pollution and drain off of rainwater (Nguyen et al., 2019). This increasing urbanization rate is putting more pressure on the finite and already stressed water resources. Sustainable strategies are needed to be prepared to make urban water management effective and efficient as there exists a gap between the supply and demand of water in urban areas. Urban centers heavily rely on groundwater which caters to half of the city's water demand (UNESCO & NIUA, 2021). Currently, most countries have their water management plans and policies to name a few, the United States has LID (Low Impact Development), the UK has SUDS (Sustainable Urban Drainage Design), Ger many has DUD (Decentralised Urban Design), China has Sponge City, Singapore has ABC (Active, Beautiful and Clean) Water Programme, Japan had WBHS (Well- Balanced Hydrological System), South Korea has HWCC (Healthy Water-Cycle City), Australia has WSUD (Water Sensitive Urban Design) and New Zealand has LIUDD (Low Impact Urban Design and Development) but the core principle behind all these programs and designs is the same that is the management of rainwater or stormwater ecologically and make cities resilient to climate change.



Map 1: Unique Water Management Practices across the globe

Every country has its unique physical, climatic, and soil characteristics as a result the technological designs and implications for development must be appropriate for each location/site and should not be projected erroneously. India like any other nation has issues while implementing any water management strategy. As a result of its expansive size, there exist substantial variations at the regional level in climatic and socio-economic characteristics. Indian cities are huge and densely populated, and there is no land available for source management of urban runoff. Given India's enormous population and the limited water resources accessible per person, it is crucial to managing urban water shortages. No doubt that India is still in the phase of rapid and continuous urbanization, but this rampant urbanization is contributing to intricacy by heaping new issues on top of existing issues (Wang et al., 2018). Lack of research at the local or regional level restricts the idea of urban water management strategies.

Following are the key challenges faced by Indian Cities when it comes to the implementation of the Sponge City Concept:

1. Climatic Variations

Successful implementation of Sponge City is hampered due to the issues put forth by various natural limitations related to climate, soil, and geographic factors. The extensive area of India offers a challenge in SC implementation because due to the huge area, the climatic conditions, as well as the availability of land-water resources, varies in all directions. Thus, giving considerable emphasis to local context is a crucial indicator for the implementation of the Sponge City concept. Each city or place has an individual problem of its own. Chennai, a metropolitan city in India, receives an average rainfall of 1400mm twofold as London but still went dry in 2019.

2. Site Challenges

One of the major operating challenges in India is the locational/spatial aspects. Determining the ideal location for setting up the LID is a cumbersome task keeping in my mind the density and urbanization (NIUA & UNESCO, 2021). India is a densely-populated country. The land prices are higher, especially in the cities (developed urban areas). The traditional stormwater management system at present is underground contrary to what sponge city needs i.e., on-site infrastructure. For the stormwater that will be infiltrated into the ground, additional space is required for its restoration. Retrofitting the existing area is the idea that needs to be adopted for planning for new developments. Also, keeping space entirely dedicated to sponge measures can result in conflicts with other developments. There are always space limitations issuesas some of the measures require space along the roads. Each urban area is unique in terms of its hydrology, planning, soil, and climate characteristics, and understanding the local conditions in implementing the Sponge City concept is the key to success (implementation) (Li et al., 2017). It should be kept in my mind that not all LIDs perform in the same way when set up in different locations. Therefore, to select the proper installation for a location, it is crucial to understand how well a certain LID performs on a particular site. For instance, for small parking spaces, vegetation-covered filter strips could be appropriate; but, may not be an ideal solution for a huge drainage area. Most studies revealed that porous pavement is quite good at reducing flood damage, however, not everybody around the globe may find it to be economically viable. Thus, along with space, economic aspects are also important.

3. Financial Status and management

Lack of funding is one of the main obstacles faced by Indian cities to enhance water security. The infrastructure involved in the construction of Sponge City requires substantial investment as it is often capital-intensive, long-lasting, and expensive, at the same time due to the greater expenses and lack of matching earnings or returns, significant upfront cost, and a protracted payback time, the private sector in India is reluctant to engage in the Sponge City project (Li et al., 2017; Sodhi, 2018). There is always some uncertainty about the lifespan and performance, and benefits of the LID. Thus, in many aspects, the financial health of a city plays a crucial role in setting the level of ambition.

4. Technological challenges

There exist significant technological gaps between developed and developing nations, with the latter having inadequate experience or abilities in the implementation of new management strategies (NIUA & UNESCO, 2021; Xia et al., 2017; Zevenbergen et al., 2018). LID technologies are limited to the hands of major stakeholders and government organizations that are dealing with flood control and mitigation. Most of the municipalities in India do not give enough emphasis on LID adoption, mainly because they are unaware of available technology options. Even after the frequent events of urban flooding resulting from unsustainable urban expansion, these technologies are not widely used. India also lacks the green infrastructure essential for making the concept into reality. Wealthier developed countries like the USA, the UK, and Australia have dedicated industries for manufacturing components of green technology such as detention tanks, infiltration tanks, and, monitoring systems and India falls short in this technological advancement. Indian cities should modernize the traditional methods and technology by learning from the world led examples, as adapting to conventional methods can aid in managing the urban water sector which is highly affected by climate change Adoption of LID will reduce the frequent water losses, provide real-time flood warnings, and reduce energy use, etc. Along with this, these technologies would guarantee that all societal segments are having access to water, that energy costs are minimal, that less land is needed for implementation, etc. A city's degree of technical development is a reliable measure of how well it has kept up with the present urban water sector drivers.

5. Human Resource Capacity

The level of general human capability within the urban water sector's institutions may be determined by the presence of critical technical proficiency. The availability of specialized water engineers with degrees from reputable universities is an important factor in planning and implementing any water management strategy (Jiang et al., 2018; Sun et al., 2020). On the other hand, high vacancy rates in top technical jobs point to a limited capability for change. In addition to formal education, training and exposure are other ways that skills are created. The presence of on-the-job skills training is another factor to consider when evaluating the capacity of urban water organizations. In India, there exists a general gap in the experience of integrating a conventional method for water management, No proper training, and education of the staff, and limited resource person with expertise. No sync between designing, planning, and maintaining infrastructure. The development and consulting sectors lack a significant understanding of sponge city concepts and practices, in addition to local practicing staff and management professionals. As a result, the industry culture is either dubious of the sponge city approach or results in bad planning and design.

6. Poor Database

For accurate and reliable decision-making water-related information across various urban water sectors is essential. It is the precision and accuracy of the data that decide the ambition of planning. For the successful implementation of Sponge city, a wide category of a database is required including land use and land cover maps, soil characteristics, water sources, water supply and demand, drainage network, distribution of water bodies and green spaces, etc. But unfortunately, this requirement is a challenge in the Indian context; as such performance data are not available for the entire country. Only the database of major metro cities is maintained but not for all other cities (Li et al., 2017; NIUA & UNESCO, 2021). In this situation setting up a common GIS-based database for the spatially stratified water sectors and their data is the ideal solution. This centralized system can aid consistent water data updating, and reduce data duplication and redundancy. However, there aren't any centralized databases in the majority of Indian cities. The data is collected according to the needs of individual agencies. A method for data exchange amongst the agenciesis essential in these circumstances because it may compensate for the absence of a centralized database.

7. Collaboration between different sectors

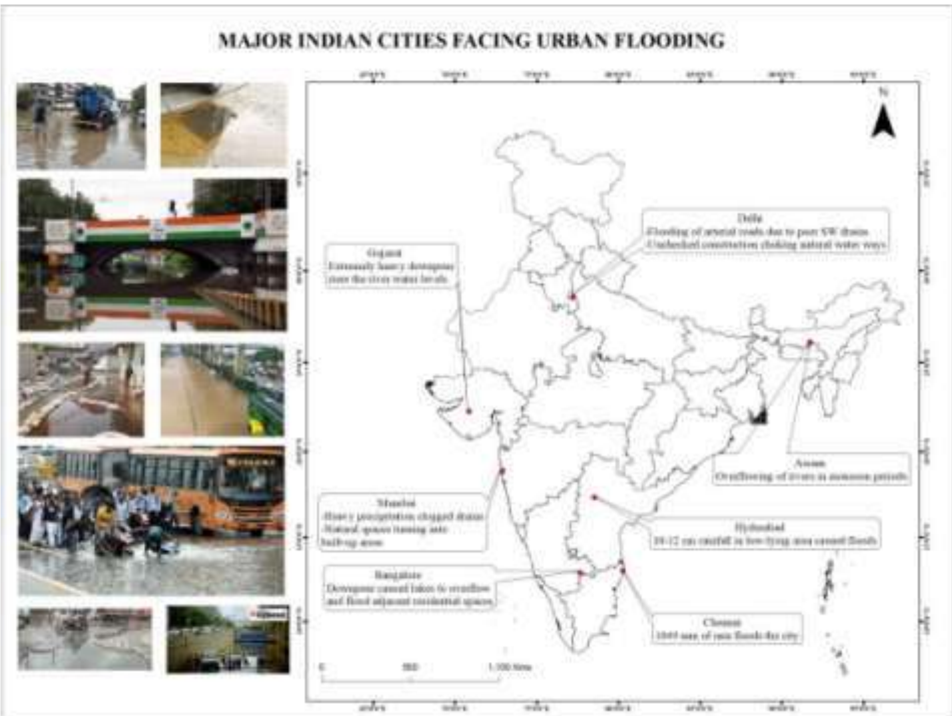
India lacks coordination between the departments and agencies involved in the water sector. There exist several agencies and components to be administered in most Indian cities. For instance, one agency may construct the wastewater and water supply infrastructure while another organization may monitor it. Stormwater management is the responsibility of a third organization. Maintaining the city's lakes and other water features is the responsibility of a fourth. To break down the silo across the sectors and achieve common knowledge grounds Stakeholder engagement is required (Jiang et al., 2018; Lu et al., 2018; Zevenbergen et al., 2018). With the spirit of cooperation and great coordination in sharing data and financial resources, the goal of implementing Sponge City can be accomplished. This is made much easier if there is a central body to coordinate and control various pieces. A well-known illustration of one such setup is the Public Utility Board in Singapore. The coordination can assist in a common vision of emerging issues and challenges, maintaining a balance of diverse interests, strengthening the sustainability and managing the realistic demand. Circulation and sharing of data related to water quality, the volume of stormwater runoff, the environment, transportation flow, energy aspects, retrofitting plans, etc. is necessary for the establishment of collaborated communities and inter-agencies and thus aids in the creation of sponge cities since this project calls for knowledge in a variety of field. The partnerships across sectors and departments can yield economic benefits and improve efficiency at the same time. This collaboration requires a lot of skill and patience. Thus, it is clear that without coordination among stakeholders, the goal of accomplishing a sponge city in India will be more challenging.

8. Strengthening the Research and Development

Sponge city is a new and dynamic topic for India to adopt, so surely adapting to it will take time. Since there is no universal model for the concept, all the cities will be adapting to it differently. For the proper implementation of any project, sound background research is required, the same in this case. Qualitative research will aid the cities in better understanding their own needs and ultimately acknowledge the best model or infrastructure suited for them. Research should follow a bottom-up approach, starting from the residential/local level to the city level. Sound research can help in preparing the cities for less known challenges. R&D should run parallel to the changing environment, technical advancement, and ever-growing scientific knowledge to deal with the upcoming obstacles in the water sector.

9. Citizen participation and acceptance

For the successful development of any project, citizen engagement is the most important as everything that is being executed is for the benefit of the citizens. Planning should be inclusive as well as participatory, to give citizens a sense of ownership. A good plan can increase engagement, especially among the underprivileged, women, and other disadvantaged groups to participate in decisions and can have a significant impact on their lives. The traditional stormwater management system is an underground system with linkages of pipes, contrary to this sponge city is more out there, dispersed all across the city and taking public spaces. This intervention must be acknowledged by the citizens otherwise it will become a hindrance to its effective implantation. Since public perception is important, the government should conduct outreach programs for residents where the plan will be executed and educational activities & training to the municipal staff to shift their perceptions. Education in both forms i.e., formal and informal should be provided to make the community understand the concept of a sponge city.



Map 2: Major Indian Cities facing Urban Floods

5. Benefits Sponge City Can Yield

India has made its mark in every sector be it medicine, science & technology, agriculture, sports, etc. It is extremely important to be self-sufficient in the water sector also, and able to face and mitigate water-related problems. Most of the countries at present have their IUWM practices, so it is important that India learn from these practices and develops one of its own. To begin with, India can use the experiences of other developing countries i.e., China's Sponge City tries to mimic the ecological and hydrological process and work on the lines of developing nature-based solutions that will address urban water issues. After considering the challenges stated in the above section, the successful implementation of sponge city ideas can yield numerous benefits to Indian Cities.

Sponge City implementation can improve the sustainability of water resources, keep the urban water cycle continuous and healthy, Inundation and waterlogging, and make the environment ecologically friendly (Liu et al., 2017; Sun et al., 2020; Zevenbergen et al., 2018). It has the potential to significantly reduce the catastrophic risks and losses associated with urban floods, and urban flooding can be easily decreased with the drainage systems' of high-capacity along with more amount of rainfall seeping into the grounds, the quantity of total runoff and the peak flow can be greatly decreased, it can also alleviate water scarcity as most of the downpour will be infiltrated in the groundwater, which can be partly saved and utilized as supplement water in water strain situations (Liu et al., 2017), reduce water pollution as the infiltration process will organically purify the rainwater (Fletcher et al., 2015; Xia et al., 2017). Furthermore, separate rainfall and sewage drainage systems help prevent pollutants from contaminating rainwater and entering rivers. The sponge city idea offers a variety of cutting-edge, environmentally friendly technologies and facilities to assure the appropriate functioning of hydrological, geomorphologic, and ecological processes by fusing natural methods with artificial ones. It comes out to be a potential solution as it lessens or eliminates numerous threats caused by urban water issues to human life and property.

6. Conclusion

India deals with huge water problems, each city has issues of its own, some are water deficit while some are water surplus; to bring the water balance an integrated strategy should be implemented. Sponge City is such a strategy that India can learn from as it is practiced in a developing country China. Numerous challenges have been stated in this paper regarding the adoption of the sponge city concept. Overcoming these issues is not one-day work, it requires patience and a considerable amount of research. Since we are introducing advanced foreign technology, it should be first understood correctly and correlate with the Indian local conditions. Sponge city has the capability of solving our urban water issues- urban flooding, water shortage, and pollution. For the accomplishment of these goals first, we need to dive into basic theory research and practice small-scale pilot projects, consequently strengthening the data sharing among water-related organizations, followed by incorporating these new and innovative ideas in Indian planning and policy making.

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Geography and Geospatial Science

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Abstract

This paper explores into the complex relationship between geography and Geographic Information Systems (GIS). It explores the definitions of geography and GIS, highlighting their interdependence and how they have evolved over time. The paper discusses the positive impacts of GIS on geography, emphasizing its role in spatial analysis and data management. It also addresses the challenges and controversies in integrating GIS into the academic discipline of geography. Furthermore, the paper sheds light on the state of geospatial education in India, emphasizing the need for a strong foundation in this field. While acknowledging the ever-changing nature of both geography and GIS, this paper underscores the importance of their symbiotic relationship in understanding our dynamic world.

Keywords: Geography, GIS, geospatial science, spatial analysis, geospatial education.

1. Introduction

Recently, there have been many symposiums, conferences and seminars on the themes "Re-Orienting Teaching & Research in Geography" and "Geography & Geospatial science". There were debates on whether geography is a science or an arts discipline and the debate is still very much alive. The debate even questions whether a dichotomy exists between physical geography (physical geographers) and human geography (human geographers)? Different schools of thought are prevalent regarding quantitative geography and cultural geography. Added to these numerous discussions and debates, is the topic of GIS. There are different opinions among geographers about the usage of GIS as a tool in geography, and even then GIS is considered as a separate science unto itself. At this juncture, this paper tries to bring out the basic relationship that exists between geography and GIS.

This paper first discusses various definitions of geography, GIS and geo spatial science to bring out the core concepts for a better understanding of the nature of these subjects. This is followed by a discussion on the relationship between these disciplines and to just what extent they are inter-dependent. In the final section, this paper also tries to explore the nature of geospatial education in India and its future requirements.

2. What is Geography?

According to William Hughes, (1863), *"...mere names of places...are not geography...know by heart a whole gazetteer full of them would not, in itself, constitute anyone a geographer. Geography has higher aims than this: it seeks to classify phenomena, to compare, to generalize, to ascend from effects to causes, and, in doing so, to trace out the laws of nature* *and to mark their influences upon man. This is 'a description of the world'—that is Geography. Thus, Geography is a Science—a thing not of mere names but of argument and reason, of cause and effect".*

'*... geography is that discipline that seeks to describe and interpret the variable character from place to place of the earth as the world of man' and '... geography is primarily concerned to describe... the variable character of areas as formed by existing features in interrelationships* (Hartshorne 1959).

So, the earlier definitions emphasize on "description". But many empirical scientists seek not only to describe accurately but also to explain: geographers aim both, to show what is where and to indicate why. Geographers are concerned with the where, how, and why of the physical environment on which material life is based, the spatial organisational structures erected and operated by human societies to sustain and promote their material well-being, and the nature of the places which they have created within those structures. In pursuing those interests, they have engaged with a variety of approaches to science, and applied their findings in a number of separate ways (Johnston R J, 2005)

The current trend is knowledge about how the world works, which is more valuable than mere knowledge about how it looks, because such knowledge can be used to predict. Hence, geography is not just the description of a phenomena. It answers the following questions -

- What is happening?
- How is it happening? and
- Where is it happening?

It also explains/analyses and makes us understand

- Why it is happening? and
- Why does it not happen in some other place?

Thus, there have been many changes in the practice of geography over the decades, but the discipline has sustained its core concern with *spatial variations in the nature of and the interactions among environment, space, and place* (Johnston R J, 2005).

3. What is GIS?

"GIS", is a popular acronym now and has slowly become an essential part of every one's day-to-day affairs. Knowingly or unknowingly all of us are using GIS or depend on GIS for many activities ranging from simple navigation to the planning of smart cities. What does GIS stand for? GIS actually stands for two things - Geographic Information System and Geographic Information Science.

Geographic Information System is a system designed for storing, analyzing, and displaying spatial data with the use of hardware, software, people, procedures, and data (Yuji Murayama, 2010). It focuses on the processes and methods that are used to sample, represent, manipulate and present information about the world (Goodchild, 1992). GI Systems provide the infrastructure, tools and methods for tackling real world problems within acceptable timeframes.

In the 1990s, Michael Goodchild suggested an alternative decoding of the GIS three letter acronym as Geographic Information Science (Goodchild, 1992). Geographic Information Science is the science concerned with the systematic and automatic processing of spatial data and information with the help of computers. It is the theory behind the solving of spatial problems with the aid of computers. It presents a framework for using information theory, spatial analysis and statistics, cognitive understanding, and cartography (Longley et al., 2005). GI Science allows us to consider the philosophical, epistemological & ontological contexts of geographic information.

4. Geography and GIS- Positive Sides of The Coin

Geography is the study of Earth's features and the patterns of their variations in spatial location and time. This very definition shows the fundamental relationship between Geographic Information (System) Science and Geography as a subject. The success of GIS has in some ways proved to be a mixed blessing to academic geography. While quantitative geography has developed as a disciplinary specialism over a long period of time, the infusion of GIS has led to a more rapid and applications-led growth.

Geographic information science, the science of GIS, is concerned with geographic *concepts*, the primitive elements used to describe, analyze, model, reason about, and make decisions on phenomena distributed on the surface of the earth. These range from the geometric primitives of points, lines, and areas to the topological relationships of adjacency and connectivity through the dynamic relations of flow and interaction to domain-specific concepts as such as neighborhood, geosyncline, or place. The digital representation and manipulation of geographic concepts raise a number of fundamental research issues, many of which, though long-standing in traditional disciplines, have been re-energized by the development of GIS (Dawn J. Wright et al, 1997).

Although the capabilities of GIS are improving, geographers who use it still look forward to the stage at which all geographic concepts and procedures are implemented digitally (Dobson, 1983; Couclelis, 1991; Dobson, 1993). The crucial concept in GIS is the separation of spatial or geographic reference information and attributes from the descriptive information of map features for data entry and database development, and their linkage during analysis. In GIS, any variable is a function of location. The "atom" of geographic information consists of location, time and attribute, $z = f(x,y,z,t)$. This is a way of conceiving geography as a set of variables, each having one value at every location on the planet (Goodchild et al, 2007). This is the fundamental relationship between Geography and GIS.

The major contribution of geography to GIS is Tobler's first law of geography: "Everything is related to everything else, but near things are more related than distant things" (Tobler, 1970). This is the base for spatial analysis and spatial statistics in GIS. According to Harvey J. Miller (2004), Tobler's First Law (TFL) is central to core spatial analytical techniques as well as analytical conceptions of geographic space. Continuing progress in spatial analysis as well as the rise of digital geographic databases, geographic information technologies, and geographic information science is breathing new life into TFL.

Another significant influence on GIS is quantitative geography. It is been nearly fifty years since the `Quantitative Revolution' in geography led to the first systematic attempts to structure and understand digital data that are geographically referenced. Today, the volume of available digital data, and the processing power of the computer hardware to analyse it, is simply mind-boggling by even the standards of the recent past (Longley, 2000). GIS is an influential set of computational geographic practices, which has been used to revive the spatial science research program in geography. As a result, GIS has recently become a focus of debates about quantitative and positivist geography (Eric Sheppard, 2001).

Similarly, GIS saved time and served to accelerate many geographical processes. The benefits of GIS to geographers are related to its operability and utility. This is evident below-

- The biggest geometric measurements of distance, circumference, center of gravity coordinates, area and volume
- Table operations that can make logical calculations of attribute information from map data
- Nearest-neighbor analysis that searches for spatial relationships (proximity) between geographical elements
- Spatial searches that are made by attaching conditions map and positional data
- Buffering that establishes equidistant regions from map features such as points, lines and planes
- Overlay analyses that create new theme maps by juxtaposing layers with different attributes
- Network analysis that enables continuous measurements, searches for shortest routes, provides information for sales rounds, analyzes water systems etc., and
- The use of Thiessen division to theoretically establish spheres of dominance, hinterlands etc.

Thus, these complex spatial operations which previously had to be carried out painstakingly by hand can now be done easily using GIS. The development of DEMs (Digital Elevation Models) has led to advancements in geomorphology and hydrology. GIS is also effective for structural understanding and pattern recognition. The best example for this is construction of choropleth maps in GIS (Yuji Murayama, 2000)

The above is a list of only few of the possible applications of basic spatial analysis functions, but they are all functions that provide geographers with powerful analytical tools. Therefore, GIS has had a historically close connection with cartography and regional analysis and has developed alongside quantitative Geography. The best way to systematically teach this inter disciplinary subject of GIS would be through the field of Geography, which has a long tradition of taking a holistic approach from a variety of fields.

5. Geography and GIS – The Other Side of The Coin

The `G' in GIS has led some geographers to feel that the discipline has some kind of proprietary interest in the subject, yet it is important to remember that (cartographic design work aside) geographers have actually played a negligible role in the development of most proprietary systems that are a part of GIS. It seems rather insincere for geographers to speculate `what kind of distortion will result, if the discipline strives to retain a central role in the emerging GIS ``profession'', because geography has never been central to the development of GIS (Pickles, 1995). Indeed, the general skill base of geography today is such that many of its practitioners are unable to take an informed insider's view of the remit and use of GI Technologies in the 21st century (Longley, 2000).

The case for teaching GIS within geography, in the higher education curriculum rests on several propositions regarding the general significance of GIS to geography, some widely accepted and some controversial. There even existed an argument that geography is the home discipline for GIS. This is perhaps one of the weakest arguments from the discipline’s viewpoint. GIS has developed as a multidisciplinary field with no single home as a consortium of photogrammetry, cartography, spatial statistics, spatial analysis, computer science, engineering, remote sensing etc. None of these fields has any particular claim to ownership, although all of them have made useful contribution. (Karen K. Kemp et al, 1992).

Geographers have largely been passive observers in the development of proprietary GIS, yet it is in the use of GIS as a tool for spatial analysis in the digital age that geographers are likely to demonstrate their worthiness in terms of cumulative academic activity. GIS is changing too, and the replacement of monolithic systems with reusable software modules and networked environments will allow GIS to be used in such a manner as to reinforce our increasingly sophisticated understanding about the nature of spatial analytic conundrums and problems (Longley, 2000).

There is a very real danger, that if geographers continue to play only a very limited role in the development of GIS, they will find themselves using tools not of their own creation, and future developments in GIS may not remain appropriate for use in spatial analysis. The proliferation of digital data will enhance our abilities to make ever-wider ranges of abstractions and, through redefinition, to provide the tools to think about them more clearly. Yet while new sources of digital data will enable us to paint ever-more vivid portraits of the real world, we should be cautious that such portraits may be fiction, not fact, triumphs of gloss over substance (Longley, 2000). Therefore, it is the time to concentrate on the quality of geospatial education at the higher education level, which is mostly handled by geographers.

6. GIS in Geography Curriculum

There are very strong links between GIS and the academic discipline of geography, which extend well beyond the commonality of titles. Although numerous courses in geographic information systems (GIS) have been introduced into the geography curriculum over the past few years, there has been remarkably little debate over the issues involved (Karen K. Kemp., et.al, 1992).

University instruction in GIS is usually offered through geography departments. In North American and European Universities, a large number of GIS specialists are teaching courses and most of them belong to geography departments. In India too, more than 50% of GIS courses have been thought through geography departments. Many, if not most of the editors of GIS related academic journals are geographers. In short, GIS has become an essential tool for geographic instruction and research.

7. Geospatial Education in India

There are around 140 institutions which offer GIS courses in India. Geospatial science is taught mostly at Post graduate level except in engineering courses, where it is being taught at undergraduate level as Bachelor of Engineering (BE)/ BTech in Geomatics/ Geoinformatics. It is also taught as one of the elective subjects in BE Civil Engineering and B Planning courses at undergraduate level. PhD in Geoinformatics is also available in some selected Institutions which includes IIRS (Andhra University), IITs, Bharati Vidyapeeth, Pune and Symbiosis Institute of Geoinformatics, Pune. The Post graduate courses also vary from M.Sc., in Geoinformatics, M.Sc., Applied Geography and Geoinformatics, MTech., in Geoinformatics and MTech., in Remote Sensing for two years, Post Graduate Diploma for one year. There is also a B.Sc. Applied Remote Sensing course for one year and there are certificate courses varying from six months to two months, also taught at the university level. Most of these courses are taught through geography and geology departments in India.

The current scenario of the University system is capable of producing a skilled work force (lower order) in more numbers than the technical geospatial professionals and experts (higher order). Lack of subject experts, adequate infrastructure and other aspects impact the quality of education and knowledge generated and so restricts the capacities to the lower-end, labor-intensive activities – say, surveying and mapping. This is not a good scenario as it makes India a “labor-force” instead of being a “knowledge force” in geospatial technology (Volume 2, MHRD Report 2013).

To avoid this, many universities should start the geospatial science courses at undergraduate level (B.Sc., B.Tech.). Students from science background in their +2 will be the ideal intake for these courses. These UG courses will supply enough students with proper geospatial background for the Post Graduate level programs. This will actually give us better qualified students for high quality research at PhD level. Therefore, strengthening the base is very essential for quality education (Shekhar, 2014).

The Geospatial Industries also play a vital role in the growth and development of this science. Western countries take a lead in developing this science, because of collaborative work between both, industries and universities. But in the Indian scenario, there is a gap between geospatial industries and universities. There is a need to integrate the industrial demands in to the university curriculum and train the trainers to meet the requirements.

8. Conclusion

Except change, nothing is the permanent in the world. Rapid growth means constant change. The subject, which adapts to the changing technology and new ideas, grows with time and survives. Geography as a subject not only survived but also grew with time gaining new dimensions. Whether physical or human, it has taken a holistic approach and provided understanding. It has also accepted and imbibed the rapidly advancing GIS as a tool to analyse the geographical processes. It has refreshed its content by re orienting its teaching and research methods by adopting the changes. This paper brought out only some aspects of geography and its connection with geo information science. There is much more to explore and comprehend in geography.

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Drought Risk Assessment in Coastal Plains of Tamil Nadu

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Abstract

Drought is one of the most significant natural hazards when water availability in a given region declines significantly compared to normal hydrological conditions. This study examines the drought risks in the coastal plains of Tamil Nadu, covering 5,048 villages/wards. The drought risk assessment was carried out by preparation of hazard, vulnerability, and exposure layers using multiple data sources including field surveys, satellite data and secondary data sources. Drought prone region is delineated through the comparison of normal (2007-08) and drought (2017-18) years of NDVI data. The NDVI is extracted from MOD13Q1 (MODIS) data with 16-day intervals for Jan-Feb months. The difference in NDVI was used to assess the intensity of drought. Non-vegetative pixels (<0.25) were omitted in the analysis. The vulnerability and exposure of the population to drought hazard was determined using Census and household data-based indicators. A focus group interview was conducted targeting deprived communities covering all major settlements along the coastline. The public perceptions, collected from 514 locations, were used to understand the drought risks in the coastal plains and to validate the hazard and vulnerability layers. In the study, Sivaganga, Ramanathapuram, Viruthunagar, and Thoothukkudi districts are identified as high drought-risk districts. The northern agricultural-dominated districts such as Villuppuram and Cuddalore are found with moderate drought risks. The results of the study would help the planners as well as farmers take precautionary measures to mitigate the risks of drought in the coastal plains of Tamil Nadu.

Keywords: Drought, Hazard, Vulnerability, Risk assessment, Coastal plains

1. Introduction

Coastal plains are low-lying areas adjacent to the sea or ocean, as it marks a transition zone between air, land and ocean. These areas are densely populated and highly prone to hazards and dynamic coastal processes (Karuppusamy et al., 2021). On the ongoing sprawl of diverse economic activities along the coastal plains, there is an immediate need to monitor and to evaluate the risk in several aspects. Several natural hazards along the coast are termed coastal hazards by Kaiser (2006), including drought. According to IPCC (2012), drought is a period of abnormally dry weather lasting long enough to cause a serious hydrological imbalance. However, drought can be defined differently around the world based on meteorological, hydrological, agricultural, technological and economical parameters. Irregular rainfall, over-exploitation of groundwater usage, poor reservoir management and crop stress are the main causes of agricultural drought (Nathan, 1998). Droughts are recurrent, their risk is consistently underrated, they can endure for a few weeks to several years and they have a significant negative impact on the environment, economy and people. The associated effects take time to materialise, usually non-structural and indirect, and may last far after the drought has ended. Economic losses, environmental harm, and human misery are the most significant drought effects.

In India, severe droughts occur approximately every third year, leading to significant agricultural area loss. The country experienced 44 severe drought years from 1801 to 2016, mostly as a consequence of inadequate or uneven precipitation (Sharma & Ashish, 2019). Tyalagadi (2015) evaluated the monsoonal droughts in India using rainfall data from 1350 rain-gauge stations around the country, collected between 1901-2010 and discovered that the southern peninsular region had a large decrease in rainfall and was prone to droughts. In southern peninsular India Palar, Then Pennai, Vellar, Cauvery, Gundar, Vaigai, Vaipar, Thamiraparani, and Kothaiyar are the major rivers which drain into Tamil Nadu's coastal plains. Most of them are non-perennial and rain-fed, which dry for a prolonged period and largely depend on the monsoon. Rainfall during the Indian monsoons is notorious for being dispersed unevenly over space and time. During a year with insufficient monsoonal rainfall, it will result in shortage of water delivery from the upper sections of the basin to the coastal plains. This will reflect as a drought in the immediate next summer months due to severe water scarcity and lead to a significant drought-related impact on the coastal plain's wet crops. The influence varies from place to region across the plains due to a variety of factors, including physiographic features, climate, soil types, and socioeconomic conditions.

A lack of adequate management of the natural resource systems may cause the drought to worsen even more (Singh et al., 2019a). It takes time to predict droughts and other threats in the riparian area. Understanding drought-related issues in society are essential for implementing effective management strategies. This can be achieved by creating hazard and vulnerability layers and conducting a risk survey across the coastal plains of Tamil Nadu. So, this study focuses on Tamil Nadu’s coastal plains to identify the whole range of drought risks at micro-administrative level for identifying site-specific mitigation and management implications.

2. Geographic Profile of the Study Area

Tamil Nadu is located in the southern part of the Indian sub-continent bounded by Kerala and the Arabian Sea in the west, Karnataka and Andhra Pradesh in the north, the Bay of Bengal in the east and the Indian Ocean in the south. Coastal Tamil Nadu extends between 8°04’39” - 13°33’47’’N latitudes and 77°05’46” – 80°20’58” E longitudes. The physical boundary of the study area includes 40 watersheds stretching from Kodayar (Kanyakumari district) in the south to Pulicat (Thiruvallur district) in the north. The total geographic area of the study area is about 26,000 sq. km. The demarcated study area is covers 5,048 villages/wards enclosed in 75 taluks of 16 districts in Tamil Nadu. To have an effective visualization and regional comparison, the study area was broadly divided into northern (Coromandel Coast), central (Palk Strait region), and southern (Gulf of Mannar region) coastal plains which are shown in

Fig 1 as boxes A, B, and C respectively. The administrative boundary of the union territory of Puducherry (includes two geographical areas - Puducherry and Karaikal) along the Tamil Nadu coast was also included for comprehensive analysis of the coastal plains of TN.

Quaternary formations of Pleistocene and recent alluvium are draped in the coastal plains of Tamil Nadu (Usha Natesan, 2015). Agriculture is the dominant land use in the entire coastal region. The plantation is found chiefly in the Kanyakumari district and wasteland (Therikadu), predominantly in Tirunelveli, Thoothukkudi and Ramanathapuram districts. Chennai, Thoothukkudi and Puducherry are the notable urban centres.

Except in the southernmost parts (Kanniyakumari district), the coastal plains have a gentle slope (0° to 3°) as shown in Fig 2. The coastal plains of Tamil Nadu are edged by the gulf, bays, straight and strait coasts with well-shaped beaches (Priya Rajan et al., 2019). The 1,076 km-long shorelines of coastal Tamil Nadu are fringed with a variable width of the continental shelf (average is ~35 km offshore).

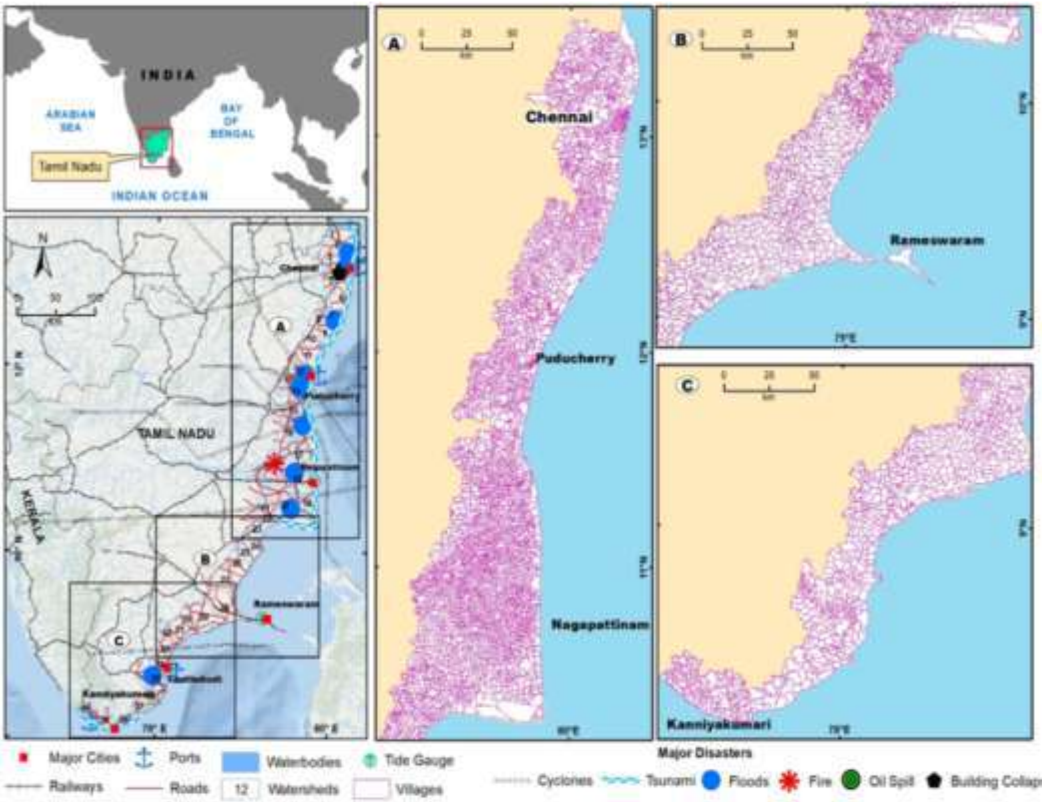

Fig. 1: Administrative divisions of coastal Tamil Nadu

The physical and socio-economic settings of the study area make it vulnerable to natural disasters like tropical cyclones, floods, storm surges, and earthquake-induced tsunamis. A low rainfall coupled with the erratic behaviour of the monsoon in 2017 led to a severe drought in the state; agricultural activities and drinking water were adversely affected and lakhs of people suffered.

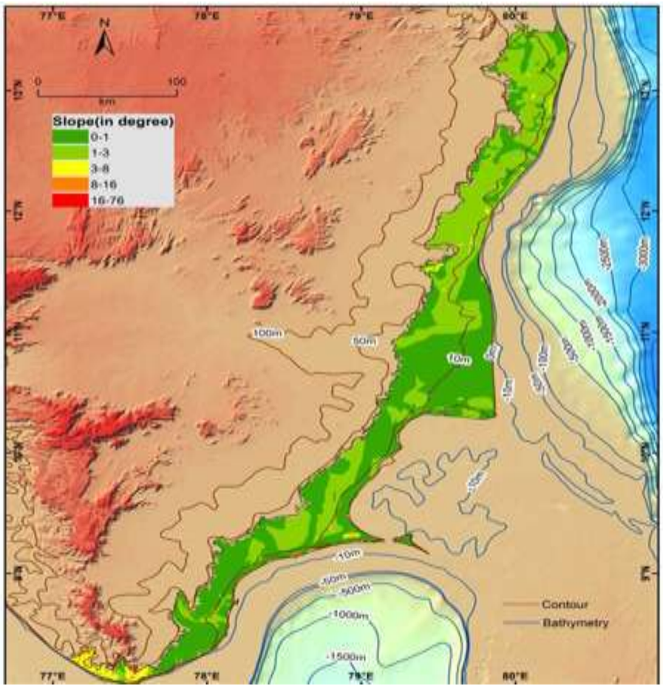

Fig. 2: Physiographic settings of Coastal Tamil Nadu

3. Methodology

In this study, NDVI differentiation was mainly used for assessing drought hazard, and socio-economic parameters were used for vulnerability assessment. In addition, a risk survey was conducted for perceptions and validation. The variables used in the study to find drought risk areas in the coastal plains of Tamil Nadu is depicted in Fig 3.

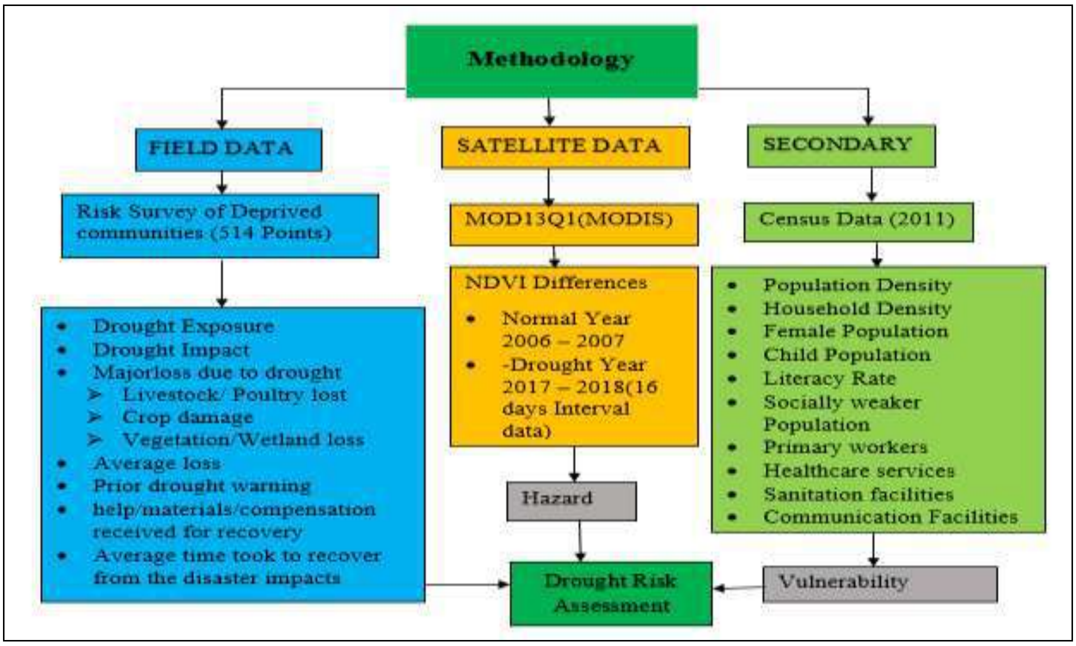

Fig. 3: Variables and methods used in the study

3.1 Hazard analysis

Satellite remote sensors can quantify a fraction of the photosynthetically active radiation which is absorbed by vegetation (Deiveegan *et al*. 2016). The Terra-Moderate Resolution Imaging Spectroradiometer (MODIS) Vegetation Indices (MOD13Q1) version 6 data are generated every 16 days at 250 m spatial resolution. The MOD13Q1 dataset provides two primary vegetation layers such as Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI). The NDVI dataset is widely used to detect drought using differentiation methods (Kogan 1997).

$$\text{NDVI} = \frac{NIR - R}{\text{NIR+R}}$$

For computing, NDVI differences, the normal rainfall year 2006-2008 was considered as base year. The MOD13Q1 datasets of January and February 2007-2008 were used for base NDVI layers. The severe drought year of last decade 2016-2018 was considered as the reference year and NDVI datasets of 2017-2018 were used for comparisons with the base year layers. All the non-vegetation pixels were omitted < 0.25 in the comparisons to minimize statistical errors. The median NDVI images of base year (2007-2008) and reference year (2016-2018) were identified in ArcGIS 10.3 software and used for deriving NDVI difference image. The difference image provides pixel-wise ratio ranges from -0.31 to +0.18 with an average of -0.01.

The village/ward boundaries of the coastal plains, complied from the District Census Handbook (DCHB) of 16 districts, were overlaid with the NDVI difference image and the average ratio value for each village/ward was obtained. Based on the statistical distribution of ratio values and rainfall patterns, the villages were classified into different drought hazard classes: very low (0.03 or above), low (0.03 to -0.02), moderate (-0.03 to -0.07), high (-0.08 to -0.14), and very high (-0.15 or less).

3.2 Vulnerability analysis

All the possible direct and indirect parameters which affect socioeconomic vulnerability of the study area were extracted from DCHBs and Primary Census Abstracts (PCA).

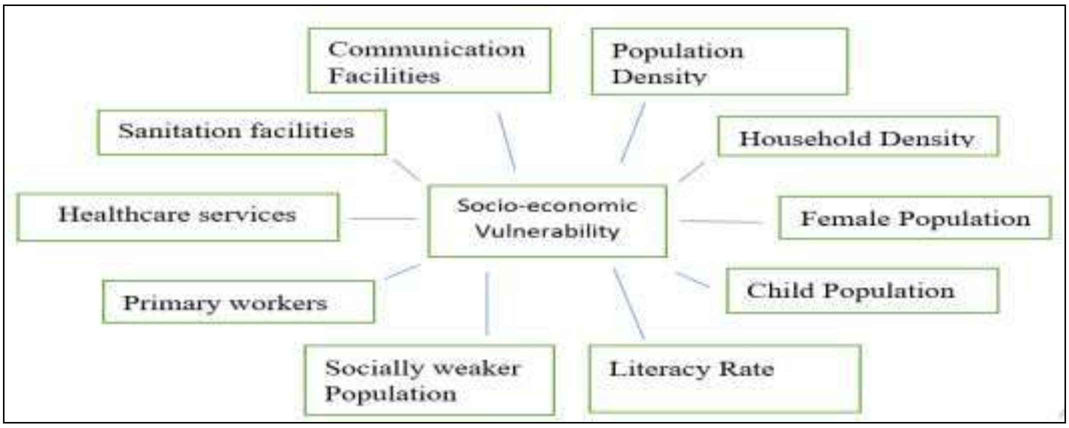

Fig. 4: Vulnerability indicators used in the study

The vulnerability indicators used in this study are given in Fig 4, which were used for arriving at the composite socio-economic vulnerability index. These indicators were grouped into two categories: exposure and capacity. The exposure-related vulnerability indicators are population density, household density, child population ratio, female population ratio, primary workers and socially weaker population. They are further grouped into very high, high, moderate, low and very low classes of vulnerability based on the assumption that higher values correspond to higher vulnerability. Likewise, the capacity-related indicators, such as literacy rate, sanitation facilities, communication facilities and access to healthcare facilities, are grouped as higher values correspond to lower vulnerability. These two indicators were compared and a composite vulnerability index was prepared. The detailed methodology adopted for arriving composite vulnerability index is detailed in Karuppusamy et al. (2021). Overall, in this study, the vulnerability is classified into five classes from very low to very high, which corresponds to a scale of 1 to 5, where 1 denotes very low vulnerability and 5 denotes very high vulnerability.

3.3 Risk Survey

The focus group survey was carried out throughout the coastal region of Tamil Nadu targeting deprived communities in major settlements of the study area. A questionnaire survey was conducted in the study area and a total of 514 responses were collected. The questions asked in a group environment to understand the drought exposures and impacts are illustrated in Fig. 5.

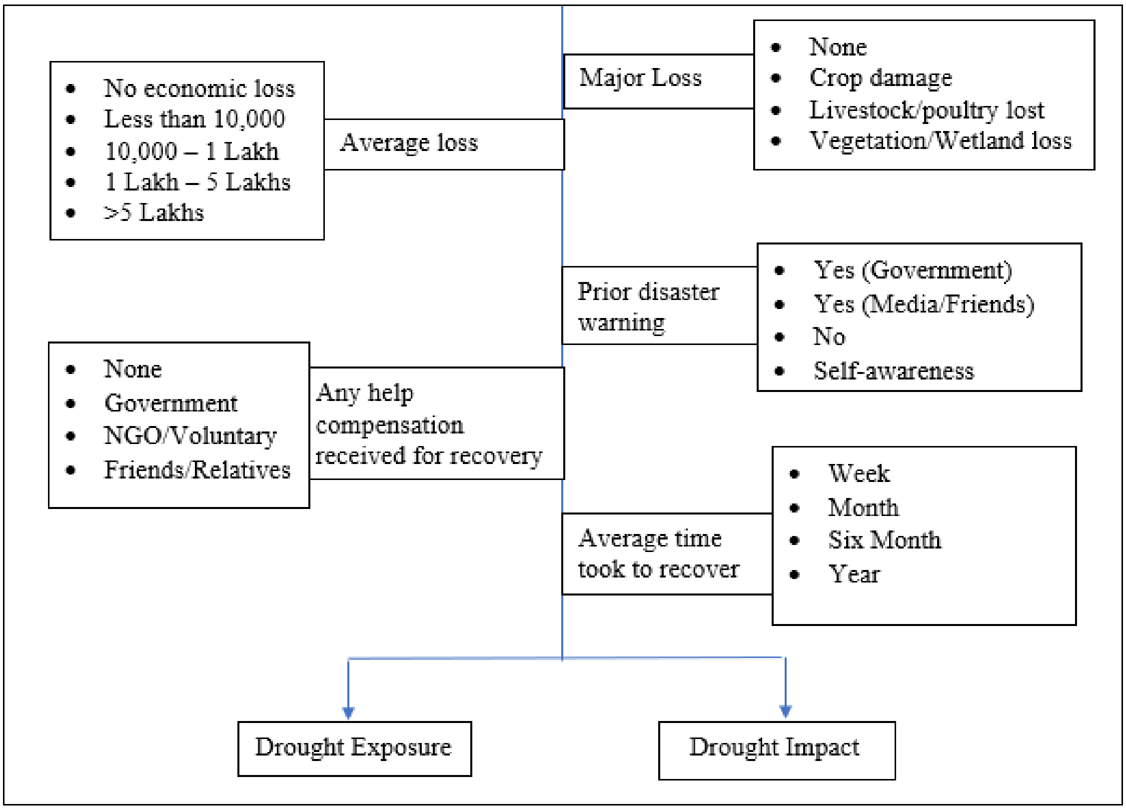

Fig. 5: Data and coded responses used during the focus group survey

All the responses were recorded with location, date and time and prepared as spatial layers for spatial representation and validation of hazard and vulnerability layers.

4. Results and discussion

The study of drought risk assessment in the coastal plains of Tamil Nadu is based on rainfall analysis, NDVI based drought hazard, socio-economic vulnerability and risk survey.

4.1 Rainfall analysis

The rainfall pattern of the state is mostly distributed across four seasons: the winter, summer, southwest monsoon, and northeast monsoon. The average rainfall of the coastal plain is about 950 mm/year. The coastal Tamil Nadu receives heavy rainfall from northeast monsoon winds from October to December. The northeast monsoon results in around 50% of the total annual average rainfall, while the southwest monsoon season receives around 31% and the rest falls during the winter and summer months. Fig 6 depicts the average seasonal rainfall distribution in the coastal plains of Tamil Nadu.

Northern districts especially Chennai, Thiruvallur and Chengalpattu receive heavy rainfall 650-700mm. Kanyakumari, Thirunelveli, Thoothukudi, Nagapattinam, Mayiladuthurai, Villupuram and Cuddalore receive moderate rainfall 500-550mm. Districts of Ramanathapuram and Pattukottai receive low rainfall compared with other coastal districts. Southwest monsoon during June to September provides heavy rainfall in Kanyakumari and moderate rainfall in Thirunelveli and Thoothukkudi. Entire coastal districts receive low to very low rainfall in summer and winter except Kanyakumari, which receives moderate rainfall in summer (250-300mm).

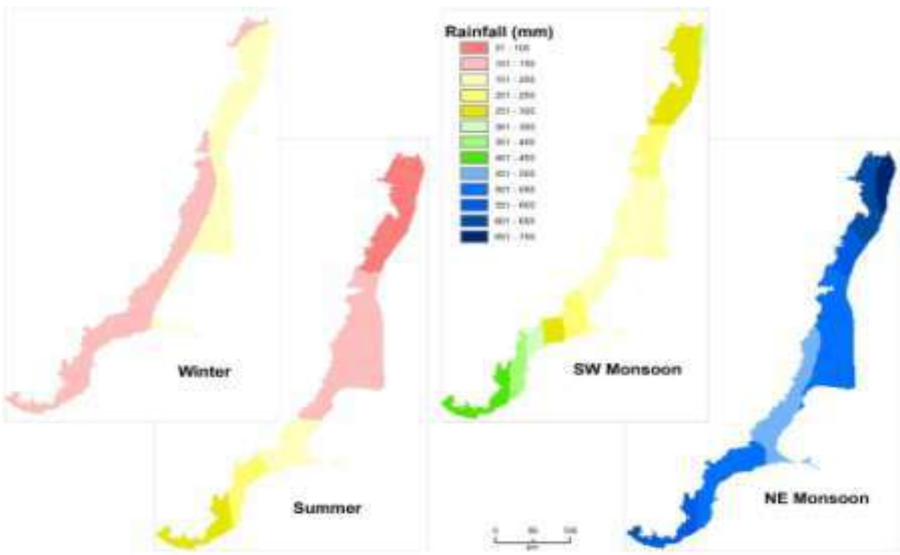

Fig. 6: Season-wise rainfall over coastal plains of Tamil Nadu

4.2 Hazard analysis

Analyzing hazards is one of the most important steps in risk assessment. The spatial extent of drought severity is determined through the differences in NDVI. Based on NDVI differences, the hazard-prone zones are classified as very high, high, medium, low, and very low (Fig 7). In the northern region, most of the places come under very low and low levels of hazard, except Cuddalore district which has a medium level of hazard. In the central region, most of the places are affected by a very high to high level of hazards. The very high level is noticed predominately in the south of Ramanathapuram to the north of Thoothukkudi. The southern districts of Kanyakumari and Tirunelveli are affected by a low level of hazard. Fig 7 represents the percentage of villages that fall under different categories of drought hazard. About 2/3rd of the coastal villages (69%) of the study area come under very low to low levels of drought hazard. About 13% of the study area comes under very high to high levels of hazard and about 18% fall under moderate levels of drought hazard.

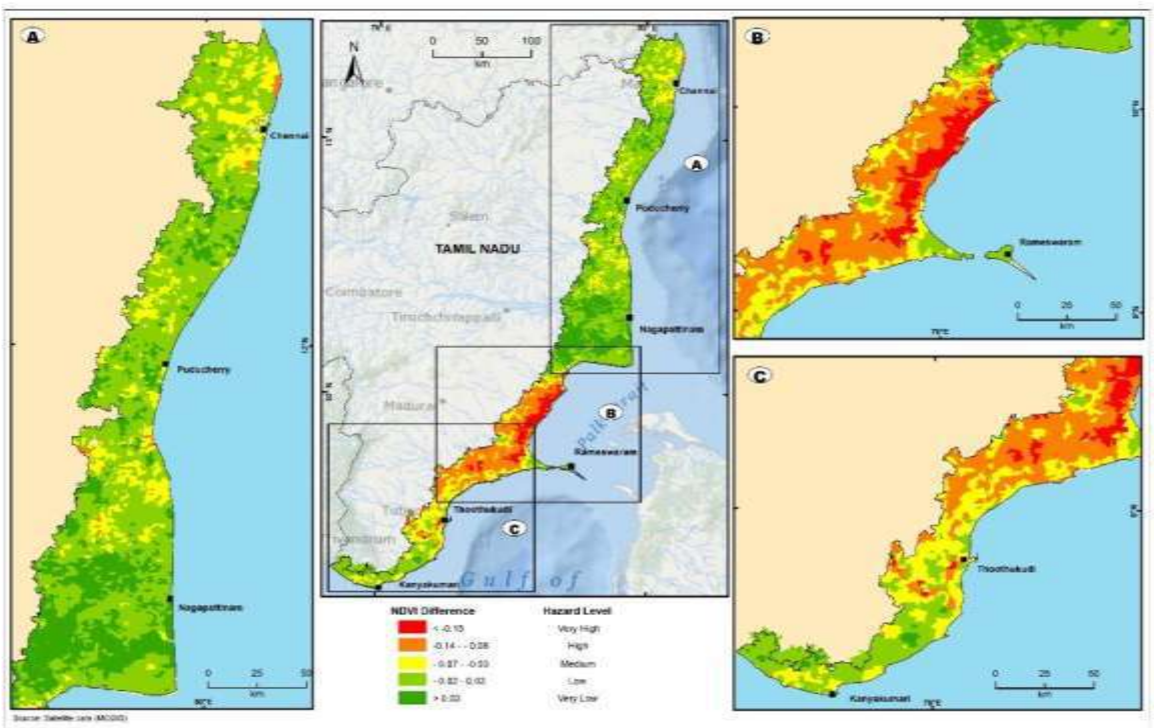

Fig. 7: Spatial distribution of drought hazard

4.3 Vulnerability assessment

The socioeconomic vulnerability was chosen and analysed based on direct and indirect parameters which are represented on the scale of very low, low, moderate, high, and very high. They are classified based on the exposure and capacity vulnerability indicators. In this study, the exposure vulnerability indicators like population density, household density, child population ratio, female population ratio, primary workers, and the socially weaker population were analysed. For the capacity-based indicator, literacy rate, sanitation facilities, communication facilities, and access to healthcare facilities are studied. By combining all the above data, socio-economic vulnerability is categorized into very low to very high, which is represented in Fig 8.

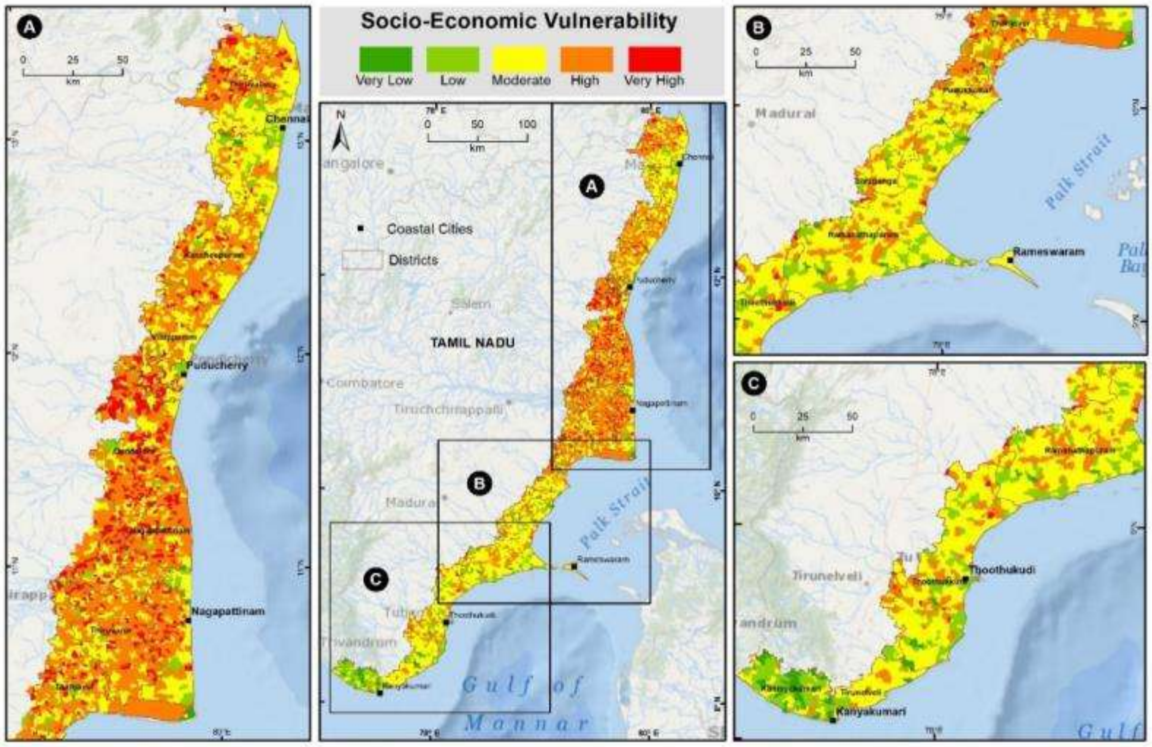

Fig. 8: Spatial distribution of Socio-Economic vulnerability

The vulnerability is very high in the northern part except Chennai. Thiruvallur, Cuddalore, Nagapattinam, and parts of Thanjavur are the most common district with very high vulnerability. The highly vulnerable regions are found in the areas surrounding the very high zone as well as more in Villupuram, Kancheepuram, Thiruvarur, the majority of Nagapattinam, and Thanjavur, and parts of Pudhukottai, Ramanathapuram, and Thoothukudi. The moderate vulnerability is scattered throughout the northern districts in patches and it is high in the central and southern districts. The low vulnerability is more in Ramanathapuram, Thoothukudi, Thirunelveli, Kanniyakumari, and Chennai. The very low vulnerable areas are found in Kanniyakumari, parts of the central zone, Puducherry, and parts of Chennai.

4.4 Risk survey

The drought risks in the coastal plains vary from place to place. A vast focus group survey was conducted to understand the public perceptions of the risk of droughts, especially among the deprived communities in the study area. The results of the survey are discussed under the topics such as frequency, exposure, major loss, drought warning, and recovery from the past drought events.

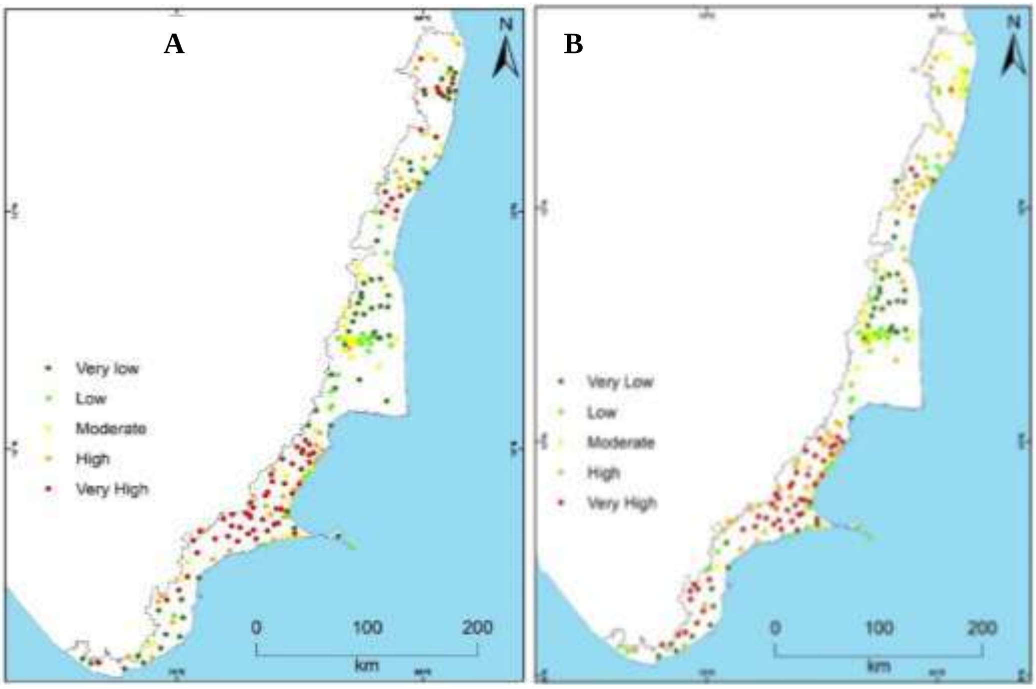

Fig. 9: Spatial distribution of A) drought exposure, and
B) Maximum drought impacts perceived by the deprived communities

The survey results show that the perception of drought exposure is very high to high in the districts of the central region. The drought impact follows the pattern of drought exposure where the central region districts respondents were perceived a very high impacts of droughts (Fig. 9). Most of the northern coastal plains witnessed drought without any economic losses. Only respondents in the district of Villupuram in the northern plains encountered some economic losses. In contrast, the villages of central and southern coastal plains encountered an average loss of 1 lakh to 5 lakhs due to severe droughts in the past. The impact of drought in the agricultural-dominated delta districts is moderate to low. Crop damage is the most reported loss due to drought which is noticed almost in all drought-prone regions. At some locations in the northern plains, people perceived that the vegetation and wetlands were lost due to droughts. In severe drought-prone villages, the people reported a loss of livestock/poultry.

Drought is a complex phenomenon and issuing prior warnings is a very challenging task for Government agencies. The survey results show that about 50% of respondents do not receive any warnings from the government before occurance of droughts. Only less than 10% of respondents reported that they received hints about upcoming drought situations through government agencies and media. Majority self aware about upcoming drought conditions, based on rainfall patterns and availability of water levels. About 37% of respondents reported not receiving any compensation for recovery from the drought events. An equal number of respondents said they received compensation from the government.

As drought is a long-term disaster risk, more than 2/3rd of respondents took more than a year to recover from severe droughts in the past and 1/3rd managed to come back within six months. About 50% of respondents reported that they are not taking any steps locally to mitigate the drought impacts. Only 30% of respondents reported that they took proper crop insurance in the past to lessen the impacts. About 13% of respondents have taken crop insurance sometimes to manage the drought impact.

The public perception survey matches with the patterns of hazard and vulnerability analysis. Almost all respondents of the Sivaganga, Viruthunagar, and Thoothukkudi districts reported that they are under severe impacts of drought hazards and experiencing severe crop damage during drought years. The villages in these districts are identified as severe drought prone through the NDVI based hazard analysis. Through the government crop insurance programmes, the highly vulnerable people in the drought prone regions are compensated for their losses to some extent.

5. Conclusion

This systematic study on drought risk assessment in the coastal plains of Tamil Nadu shows that drought risk varies spatially. An analysis of drought hazards through NDVI shows that districts in the central and southern coastal plains are experiencing severe drought conditions. Most villages in Sivaganga, Ramanathapuram, Viruthunagar, and Thoothukkudi districts fall under very-high to high drought hazards. The high impacts of drought hazards are also noticed in the agricultural-dominated villages in Villupuram and Cuddalore districts. The socio-economic vulnerability analysis shows that the northern coastal plain is very vulnerable to hazards due to high population density and primary workers. The combination of hazard and vulnerability characteristics illustrated that the districts of Villupuram and Cuddalore are at severe risk of drought. Although most farmers in drought-prone areas favour drought-resistant crops, the catastrophic droughts that occurred a few times in the past resulted in financial loss. The drought hazard is seen to cause smaller economic losses than other hazards on the coastal plains, but the average time it takes for recovery is more than a year. Compared to all other discrete hazard events in this coastal plain, drought constantly threatens poor livelihoods and ecosystems. However, drought risk has received little attention in the coastal plains and mostly ignored from risk management perspective.

The micro-level results of this study provide baseline databases for governments, policymakers, and other stakeholders for enhancing drought risk management strategies in the coastal plains of Tamil Nadu. A suitable drought policy must be implemented in all drought-prone villages in the interest of sustainable development of the coastal plains of Tamil Nadu.

Acknowledgement

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Land Use Dynamics and Flood Inundation Mapping of Chennai city: Utilizing Remote Sensing and Geospatial Techniques

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Abstract

Rapid urbanization in developing countries has led to the expansion of cities and urban sprawl along their fringes. This phenomenon is also evident in the regions surrounding Chennai, where significant land-use changes are taking place. It is essential to monitor and quantify these land-use changes and the urban expansion process to facilitate proper planning, efficiency, and sustainability in cities. This research aims to map the land use and land cover changes between 2001 and 2021, as well as the past flood inundation events in Chennai. The study reveals a substantial increase in built-up areas, indicating a rapid rate of urbanization from 2001 to 2021. To classify the land use and land cover, Maximum Likelihood classification has been employed. Additionally, Chennai has experienced severe flooding since 2005. Utilizing Sentinel 1 data and Google Earth Engine, the study identifies flooded areas using a threshold method to distinguish between flooded and non-flooded regions in the study area. The findings of this research contribute to the identification and quantification of urbanization trends and assist in urban flood management and regional planning, facilitating better infrastructure provision in an environmentally sustainable manner.

Keywords: Flood, Remote Sensing, Sentinel-1, Spatiotemporal analysis, Urbanization.

1. Introduction

Floods in India are considered among the most devastating natural disasters (Mohapatra and Singh, 2003) and caused by intense and uneven rainfall patterns during the monsoon season (Sanyal and Lu, 2005). The severity of flood damage is determined by various factors, including the amount of rainfall, its intensity, soil type, slope, and land use/cover (LULC) in the affected region. Additionally, the frequency of floods has been increasing due to climate change (Gupta and Nair, 2011).

Major Indian cities such as Mumbai, Chennai, Bangalore, and Hyderabad are grappling with flooding issues resulting from extreme rainfall, leading to loss of life and property. Chennai, in particular, has experienced disastrous riverine flooding and failures in the drainage system during various years, including 1943, 1976, 1985, 1996, 1998, 2005, and 2010. These events were triggered by heavy rainfall associated with depressions and cyclonic storms (Gupta and Nair 2011). Chennai city is a coastal metropolitan and experienced a major disastrous flood in the year 2015, 2016 (Vardah cyclone), 2020 (Nivar cyclone), 2021. Urbanization is defined in numerous ways (Li et al. 2013). From a hydrological standpoint, urbanisation is defined as the conversion of natural land cover to artificial land cover, which results in the expansion of built-up areas and impervious surfaces, hence modifying a watershed's hydrological regime (Clarke et al., 1997).

Due to large scale coverage and regular revisiting time, satellite remote sensing is the only viable candidate for flood monitoring systems. Frequent revisiting is necessary for flood monitoring, due to this what are the area inundation happened and how many days water stays from this damage can be estimated. Data obtained from satellite sensors encompass optical imagery (including derivatives such as Normalized Difference Vegetation Inex(NDVI)), Synthetic Aperture radar(SAR), LiDAR data, each with different advantage and drawbacks (Hansen et al., 2020). Flood mapping with SAR images uses completely automatic, semi-automatic (Kharbouche and Clavet, 2013), hybrid, and manual methodologies (Wan et al., 2019;). Researchers used P-, L-, C-, and X-band SAR imagery to map floods in urban, rural, and vegetated areas (Riyanto et al., 2022). There are various methods used for quick flood mapping such as Normalized Change Index (NCI) (Yulianto et al., 2015), Ratio Index (RI), Difference Index (DI) (Lim and Lee, 2018), Fuzzy logic (Pulvirenti et al., 2011) and thresholding algorithms (Amitrano et al., 2018) and also, supervised maching learning algorithm like Support Vector Machine (Sun et al., 2015), Random Forest, Neuro fuzzy, and Artificial Neural Network (Skakun, 2010) were used. Automatic threshold approach and regression based optimized threshold were used for flood inundation mapping (Huang and Jin, 2020). The significant challenge of urban flood inundation mapping are lay over, shadow area, presence of water like reflecting surface and foreshortening (Vanama and Rao, 2019). Many researchers have used and suggested the use of satellite data for mapping and monitoring flood inundation for such disaster mitigative purpose. Recent studies highlight the potential of Sentinel-1 C band SAR images for flood mapping. Few research have used Sentinel-1 SAR satellite imagery for urban flood mapping. This research main objectives are to map the land use land cover change for the year 2001 and 2021 and to map the Chennai past flood inundation events using Google Earth Engine.

2. Materials and Methods

2.1 Study area

The study area is the Chennai city (Figure 1), the capital of the Indian state of Tamil Nadu. It is one of five megacities and the sixth most populous city in India. The city lying between longitudes 80° 08′3.9411″ East and 80° 20′ 2.398″ East and latitudes 13° 06′ 26″ North and 13° 14′ 3.924″ North. The administrative divisions of the 426-square-kilometer Chennai city are comprised of 15 zones and 200 wards or divisions. It is a flat coastal plain known as the Eastern coastal plain, and Cooum and Adyar are important rivers and minor canals flowing through this region.

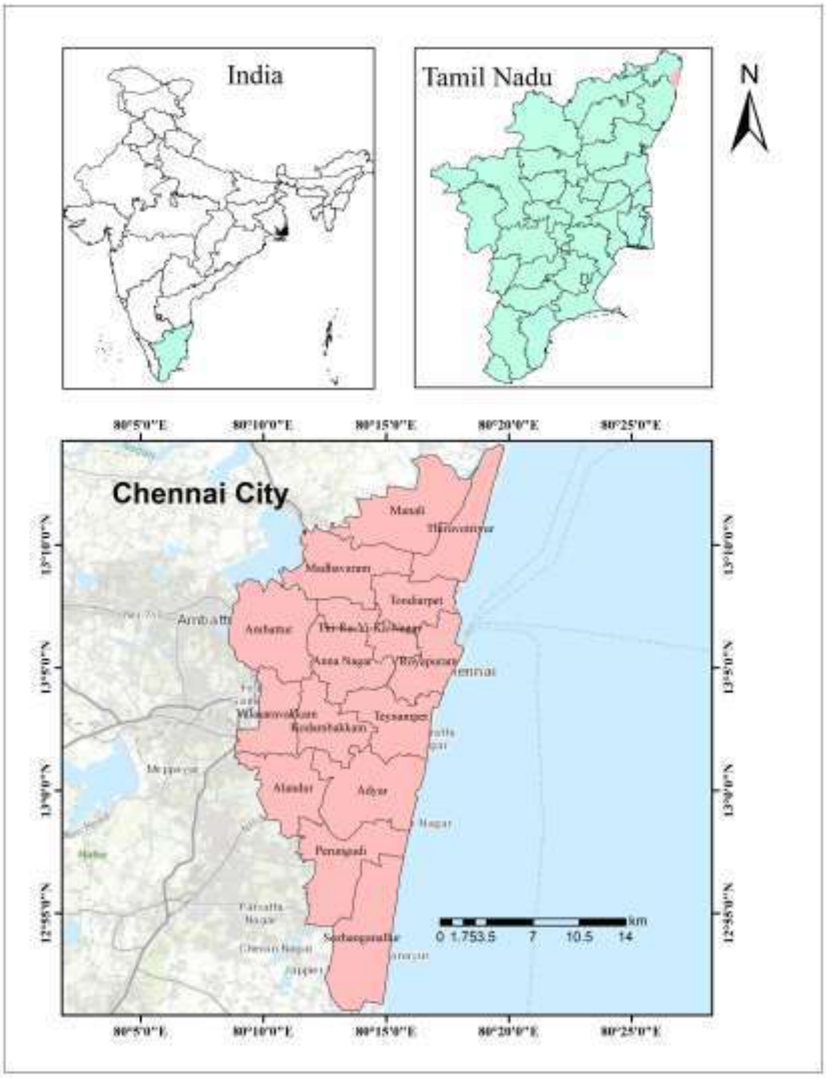


Fig. 1: Study Area

2.2 Datasets

Multiple satellite images, including optical and microwave data, were used to map the flood inundation event and changes in land use and land cover (Table 1). Sentinel 1 Ground Range Detected multi temporal SAR images are obtained before and after the flood as shown in table 2 to analyse the Chennai city flood inundation event. Sentinel-1 GRDH images are available with both VV and VH polarizations and both images choosen for analyse the flood event. Shuttle Radar Topographic Mission (SRTM – 30m resolution) has downloaded from USGS earth explorer. The Landsat 5 TM (obtained date – 2001.07.03) and Landsat 8 OLI (obtained date – 2021.02.16) have acquired from USGS earth explorer, due to cloud cover same month image could not obtain.

Table 1: Data Source

Data	**Source**
SRTM DEM	USGS Earth Explorer
Sentinel 1	Copernicus Open Access hub
Waterbody	SOI toposheets

Landsat	USGS Earth Explorer

Table 2: Remote Sensing data used for Chennai Flood Mapping

Before flood	**After flood**
2021-10-10 to 2021-10-23	2022-01-03 to 2022-01-15
2021-10-10 to 2021-10-23	2021-11-08 to 2021-11-17
2020-10-10 to 2020-10-23	2020-11-29 to 2020-12-10
2015-10-10 to 2015-10-23	2015-11-16 to 2015-12-10
2016-10-10 to 2016-10-23	2016-12-13 to 2016-12-19

2.3 Methodology

2.3.1 Land use and land cover (LULC) classification

The LULC classification workflow employs unsupervised or supervised methods to categorize pixels in an image into different classes. Unsupervised classification can be performed without providing training data, while supervised classification requires training data and the specification of a classification method, such as Maximum Likelihood, Minimum Distance, Mahalanobis Distance, or Spectral Angle Mapper (SAM) (Harris Geospatial Solutions, 2019). To begin, reference training and testing data should be collected for each land cover type in order to process the training reference. Supervised classification utilizes the provided training data to classify the image and obtain information from the remote sensing satellite image."

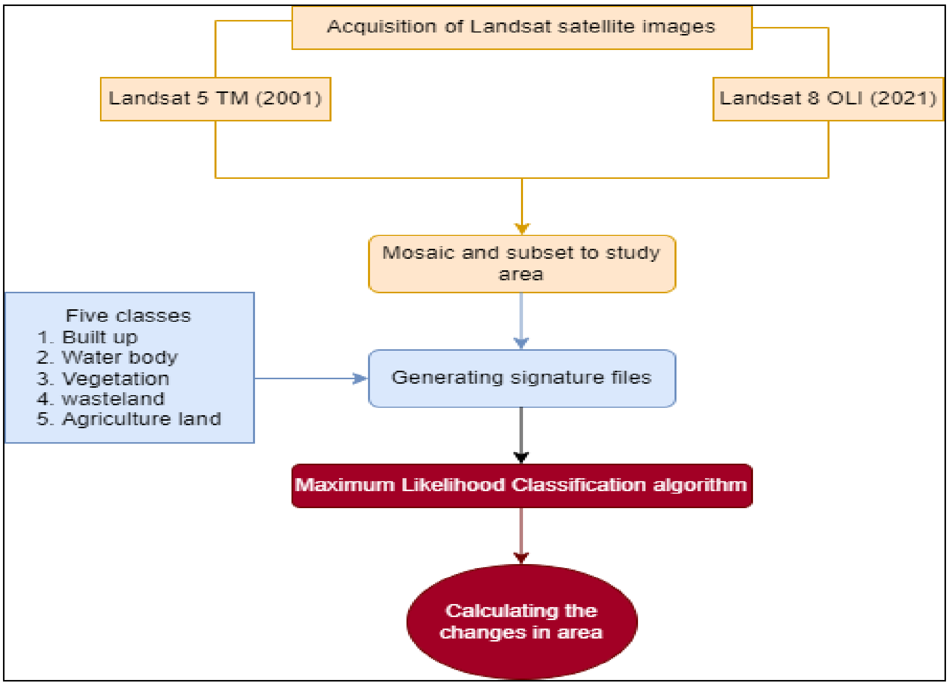


Fig. 2: Methodology flowchart

ArcGIS 10.8 software was used for the classification workflow (Figure 2). This study uses Maximum likelihood classification to classify the Landsat Multispectral image. Training pixels were collected for five land use/land cover classes identified from ground truth knowledge to classify the image. Training pixels have classes namely water body, built up, waste land/barren land, agriculture land, and vegetation. These five training ROI used as import for classify the Landsat multispectral image. The image classification input images are Landsat 5 and Landsat 8 for the year 2001, and 2021. In this research, different temporal data are used and got were classified using supervised classification method aforementioned.

2.3.2 Flood inundation mapping

Flood hazard mainly depends on topography and flood inundation of the area (Chen et al., 2015). The Sentinel 1 Synthetic Aperture Radar were used to extract flood prone areas in the 2015, 2016, 2020, and 2021 (Figure 3). The Sentinel 1 constellation currently consist of two satellites that is Sentinel 1A and Sentinel 1B, each equipped with a Synthetic Aperture Radar (SAR) sensor that operates at a C-band frequency of 5.5 GHz and produces data with a 10-meter resolution at 12 days repeat cycle(Park et al., 2020).

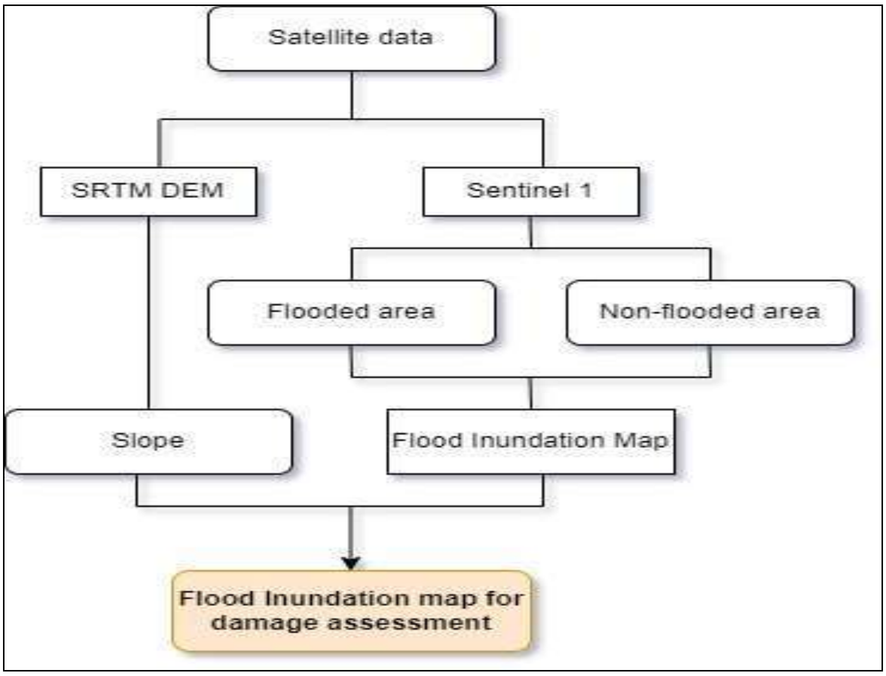


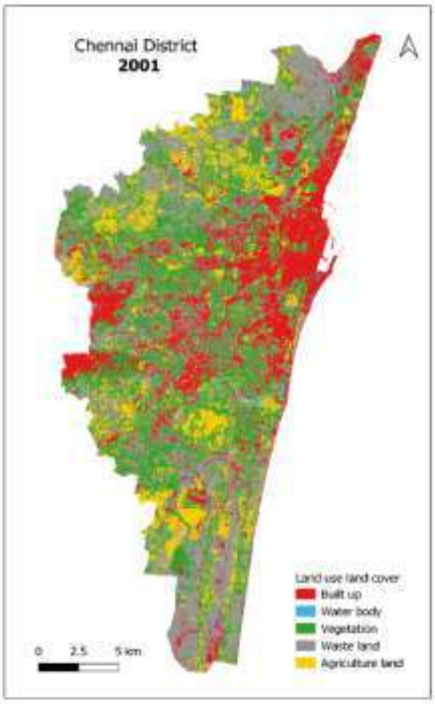
Fig. 3: Methodology flowchart

In this research, all available VH polarised SAR data have obtained for pre flood and post flood scenarios in the default Interferometric Wide swath (IW) mode and Ground Range Detected High resolution (GRDH) format (Prasad et al., 2019) as depicts in table 2. The Sentinel-1data was pre-processed and the temporal median image for each season was calculated using Google Earth Engine Platform (Google Earth Engine code for flood inundation can be available on request). The SRTM Digital Elevation model was used for extracting slope information, filter out areas of radar shadow and find out probable area of flooding (Zandbergen, 2008). The difference in sigma naught values between the pre-flood and post flood was estimated using the change detection and thresholding approach. Following that, a threshold filter is determined based on the global threshold to extract the potentially flooded area in the study area (George et al., 2022).

3. Result and Discussion

3.1 Land Use Land cover

The below figure 4 represent the LULC of two different years that is 2001 and 2021. Landsat imagery of study area have classified into five classes namely water body, built up, waste land/barren land, agriculture land, and vegetation. These two maps show the conversion in land between 2001 and 2021 time period. Land have converted from agriculture land to build up area, vegetation cover to built-up area, and waste land have converted to built-up area. In last two decades, built up area have increased rapidly in Chennai city.



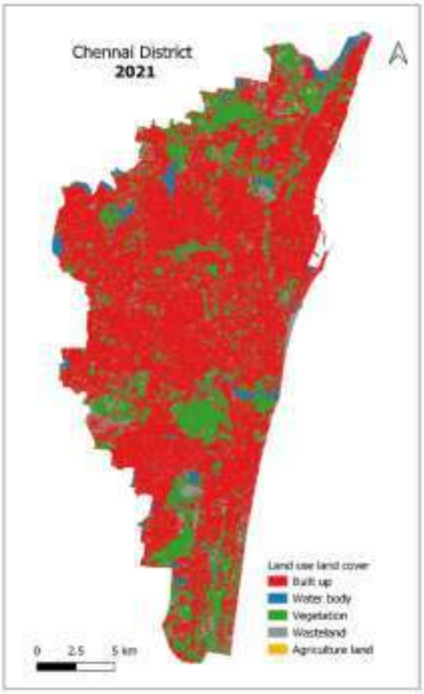


Fig. 4: 2001 and 2021 land use land cover of Chennai city

Figure 5 represents the land conversion in graphical format and it shows that built up area have increased rapidly over two decades. It also shows the other classes land use land cover conversion in the study area. Table 3 shows the land use land cover classification in square kilometer for the year 2001 and 2021.

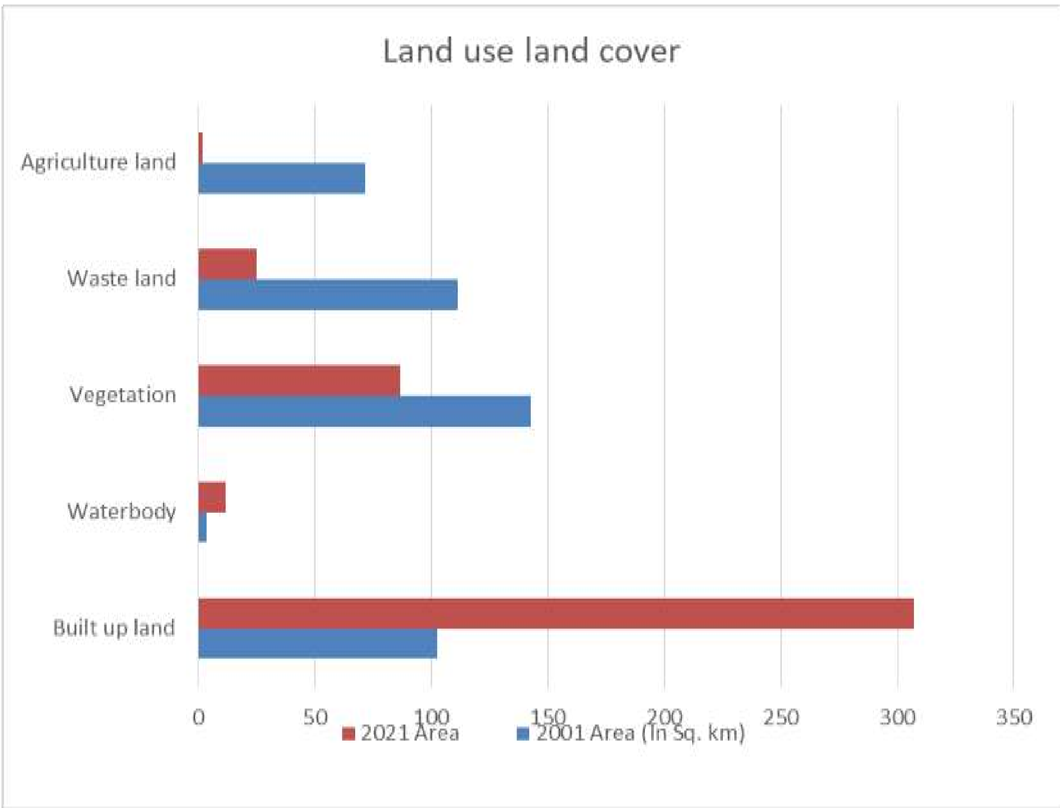


Fig. 5: Land use land cover change between 2001 and 2021 (in Sq. km)

Table 3: Classification changes in square kilometer

Class Name	2001 (In Sq. km)	2021 (In Sq. km)
Built up	102.4	307.2
Waterbody	12.8	11.7
Vegetation	142.6	86.6
Waste land	111.5	24.6
Agriculture land	71.6	1.9

The result shows (Table 3) the changes in land use for different classes between the years 2001 and 2021. The built-up area has experienced significant growth over the years, increasing by approximately 204.8 sq. km. This suggests urbanization or expansion of human settlements. The waterbody area has seen a slight difference, indicating a marginal decrease or changes in water-related features. The vegetation area has notably decreased, showing a reduction of approximately 55.9 sq. km. This decline suggests deforestation, land degradation, or changes in land use patterns. The waste land area has undergone a significant decrease, declining by around 86.9 sq. km. This may indicate reclamation, rehabilitation, or conversion of waste land into other land uses. The agriculture land has experienced a substantial decrease, reducing by approximately 69.7 sq. km. This suggests a significant shift away from agriculture, potentially due to urbanization or land-use changes.

Overall, during the study period, with notable increases in built-up, and significant decreases in vegetation, waste land, and agriculture land. These changes reflecting the dynamics of urban development, environmental alterations, and shifts in economic activities within the analyzed region. Figure 6 depicts that continues increase in population since 1951. The major reasons for the flooding in urban areas are Conversion of water bodies as resident areas. Surface runoff has been increased due to increase in impervious surface and built-up areas. Non-preservation of catchment areas, wetlands, open space, agricultural land and non-adherence of land use planning. Chennai has three rivers and many lakes spread across the city. Urbanization has led to shrinkage of water bodies and wetlands. The quantity of wetlands in the city has decreased from 650 to only 27 currently (The Hindu, 2015).

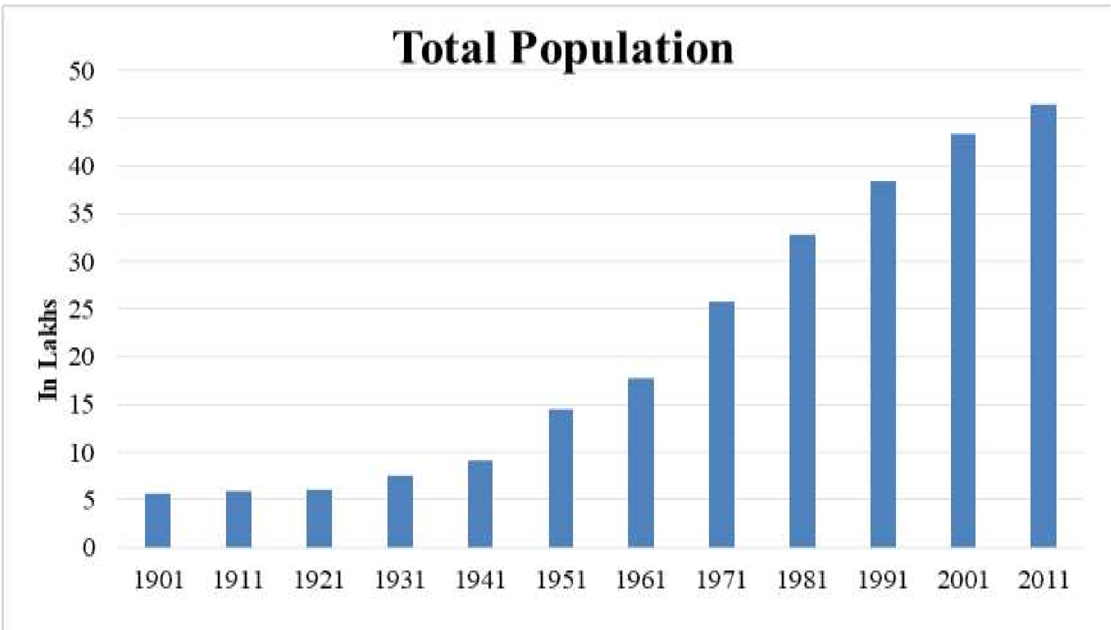


Fig. 6: Chennai Population Growth (source: Census of India)

3.2 Flood Inundation

Figure 7 shows the Flooded area of Chennai city. An automatic thresholding algorithm i.e., Otsu’s algorithm used to identify the flooded area. This threshold algorithm classified the images into two classes i.e., the binarization method was used to differentiate water and non-water pixels by choosing an appropriate threshold through trial-and-error technique. The figure 7 shows only the water pixels which is converted to vector file. The same process have performed repeatedly for 2015, 2016, 2020, 2021, 2022. The total flood area acquired from all the flood layers is 28.45 km^2. When compared to the flood area that is specified in secondary reports, the total area that was calculated using these SAR data is quite low (Government of Tamil Nadu, 2017). This is due to numerous factors, including the resolution of the SAR image, the polarisation used, and the double bounce effect from urban built-up areas. Vanama and Rao, 2019 have performed the same method for flood inundation using Sentinel-1 data. They have obtained the result that is 17.9 km^2 area got flooded in Chennai city. From the results, it reveals the potential of C band sentinel 1 SAR images for flood inundation mapping. The output shows the near real time scenario, due to low temporal resolution of imagery. For obtaining real time scenario of flood inundation for India, RISAT-1 imagery can be used. The revisit capability of RISAT-1 imagery is 3 - 4 days. The same methodology can be applied on the India RISAT-1 SAR imagery and this helps disaster management authorities to carry out the relief and restoration activities.

Figures 8 and 9 clearly indicate the current state of water bodies. The people residing along the banks of rivers or water bodies were dumping waste into these water bodies, leading to the degradation of their quality. The government should conduct an awareness program for the people living along the water bodies and riverbanks. Poor maintenance and unregulated urbanization have resulted in a significant loss of tank storage capacity, which has subsequently affected the peak flows of rivers. The built-up area is more than sixty percent in almost all the taluks, except Guindy, the industrial and institutional center of the city. The ease of road and railway access to every other region of the city from here determines the agglomeration of development even in the outskirts of the city (S.P. Sekar and S. Kanchanamala, 2011). The Adyar river basin has most of its area covered by vegetation. The Chennai River Restoration Trust, set up by the government, is working on the restoration of the Adyar river (The Economist, 2015).

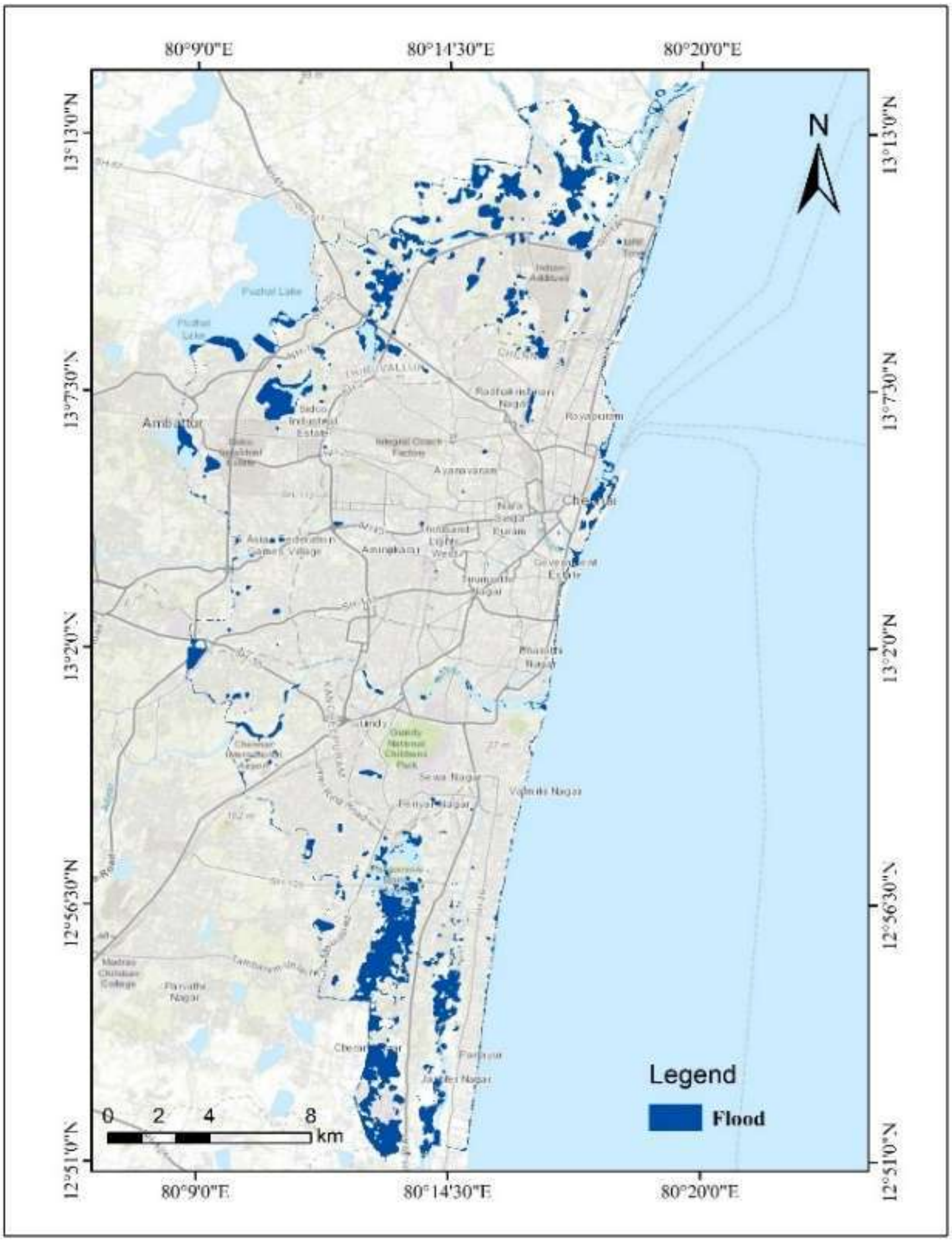


Fig. 7: Flooded area of Chennai city

Fig. 8: Cooum river, Park town and Buckimgham Canal, Mylapore, Chennai
(Source: taken by author)

Fig. 9: Adyar river, Saidapet and Buckimgham canal, Raja Annamalai puram, Chennai (Source: taken by author)

4. Conclusion

The present study demonstrated the effectiveness of utilizing Landsat and Synthetic Aperture Radar (SAR) data for assessing land use dynamics and conducting near real-time flood inundation mapping and monitoring. The research findings highlight the significant increase in the built-up class over the study period, indicating its role as a major contributor to urban flooding. Moreover, the study emphasized the scarcity of cloud-free optical datasets during the monsoon season, which hampers flood monitoring efforts.

The use of SAR data proved to be invaluable in overcoming the limitations posed by cloud cover, as it provided comprehensive coverage of areas affected by floods and enabled clear differentiation between inundated areas and high-moisture regions. The incorporation of SAR data in flood event monitoring offers critical information for decision makers, facilitating the identification of suitable locations for community shelters, determining optimal routes for rescue and relief operations during disasters, and aiding in post-disaster damage assessment. By leveraging the capabilities of SAR data, this research underscores the potential for improving flood management strategies and enhancing disaster response measures. The integration of SAR data into existing flood monitoring systems can significantly contribute to proactive decision-making, ensuring more efficient allocation of resources and timely interventions to mitigate the impact of flood events.

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Socio-Cultural and Economic Impact of Responsible Tourism in Kasaragod District, Kerala

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Abstract

Responsible tourism is an approach for establishing a sustainable relationship between local communities for dynamic economic linkages. Responsible tourism in Kerala demonstrates the capabilities of the Local Self Government to establish industry-community trust and the leadership to coordinate activities in triple bottom line areas, as well as government interaction with local community organizations. The proposed study is an attempt to illustrate the nuances of responsible tourism in the Kasargod district. It investigates the role that local communities play in tourism activity, to what extent the success of a responsible tourism program depends on their positive participation in the agenda, and how the tourism landscape has been changing the social and economic structure of the host communities. This paper also examines the role of responsible tourism during the COVID period and its impact on host communities.

Keywords: Responsible Tourism, Covid-19, Community-Based Tourism, Sustainable Tourism

1. Introduction

Tourism is a social, cultural, and economic phenomenon that entails the movement of people to countries or places outside their usual environment for personal or business/professional purposes (UNWTO, 2015). The study of tourism is the study of people away from their usual habitat, of the establishments that respond to the requirements of travelers, and the impacts that they have on the economic, environmental, and social well-being of their hosts (Wall & Mathieson, 2006). According to UNWTO (2002), tourism can lead to economic growth and economic development through its potential for job creation, linkages with the local economy, foreign exchange earnings, and multiplier effect.

In developing countries, tourism is often seen as an industry that brings foreign exchange, employment, and a modern way of life (Jenkins, 1991; Kibirige, 2003; Saayman & Saayman, 2006; Sharpley, 2002). In developing countries, a transformation from a traditional agricultural economy to an industrial economy is a prerequisite condition for modernization and economic development (Thirlwall, 1983; Wall & Mathieson, 2006). Such a transformation demands huge capital and foreign earnings, which has encouraged governments in developing countries to treat tourism as a means of generating the financial resources required for economic development (Wall & Mathieson, 2006). Tourism not only contributes to economic development. It also reduces income and infrastructure development discrimination between core and periphery areas of the region because tourists travel from core metropolitan areas to the periphery (Christaller, 1963)

There has been a tendency for policymakers in some developing countries to use tourism as an easy means of economic development (Wolfson, 1967). Some researchers are also of the view that tourism raises the spectre of the destruction of traditional lifestyles and cultures and that it initiates neo-colonialist relationships of exploitation (Mbaiwa, 2004). In response to the growing number of social and environmental problems caused by tourism, the tourism literature identifies a number of sustainable alternatives such as tourism, ecotourism, ethical tourism, green tourism, soft tourism, pro-poor tourism (PPT), geotourism, integrated tourism, community-based tourism, responsible tourism (RT), etc. (Blackstock, 2005; Cawley & Gillmour, 2008; Hall, 2008; Kontogeorgopoulos, 2009; Oliver & Jenkins, 2003; Scheyvens & Momsen, 2008; Weeden, 2002). Since the early 1980s, the tourism literature has been discussing the idea of responsible tourism (Cooper & Ozdil, 1992; Smith, 1990). However, it was not until the 2002 Cape Town Declaration that a definition was given, and a complete picture of responsible tourism was painted. Responsible tourism is based on what are called "triple-bottom-line" commitments: economic responsibility, social responsibility, and environmental responsibility.

Responsible tourism is "tourism that promotes responsibility to the environment through its sustainable use; responsibility to involve local communities in the tourism industry; responsibility for the safety and security of visitors and responsible government, employees, employers, unions, and local communities" (DEAT, 1996:4). Responsible tourism has been considered as a framework and a set of practices (Husbands & Harrison, 1996), "which respect the host’s natural, built, and cultural environments and the interests of all parties concerned" (Smith, 1990, p. 480) and minimize the negative impacts on the destination (Stanford, 2008). According to World Travel & Tourism Council (WTTC) report of 2002, the importance of responsible tourism was highlighted at the Earth Summit in Rio de Janeiro in 1992 with Agenda 21 and the Rio Declaration, which articulated the main principles for sustainable development in the 21st century.

South Africa’s tourism white paper (1996) on responsible tourism specifically mentions one of its key elements as ensuring the active involvement of communities that benefit from tourism, including their participation in planning and decision-making and the establishment of meaningful economic linkages".

When visitors feel the warmth of the host community, they are more likely to visit again and recommend the destination to others (Spenceley et al., 2002). When it comes to the principles of sustainable development and Responsible Tourism, the role of government is more on fostering sustainable practices. It is to create a conducive environment for the private sector to operate more sustainably by promoting tourists to spend locally, maximizing the community benefits, and minimizing the negative impacts of tourism (Cooper & Ozdil, 1992; Harrison & Husbands, 1996; Spenceley et al., 2002, and Venu & Goodwin, 2008).

2. Study Area

Kasaragod, the northernmost district of Kerala State, was formed on May 24, 1984. The district lies between $12^{\circ}12^{l}$ N to $12^{\circ}30^{l}$ N and $74^{\circ}\ 26^{1}$ E to $74^{\circ}\ 52^{1}$ E latitudes and longitudes, respectively. The district lies between the Western Ghats and the Lakshadweep Sea. The eastern part of the district is hilly with small forest tracts. The district is bound in the east by Kodagu and Dakshin Kannada districts of Karnataka State, in the west by the Lakshadweep Sea, in the north by Mangalore Taluk and Dakshin Kannada Districts of Karnataka, and in the south by Kannur District. The district has an area of about 1989 sq. km. It accounts for 5.13 percent of the total area of the state (38852 sq. km). Kasargod ranks 13th in the state, area-wise, among the districts in Kerala. The district is renowned for its coir, and handloom industries and has a 293 km long coastline. Kasargod is home to the largest and best-preserved fort in the state; Bekal. The historic Malik deenar juma masjid and the unique Madhur Mahaganapathy temple adds value immensely to the rich heritage of the district and state as well as they display a variety of styles in traditional architecture strategically located on the banks of the Payawini river. The district has spectacular art forms of theyyam, yakshagana, poorakkali, and kolkali. The state wings like DTPC, BRDC, and RT department are tapping the full potential of tourism in the district.

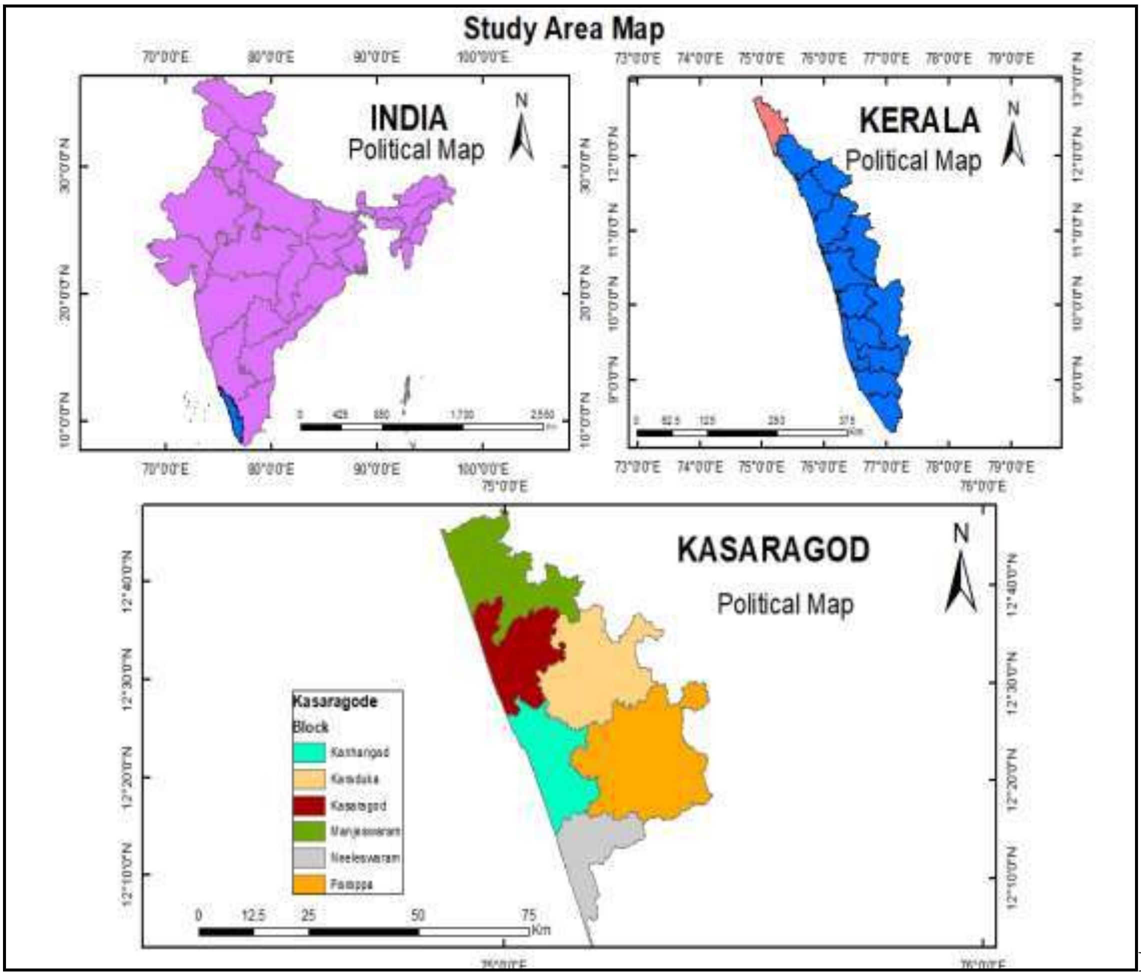

Fig. 1: Map of the Study Area

3. Objectives and Methodology

The current study is structured with a systematic approach, using multiple sources of data in order to accomplish the objectives listed below, in line with the research question of the study; "Socio-cultural and economic impact of responsible tourism: A case study of the Kasargod district."

The study objectives are to;

1. Examine the tourism in Kasargod district, Kerala.
2. Assess the socio-cultural and economic impact of responsible tourism in the study area.
3. Evaluate COVID-19's impact on responsible tourism in the study area.

The proposed study employs both primary and secondary data sources as its foundation. Data from secondary sources was used to determine the outcomes of the first objective, which concerned the tourism hotspots and RT activities in Kasargod district, Kerala. The key data that is acquired through the questionnaire survey method provides specifics to achieve both the second and third objectives, regarding the socio-cultural and economic influence that responsible tourism has had in the district as well as the impact that COVID-19 has inflicted on the RT employees. The survey, with a pre-structured format, was administered to a random sample of local residents and stakeholders in order to collect the required data for the study. Necessary statistical and GIS techniques were used to analyse the data. The study offers a chance to analytically assess how responsible tourism affects socio-cultural and economic factors and try to determine how a pandemic may affect the industry and industry workers in the study area.

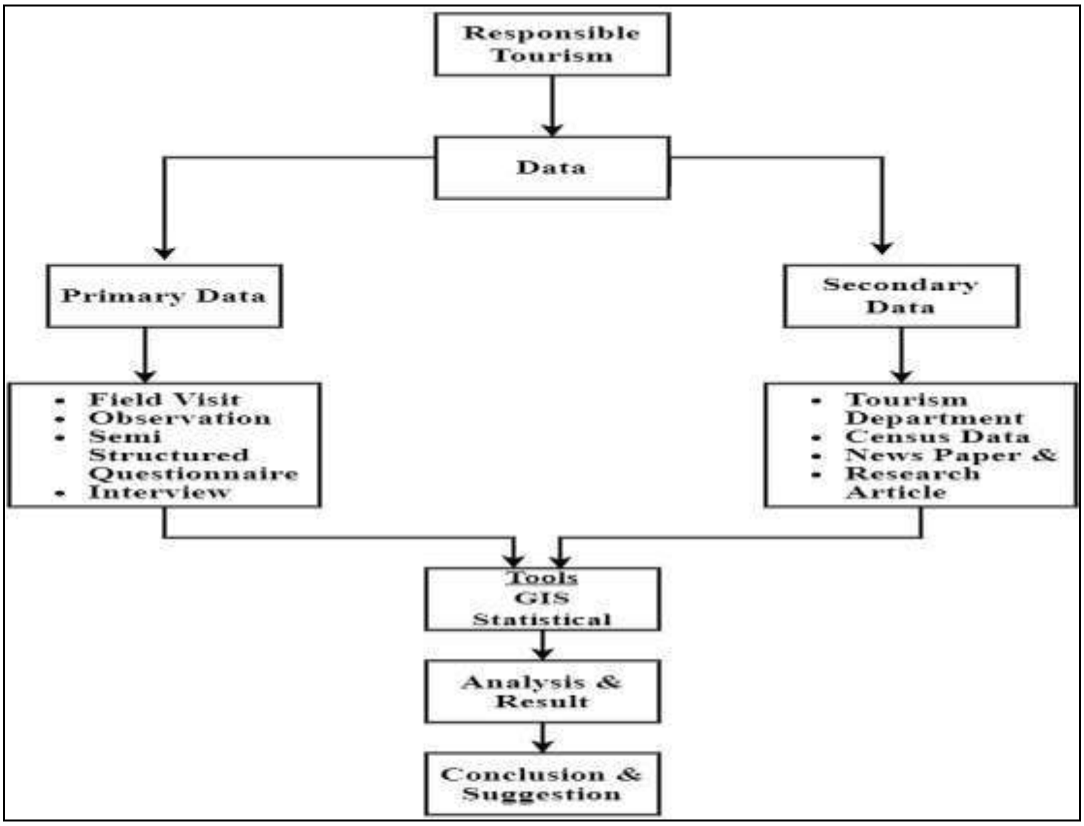

Fig.2: Schematic diagram of Methodology

4. Major Tourism Sites of Kasargod

The distinct location of Kasargod District, which is embedded with rich natural and cultural heritage, offers a wide range of scope for various forms of tourism activities. Spectacular art forms of the district include Theyyam, Yakshagana, Poorakkali, and Kolkali, amongst others. Various tourism wings of the state, such as DTPC, BRDC, and RT departments, in association with local communities, are trying their best to tap the district's tourism potential.

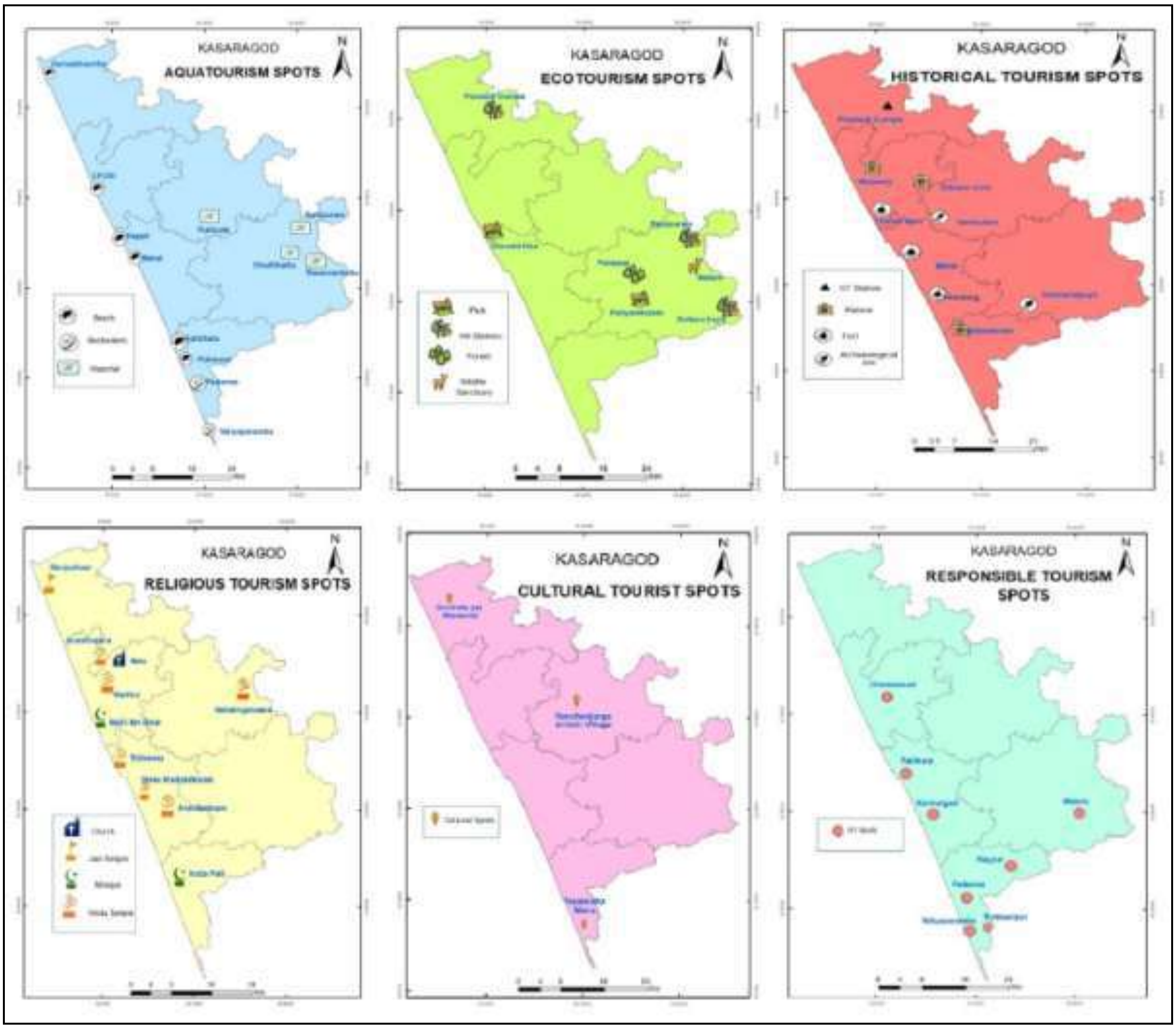

Fig.3: Various types of tourism spots in the Kasaragod district

The Kasargod district has six major types of tourism: aqua tourism, eco-tourism, cultural tourism, religious tourism, historical tourism, and responsible tourism spots. Aqua-tourism, historical tourism, and eco-tourism spots, in general, are more attractive to tourists. Responsible tourism is also attracting many foreign tourists to experience the traditional and village life of the district.

The aqua tourism spots of the district include the backwaters and waterfalls. There are six major beaches in the district; among them, Bekal is the most attractive one. Kanhangad and Neeleshwaram Blocks have a greater number of beaches. Moreover, the four major district waterfalls were mainly located in the Karaduka and Parappa blocks. Among them, Ranipuram Waterfall has the greatest number of visitors. The Kasargod district has two backwater tourist attractions, such as Valiyapramba and Padanna, located in Neelewsaram Block.

The ecotourism spots of the district may be divided into three categories: parks; hill stations; and forest and wildlife sanctuaries. These are mainly located in the Manjeswaram, Kanhangad, and Parappa blocks, which have many eco-tourism spots. Puliyamkulam and

Chembirikka are the two parks, and Ranipuram hill station attracts a significant number of tourists. Possadi Gumpe is a newly established hill station. Malom is the only wildlife sanctuary in the Kasargod district.

The historical tourist spots of the district include a fort, a Great Trigonometrical Survey Station, and archaeological sites. The whole block has some of these historical sites. The rock-cut caves called Muniyaras, dating back 2000 years, are seen at Ummichipoyill, and in Varikulam, more such architectural forms can be seen. The Possadi Gumpe GT station is one of the first surveying stations in the country.

The district has major religious tourist attractions that include Hindu temples, Jain temples, mosques, and churches. Anandheswaram spiritual centre and Ananthapuram lake temple attract many domestic tourists to the Kasargod district. Manjeshwar Jain Temple is the only Jain temple in the district, and it attracts many tourists. The Malik ibn Dinar Mosque is a famous mosque; it contains the grave of Malik Dinar, one of the companions of the Islamic prophet Muhammad. And Bela Church is a Roman Catholic church situated in the Kasargod block of the district.

The cultural attractions of the district are the Govinda Pai Memorial in Manjeswaram block, the residence of Kannada poet M. Govinda Pai. The Kanchanjunga artistic village in Karaduka block is also famous for the traditional handicrafts of the district. Thzekattu Mana is also an attractive cultural spot located in the Neeleswaram block of the Kasargod district.

There are six tourist spots that thoroughly practice responsible tourism activities like village life experience packages. The activities are held at panchayat and municipality levels. The main RT spots are Pallikara, Kanhangad, Padanna, Valiyaparamba, Thrikaripur, and Malom

5. General Tourism in Kasargod

The below line graph figure.4 shows the total number of foreign tourists arriving in Kasargod during the period between 2006 and 2019. The statistics clearly indicate that, from 2006 to 2008, there was a stagnated growth rate in terms of foreign tourist arrivals in the district, and from 2009 to 2015, the numbers increased slowly. The district’s population increased to 2973 by the year 2015. In 2016 and 2017, the district witnessed a negative growth rate in foreign tourist arrivals. It is reported that after 2017, there was a huge increase in foreign tourist arrivals to the Kasargod district. It reached 4122 in the year 2018, which is twice that of the previous year. And in 2019, there was also a rapid increase in the total number of foreign tourist arrivals to the district. Interestingly, it was during this period that responsible tourism packages peaked.

Fig.4: Foreign Tourist arrival in Kasargod between 2006-19 (in Nos.) (Source: Tourism Ministry, Kerala)

As shown in Figure 5, the total number of domestic tourist arrivals in the Kasargod district during the period 2006-2019 is shown. The district received a total number of 123,522 domestic tourists in the year 2006. After that, up to 2014, there was an increase of about 1000 people per year. In the year 2014, the district had a total number of 210691 domestic tourist arrivals, and in 2015, the trend continued. In 2016, domestic tourist arrivals in the district reached double that of the year 2015. In 2017 and 2018, there was a negative growth rate, and in the year of 2019, there was positive rapid growth in domestic tourist arrivals.

Fig.5: Domestic Tourist Arrivals in Kasargod From 2006-19 (in Nos.) (Source: Tourism Ministry, Kerala)

6. Responsible Tourism in Kerala

According to the Kerala state tourism ministry, the second international conference on 'destinations promoting responsible tourism' was held in Kerala in 2008 and focused on sharing knowledge about developing responsible tourism practices. The ideas were tested in four very different villages located across Kerala, Kovalam (beach), Kumarakom (backwaters), Thekkady (wildlife), and Wayanad (hill station). Various approaches were used and tested, all intending to increase local communities' participation in tourism. By the year 2005, there was concern about the impact of tourism on communities due to the increasing volume of tourists and the development of hotels and resorts. In retrospect, this is best seen as one of the earliest and most successful interventions to manage over-tourism and to ensure local economic benefit from tourism as an additional income source for the vast majority of households wherever a responsible tourism approach was implemented.

In the year 2015, the state tourism minister asked that a "census" be conducted in one of the villages to provide evidence of the local benefits. As a result, in Kumarakom, the research found that 70% of households engaged with and benefitted from tourism, whereas, 40 percent of households owned a tourism-related business, accounting for three fourth of it to tourism businesses, and the remaining quarter directly to tourists. This reflects the Responsible Tourism strategy in Kerala to develop producer groups to supply farm produce and soft furnishings to the hotels and resorts. The other pillar of the approach is village life experiences. Tourists can visit households to meet with farmers and craftworkers. The households gain additional income, the tourist has a guilt-free encounter with local people, and they can purchase directly from their hosts. The hotels and resorts sell commissionable Village Life Experiences guided by people from the villages. According to the Kerala tourism ministry, in 2017, Kerala created the Responsible Tourism Mission (RTM) to roll this strategy out across the state to enable many more communities to benefit from tourism, bringing an additional income source to households while avoiding household dependency. The new national draft strategy for the tourism industry adopts a responsible tourism approach, and there are responsible tourism winners across the country. Responsible Tourism Mission is an independent wing functioning in the Department of Tourism under the direct control of the Director, Department of Tourism. RT Mission will lead and implement the existing responsible tourism programs and the future RT activities & initiatives taken up by the tourism department and the Govt. of Kerala.

All the activities of the RT mission are directly linked to local community members, and the income generated from the activities is distributed among them to ensure the community's economic well-being. People's Participation for Participatory Planning and Empowerment through Responsible Tourism (PEPPER) of RT Mission is a revolutionary model for participatory development in tourism which became a tagline project of RT Mission. Through this project, places with tourism potential are identified and developed as new tourism destinations. RT Mission activities also help women's empowerment through tourism activities. There are currently 20,017 units in Kerala under the RT Mission, with more than one lakh beneficiaries as part of its activities. The units under the mission earned revenue of Rs 35 crore in three years. One of its salient features is that women head 80 percent of the total units. The Mission also runs 140 experiential tour packages and has imparted training to 7,000 people.

7. Responsible Tourism in Kasargod

As a part of the second phase, in Kerala state, the responsible tourism practice was implemented in Kasargod in the year 2012, and works like training and workshops continued till 2019, but there was a break after the COVID-19 outbreak in 2020. Bekal is the first RT spot in the district. Moreover, it later included other spots also. In 2017, several meetings were held in RT spots in the district with the active participation of the Panchayat president and members, CDS chairperson, ADS members, supply units, and village life experience units. Before that, the RT Mission conducted awareness programs in Kanhangad Municipality, Padanna Panchayat, Valiyaparamba Grama Panchayat, Pallikara Grama Panchayat, and Udma Grama Panchayat. The training programs were also held on a paper bag and cloth bag making as well as pappad making. Bekal has three candle-making units, two pappads, paper bags; and three umbrella-making units. The 'Nattinpurangalil Onam Unnam Onasammanagl Vaangam' program was successfully conducted in Bekal, which saw the participation of foreigners and native families. RT mission is also planning to conduct awareness programs in Kayyur Cheemeni Panchayat. Traditional artisans, local people, Kudumbasree, Panchayat members, and other tourism stakeholders are participating in the program. Amongst all the responsible tourism programs Pallikkara Village Life Experience package is one of the most successful RT Mission packages in the Kasargod district.

Table1: Responsible Tourism Activities Organised in Kasargod (2012-19)

Project	Year	Destination
Micro Enterprise Training	2012	Entire District
Kerala Responsible Tourism Network	2013	Entire District
Village Life Experience Tour Package	2016	Pallikara, Valiyaparamba
PEPPER	2017	Cheemeni-kayyaur, Valiyaparamba
Special Tourism Grama Sabha	2017	Pallikare, Thrikkaripur, valiyaparamba, Padanna, Neelewsaram, Uduma Chemmanad and Vellarikunduu
Tourism Resource Mapping	2017	Entire District
Tourism Resource Person	2018	Entire District
Waste-Free Tourist Destination/ Implementation of Green Protocol	2018	Entire District
Nattinpurangalil Onam Unnam Onasammaangal vaangam	2018	Valiyaparamba, Pallikara, Padanna and Thrikkaripur and Kanhangad
Human Resource Directory	2019	Entire District

Tourism Club	2019	Pullar-Periya
RT Art and Cultural Forum	2019	Entire District

Source: District RT Department

8. The socio-cultural and economic impact of Responsible Tourism

A primary survey, through a pre-scheduled questionnaire, has been conducted to get the required information from the RT workers of Kasargod District to study the socio-cultural and economic impact of responsible tourism in the district.

8.1 Socio-cultural Impact of RT

According to the survey, there are 66 percent of females and 34 percent of male RT workers in the study area. The study shows that the majority (about 53%) of them are between the ages of 18 and 36. Another 41 percent of the RT workers are in the age range of 37 to 54 years. The remaining 6 percent are older than 55 years of age. The survey reveals that 53% of RT workers have completed matriculation, 28% are graduates, and 19% have completed post-graduation or above.

According to the survey, more than 90% of RT workers are convinced that RTM implementation helps in preserving the traditional culture of the district. Interestingly, the survey suggests that the younger generation is showing a great extent of interest in RT, which is quite positive for the future growth of RT as an industry. Around two-thirds of the RT personnel has succeeded in bringing their friends or relatives to work.

The survey identifies that 44% of the people who are engaged in RT in the study area are employed in fields such as resource personnel, farming, food production, and other related fields. The handicraft industry accounts for 32%, while 10% is in the catering industry or owned homestays. In addition to that, artists make up another 4% of the total RT workers.

8.2 Economic Impact of RT

Because of the fact that RT activities were started in 2015 in the study area, as part of the second phase of the Kerala state RT mission, revenue generated from responsible tourism in Kasargod district was considered during the period from the year 2016 to 2020. In the year 2016-17, Kasargod district had an annual income of Rs. 2,341,100 from RT activities. The RT income increased to Rs. 2,715,131 in 2017-18, further increased to Rs. 3,034,431 in 2018-19, and in 2019-20 the district witnessed a rapid growth in RT income as it reached Rs. 5,112,100.

The table below indicates a strong positive correlation (r = 0.8621) between revenue generation from responsible tourism and the number of annual tourist arrivals in the study area. Therefore, the total revenue generated from responsive tourism increased due to the increase in total tourist arrivals in the Kasargod district.

Table2: Correlation of Revenue Generation and Tourist arrival in Kasargod District, 2016-*20*

	Revenue Generation	Tourist Arrival
Revenue Generation	1	
Tourist Arrival	0.862112	1

The survey reveals that almost all the RT workers are of the opinion that employment opportunities increased after implementing RT in the Kasargod district. The survey indicates that about 48 of the RT workers have a current monthly income of between Rs. 5001-10000. Around 36% of the workers have an income below Rs. 5000, while the remaining 16% of the workers have an income of Rs. 15000 or more

Table 3: Comparison of Past and present income of RT Workers (in Rs.)

Past income	**Present income**	**Change in Income Group (%)**
0	0-5000	26
<5000	5000-10000	53
5000-10000	>15000	21
	Total	100

Source: Questionnaire Survey

The survey also reveals that 26% of the present RT workers who had no income before the implementation of the responsible tourism mission in the study area have increased their income by up to Rs 5000 after the RT implementation in Kasargod district. About 53% of those who had an income below Rs. 5000 before RTM implementation had their income doubled to Rs. 5000–10,000 after the implementation of RTM. The remaining 21% have seen their income increased to Rs. 15000 and above. The survey results imply that RT had a great economic impact on the local community of the Kasargod district. The survey also finds that a great extent of infrastructural facilities has developed in the district due to RT activities.

8.3 Covid-19 impact on local Responsible Tourism

The survey to trace the COVID-19 impact on RT in Kasargod district was conducted between January and February 2021. The objective was to gauge the effect of the first wave of COVID-19. However, unfortunately, COVID-19's second wave started after March 2021, which once again severely affected the RT activities. The survey traces out that the total RT activities have come to a grinding halt because of the lockdown due to the COVID-19 pandemic starting in the month of March 2020. Only 15 percent of the RT activities, only after the lockdown relaxations, could be possible through the means of online services. As per the survey, seventy-two percent of the employees have not yet resumed their normal earning patterns following the COVID-19 lockdown. And after almost six months, only 28 percent of the workers were back to their regular RT activities and were getting salaries. It is also observed through the survey that only 22% of the RT workers sanctioned with COVID-19 relief assistance have availed it as on the date of the survey.

Table 4: Details of RT Workers Using Online Services

Online Platforms	RT Workers (in%)
RT Art and Cultural forum	40
Human Resource Directory	95
Kerala Responsible Tourism Network	62
Other platforms	70

The above table reveals that the RT workers use online and other social media platforms. About 40% of RT workers use the online platform - RT and Cultural Forum. Almost 95% of them are using the human resource directory, while 62% used the Kerala Responsible Tourism network. Many of the RT workers (around 70%) are also using other online platforms like WhatsApp groups, Facebook pages, and Official Websites for responsible tourism activities.

8.4 Success stories of Responsible Tourism workers in Kasargod district

The study also makes an attempt to take views from some of the successful RT workers through focused discussions to attain information about their personal experiences with the RT Mission activities and provides them in the form of success stories from the district.

Case.1: Anil Kumar Kartika is the owner of the Grameen Cultural Arts program and tour packages of responsible tourism in the Kasargod district. Anil Kumar, a 36-year-old resident of the Kanhangad block of the district, is well known for his temples and traditional art theyyam sculptures. He is making three-dimensional representative forms of 16-foot high 'kettukala' (ceremonial horse of wooden horses during temple festivals) and theyyam ritualistic sculptures. Mr. Anil, who sculpts on wood and cement, said he had gotten many work orders since he registered with the online platform of responsible tourism, RT art, and cultural forum. The famous international cultural coordinator, Candida Boyce, gave him a special appreciation while visiting the RT units of Kasargod. As a token of recognition for his services to the RT industry, Mr. Anil Kumar got an invitation to participate in the cultural exchange program in Manchester, England. Within two years of his work in RT, he made an income of Rs. 4 lakhs. and also started one cultural unit, and at present, the unit employs 25 workers. According to Anil, the pandemic caused a substantial economic loss in his work, and his income decreased. However, he has now started to get small work again. He also got an opportunity to interact with the students of the Central University of Kerala, and he conducted a class on the importance of sustainable tourism to the students. During the pandemic, he did many things at home, like making videos on the art and promoting it as a part of the Kasargod district's RTM.

Fig.6: Anil Kumar at his work

TOURISM | BOOKS ■ To showcase sculpture of traditional arts

Manchester beckons Anil

KRISHNA KUMAR K.E. | DC
KOCHI, MARCH 11

Anil Karthika with his sculpture works

It was always my dream to visit a foreign country. But I never thought I'd be flying out as part of my traditional occupation - sculpture.
— ANIL KARTHIKA

■ As part of cultural exchange programme, Kerala Tourism will be part of Manchester Day Parade, annual cultural show of the city, which is scheduled to fall on June 23 this year

Fig.7: Newspaper Article on Anil Kumar

Case.2: Krishnan, a 55-year-old toddy tapper, has been working in the RT field for over two years. He belongs to the Pallikare panchayat, has his own farm, and his wife also supports him in farming. As part of the Pallikare village experience package, many tourists visited his home and experienced toddy tapping and traditional farming. According to him, responsible tourism made his life more economically stable, and he was also delighted to interact with foreign and domestic tourists from various regions of the world. In the initial stages of RT work, Mr. Krishnan did not learn a single word in English, but now he has learned some words and is trying his best to better communicate with the tourists. He says he earned a decent amount until the outbreak of COVID-19, and since then it has come to a grinding halt. COVID-19 affected his work so badly that he could not get a single tourist during the pandemic. He and his wife also did work from home and made videos during the pandemic as a part of district RTM.

Fig.8: Krishnan at his Farmhouse

Fig.9: Krishnan Involving in Toddy Tapping

Case. 3: Shamsuddin is a 42-year-old responsible tourism worker from Bekal village in Kasaragod district. He is the owner of Bekal Campfire Beach Dinner Restaurant near Bekal beach. He has been working as a member of RT for more than three years. His restaurant has Indian, seafood, Asian, and contemporary Arabic cuisines. He is trying his best to use eco-friendly materials for all of his work, which includes serving the food. He uses traditional and eco-friendly products like bamboo plates, etc. Many foreign and domestic tourists have started visiting the Bekal campfire beach dinner. He was getting a monthly income of Rs. 60,000 before COVID-19. The pandemic worst hit his restaurant, which lost a large amount of income due to the COVID-19 pandemic. On December 1, 2020, he resumed the restaurant for the local tourists, but no match for the COVID-19 scenario

Fig.10: Campfire Beach Restaurant

Fig.11: Night View of Campfire Beach Restaurant

9. Conclusion

The study finds that, recently, until the outbreak of Covid-19, there has been a rapid increase in the number of tourists visiting the Kasargod district as a result of the local community's involvement in the development of RT activities such as village life experiences, the exhibition of traditional cultural artifacts and the presentation of such products, and so on. Tourist arrivals grew at a significant rate in 2018 and 2019. This was due to the greater implementation of projects and activities by district tourism agencies. The most positive impact of RT is the fact that more people are employed and that the younger generation is interested in RT projects. Women make up the vast majority of the workforce in RT, making it a very valuable resource for them in terms of gaining financial independence and empowerment. Following their involvement in RT projects, local artisans and artists who were previously hardly known to anyone gained much popularity and got new lease of life in their careers. After joining RT, the income of RT personnel increased far more than it had in the pre-implementation of RT mission activities in the district. In fact, the income of the workers involved almost doubled after the implementation of RT in the study area. The study also found that the RT industry also plays a crucial role in preserving the traditional cultural practices alongside manifesting the same to the visitors as part of the RTM activities. The RT personnel were very hardly hit by Covid-19. During the pandemic, the government provided some relief aid to the artisans and handicrafts workers associated with responsible tourism but more than 70% were redundant and could not avail any relief for them. Online video sessions and RT platforms like art and cultural forums played a little part in the lives of local tourism workers during the pandemic, as they helped them market their art/wares online. The study finds that an inventory of new tourist attractions and initiatives are needed in Kasargod to attract more visitors, while some parts of the district are underrepresented in RT projects. The study also suggests responsible authorities should promote the local RT products more and create new market opportunities, especially in the local and domestic markets. The study also identifies that to cope-up with troubled times such as the Covid pandemic, the project authorites need to find more ways of online means like; workshops, tutorials, and learning from home, to target online visitors from both local and international communities.

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Multi-Hazard Risk Assessment Through Public Perception Survey – A Case of Coastal Plains of Tamil Nadu

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Abstract

The coastal plain of Tamil Nadu is densely populated and highly susceptible to different coastal hazards. Assessing a disaster risk based on public perceptions is crucial for disaster risk reduction, recovery, rehabilitation, and reconstruction. In this study, the prevalence of multi-hazard risks was analysed for the entire stretch of the coastal plains of Tamil Nadu using a likelihood-impact risk matrix approach. All the major and minor coastal hazards in the study area were considered to determine the degree of disaster risk on a relative scale. A total of 406 random respondents from 363 villages in the coastal plains of Tamil Nadu were selected. They were asked about their perception of the occurrence of ten coastal hazards and associated consequences. Their responses for each hazard were recorded in a matrix and used to determine the relative risks under five classes (very high to very low). The spatial patterns of the risk assessment show that the respondents living in the coastal villages of Chennai, Puducherry, Cuddalore, Nagapattinam, and Thoothukudi districts perceived a very high risk due to higher likelihood-impacts of multiple coastal hazards. The first-hand information retrieved on a relative scale offers insights into understanding the disaster risks in the coastal plains of Tamil Nadu and it can be used to develop effective disaster risk management plans.

Keywords: Coastal hazards, Disaster risk, Tamil Nadu coast, Risk survey

1. Introduction

The coastal areas are naturally exposed to rapid changes due to physical weathering, denudational activities, and other hydrological and atmospheric phenomena (Kantamaneni et al., 2019). The increasing urbanisation in the coastal regions leads to anthropogenic-induced changes in the coastal environment, causing it to be more vulnerable to natural and human-induced hazards (Saxena et al., 2013). The global statistics of disasters from 1975 to 2018 indicate that number of reported disasters and people affected has increased nearly five times in the coastal regions and inflicts substantial economic losses (EMDAT, 2019). Due to the multitude of economic activities in the coastal areas, the risks associated with natural hazards have increased exponentially during the last few decades (BalaSundareshwaran et al., 2018; Weinstein et al., 2007). As forecasted by the Intergovernmental Panel on Climate Change (IPCC), by the end of this century, sea levels could be as much as 1.1 m higher than the present level due to the faster melting of polar ice caps and the occurrence of severe flooding events will become regular in low-lying coastal settlements. According to the World Bank estimates, this can make nearly 190 million people vulnerable to coastal flooding (Broom, 2021).

In India, more than 26% of the population lives in the coastal regions. Tamil Nadu, the southernmost state, is among India's important coastal states, holding a population density of about 2,000 per sq. km. in the coastal area (ENVIS, 2018; Saxena et al., 2013). The coastal plain of Tamil Nadu has a total population of 24.3 million (nearly one-third of the people of the state). It is an ideal region for human habitation, trade, economic and recreational activities (BalaSundareshwaran et al., 2018). Lying in the south-eastern part of peninsular India, the coastal region of Tamil Nadu is prone to disasters owing to its physiographic nature, where the atmospheric, physiographic, and anthropogenic processes liaise with each other and operate together (BalaSundareshwaran et al., 2018). The state's coastal ecosystems are under potential threat due to natural and man-made hazards. The physical, human, and economic elements of coastal Tamil Nadu are highly vulnerable to cyclone, storm surge, coastal erosion and flood events, especially during the northeast monsoon (October to December) season (Saravanan et al., 2018). Chennai, Cuddalore and Thoothukudi are the major industrial hubs in coastal Tamil Nadu, and they operate at the cost of the destruction of mangroves, coral reefs and other sensitive habitats (Menéndez, 2020; Sridhar, 2006).

Since the coastal hazard events are complex, multi-factorial and occur on varied scales, it requires proper discernment of coastal hazards and vulnerability to develop managerial and mitigation measures to cope with future hazards (Kappes et al., 2010; Balasubramani et al., 2021). Further, preparing coastal disaster risk management plans and effective implementation of sustainable development goals necessitates a systematic study on multi-hazard risk assessment at a micro level. Assessing disaster risks at a micro-level is essential for disaster risk reduction, recovery, rehabilitation and reconstruction. Natural hazards are inevitable, but the associated risks can be reduced if proper disaster risk assessment plans are in place (MHA, 2011). A community's vulnerability to the impact of coastal hazards is determined by the physical, social, economic, and environmental factors or processes (UNISDR, 2017). Many direct and proxy indicators have been used to assess vulnerability, and these indicators vary from place to place and from time to time.

A multi-hazard and vulnerability assessment is essential for potential hazard regions like coastal areas (Kappes et al., 2010). It helps acquire information on community weaknesses and identify the sensitive areas of disaster risks. It aids the government, planners and engineers to put forward resilience and mitigation plans to curtail the losses due to disaster events and prepare land use protocols accordingly (DST and SDC, 2020; Eshrati et al., 2015; MHA, 2011). Community-based hazard and risk assessments are very much needed in the coastal plains of Tamil Nadu, which are being affected by multi-hazard events (Balasundareshwaran et al., 2020). Any disaster management steps based on merely the physical model-based hazard assessment would probably result in ineffective planning mechanisms because certain areas/communities are better prepared for frequent hazard events but ignorant of other potential hazards (Skilodimou et al., 2019). Therefore, a multi-hazard risk assessment approach based on community surveys at a micro-level is essential for effective disaster risk governance in the coastal plains of Tamil Nadu, which forms the basis for this study.

2. Hazard Profile of Tamil Nadu Coasts

Tamil Nadu (TN) is located in the southernmost part of India and is bounded by Kerala on the west, the Bay of Bengal on the east, Karnataka and Andhra Pradesh on the north, and the Indian Ocean on the south. The coastal plains of Tamil Nadu are home to one-third of the state's population (~24.3 million), which provide an advantageous environment for human habitation, commerce, services, and recreation (Balasundareshwaran et al., 2018). The physical and socio-economic settings of the coastal plains of Tamil Nadu make it vulnerable to natural disasters like tropical cyclones, floods, storm surges, and earthquake-induced tsunamis. Among the disasters, cyclones are more frequent and severe (120 to 180 km/hr), usually occurring in October-November. Seasonal and cloudburst flooding are also frequently observed in the coastal region. In recent decades, the low-lying parts of the Cuddalore district and Chennai metropolitan area have witnessed widespread flood inundation. Drought hazards, storm surges, and coastal erosion are much more pronounced in the Southern coastal plains. The coastal region has not experienced significant earthquakes in the past 100 years. The Peak Ground Acceleration (PGA) data show that the northern part of the Coromandel coast is prone to moderate damaging risks (Zone III). Among the recent natural disasters, the tsunami in 2004, the flood in 2015, and severe cyclonic storms (Vardah in 2016 and Gaja in 2018) caused the most destruction to lives, properties, and services. Eight cyclones, five floods, one drought, one tsunami, and four man-made significant accidents have occurred during the last two decades in the coastal plains of Tamil Nadu. Compared to other parts, the coastal plains of Tamil Nadu are the most populous region of the state, housing nearly 24 million people at a population density of 2,186 per sq. km. in the coastal plains, making it more vulnerable to the coastal hazards.

3. Methodology

Disaster risk is usually associated with the degree to which humans cannot cope with a particular situation (e.g., Natural hazard). Worldwide disaster risk is generally measured by hazard, vulnerability and coping capacity. A hazard is a dangerous phenomenon, substance, human activity, or conditions that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage. Vulnerability is defined as the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard. Coping capacity refers to people, organisations and systems' ability to employ available skills and resources to face and manage adverse conditions such as hazards, emergencies or disasters (UNISDR, 2009).

This study uses a public perception survey to assess the multi-hazard risk at a relative scale. Multi-coastal hazards such as cyclone, flood, tsunami, strom surge, and shoreline erosion are common in Tamil Nadu's coastal plains and cause loss of livelihood, services, infrastructure, social and economic disruption, or environmental damages. Hence, a reconnaissance survey was conducted throughout the coastal plain of Tamil Nadu through a likelihood-impact risk matrix approach (Table 1). This relatively simple approach will help to understand and comprehend the public perception of the multi-hazard risks in the study area (Dumbravă and Iacob, 2013).

Table 1: Likelihood-impact risk matrix and the associated level of risks

	Impact / Consequence					
Likelihood / Probability		Negligible	Marginal	Critical	Catastrophic	
	Frequent	*Low Risk*	*Medium Risk*	*High Risk*	*Very High Risk*	*Likely to occur often*
	Occasional	*Low Risk*	*Medium Risk*	*High Risk*	*Very High Risk*	*Likely to occur sometime*
	Remote	*Very Low Risk*	*Medium Risk*	*Medium Risk*	*High Risk*	*Unlikely to occur, but possible*
	Improbable	*Very Low Risk*	*Low Risk*	*Medium Risk*	*Medium Risk*	*Assumed that it will not occur*
		No injury and negligible system damage	*Minor injury and/or minor system damage*	*Severe injury and/or major system damage*	*Results in fatalities and/or loss of system*	**Description used to determine the class**

The matrix is individually developed for six natural (cyclone, coastal erosion, storm surge, tsunami, flood, and drought) and four human-induced (wetland loss, fire accident, transport accident, and chemical accident) hazards. In this study, 406 respondents were interviewed from 363 villages in the study area during March-May 2019. The locations were randomly selected, and respondents from each location were selected based on their prior exposure to natural or human-induced hazards in that region. All the respondents were questioned about the probability of natural and human-induced hazards and associated consequences using a matrix with likelihood possibilities (frequent, occasional, remote, and improbable probabilities) and impact levels (negligible, marginal, critical, and catastrophic). Later, the intersection of possibilities and impact levels is used to identify five relative risk classes: very high, high, moderate, low, and very low. All the surveyed results are geocoded and used to prepare spatial layers for mapping and overlay analysis in GIS.

4. Results and Discussion

4.1 Likelihood-impact of major coastal hazards

Hazard mapping is highly relevant and imperative if the disaster's impacts are likely repetitive in a specific place. In general, the effects of natural hazards are more severe and widespread than human-induced hazards. The public perception risk survey in the coastal plains of Tamil Nadu revealed that cyclone and tsunami are the most likelihood-impact natural hazards in coastal Tamil Nadu. Most respondents living in the Northern coastal plains perceived that they were at very high risk of cyclones (Fig.1). The respondents residing in the districts of Cuddalore reported that they were at very high risk of cyclones. Next to Cuddalore, the respondents in Villupuram and Puducherry also perceive they are at very high risk of cyclones. The increased risk of cyclones is noticed majorly in the districts of Nagapattinam, Pudukottai, Ramanathapuram, and Thoothukudi (George et al., 2021).

When examining the Indian Meteorological Department's best cyclone track data, it is clear that the northern Tamil Nadu coast (from Vedaranniyam to Pulicat Lake) is much more prone to cyclones and depressions than the southern parts of the state. Similar to previous studies (Bhaskaran et al., 2014; Punithavathi et al., 2012; Bhaskaran et al., 2013; Rao et al., 2013), this survey also proves that cyclone hazard relatively produced significant impacts in the regions of Cuddalore and other northern Tamil Nadu's coasts. The southern and central coastal plains are witnessed with a moderate to low cyclonic hazard (Saravanan et al., 2018). Due to Sri Lanka's physiographic position, most cyclones generated in the Bay of Bengal are diverted towards north Tamil Nadu, making the northern plains more susceptible to cyclones.

Storm surges and associated coastal erosions are constant threats to the infrastructure, environment and economic activities of the coastal plains of Tamil Nadu. The districts such as Kanyakumari, Thoothukudi, Kancheepuram and Chennai are observed with a high likelihood-impact of storm surge and coastal erosion. The impact of coastal erosion takes months or years to be recognised by any; therefore, usually known as a "long-term coastal hazard" (Prasad and Kumar, 2014). In addition, combined with high tides, storm surges generate high-energy waves that may result in catastrophic damage to coastal assets and accelerate severe coastal erosions. Shoreline analysis using DSAS shows that the erosion and accretion pattern of the study area is highly variable; however, the villages of the southern tip of the Tamil Nadu coast experience very high erosional activities compared to other places (George et al., 2023). Although the structural measures are implemented at several locations to control the coastal erosion, a moderate erosional risk is observed throughout the coastline of Tamil Nadu.

Tamil Nadu coast was one of the worst affected regions by the Indian Ocean Tsunami of 2004, which reported many casualties, mainly the coastal villages from Nagapattinam to Cuddalore districts. Significant structural damage has been documented due to the Indian Ocean Tsunami of 2004 throughout the study area, including damage to compound walls, brick masonry, the collapse of rural homes, column failure, roof toppling, and general structure damage (Maheshwari et al., 2005). Similar to the previous studies, a very high level of tsunami risk is perceived by respondents mainly in the northern coastal districts, especially in Cuddalore and Nagapattinam districts. Respondents from the Karaikal and Puducherry shoreline villages also reported a very high likelihood-impact of Tsunami hazards. The high category of tsunami risk is also noticed in all coastal districts of Tamil Nadu. However, the number of responses with a high likelihood-impact of Tsunami hazard is widespread in the northern coastal plains of Tamil Nadu.

The survey showed that respondents living in the low-lying areas of the major cities such as Chennai, Cuddalore and Thoothukudi perceived very high flood risks. Although very high or high categories of flood risks are reported significantly less, some extent of flood risks are reported throughout the coastal plains of Tamil Nadu. Almost all of the Tamil Nadu rivers flow eastward and bring large quantities of water and sediment to construct deltas as well as floods. The previous studies and reports conform with the present hazard analysis (Ramkumar et al., 2015). The villages in and around Cuddalore have a very high risk of flooding (Thirumurugan and Krishnaveni, 2019). In recent decades, the northern parts of coastal Tamil Nadu encountered heavy flooding after every heavy to extreme rainfall event (Mahendra et al., 2011). One of the most devastating flood events in recent history occurred in 2015 in Chennai, when many people's homes and ecosystems were destroyed (Selvaraj et al., 2016; Seenirajan et al., 2017; Sharma et al., 2017).

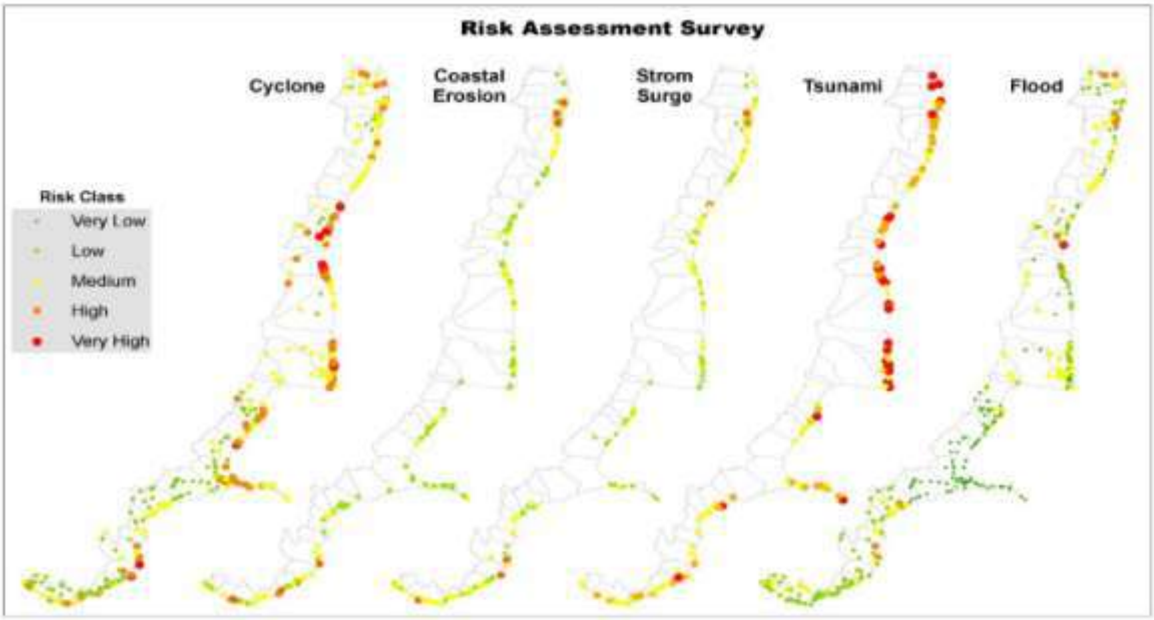

Fig. 1: Spatial distribution of public perceptions on risks of major coastal hazards in the coastal plains of Tamil Nadu

4.2 Likelihood-impact of other coastal hazards

The risk perception survey was also conducted for other minor hazards in the coastal plains of Tamil Nadu and the results are presented in Fig. 2. The likelihood-impact of higher drought risks is perceived in the southern plains as these regions are comparatively dry. Moderate to low drought risks are perceived through the coastal plains. The northeast monsoon brought over 60% of the annual rainfall. If the monsoon fails in a given year, drought conditions will develop in the following summer months due to severe water shortages (Vengateswari et al., 2019). The residents living near the major coastal wetlands of Tamil Nadu responded with a high likelihood-impact of wetland losses, especially in the Cuddalore, Pudukkottai and Thoothukudi districts. To the questions about fire and chemical-related accidents, the respondents from Chennai and Thoothukudi feared a high risk due to the presence of large-scale industries, power plants, oil refineries, and chemical industries. A very high likelihood-impact of transport accidents is perceived in major cities such as Chennai and Thoothukudi. A moderate to high occurrence and impact of transport accidents is noticed throughout the coastal regions.

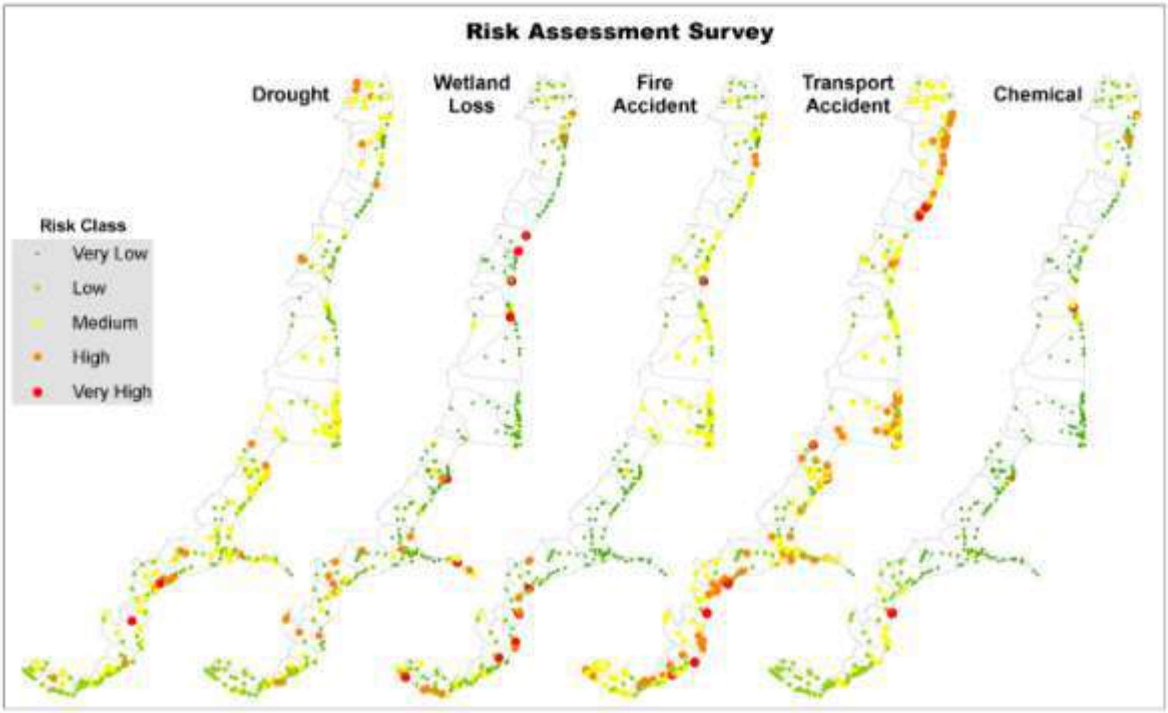

Fig. 2: Spatial distribution of public perceptions on risks of other and human-induced hazards in the coastal plains of Tamil Nadu

4.3 Multi-hazard risk assessment

The coastal plains of Tamil Nadu are susceptible to the occurrence of different coastal hazards and most of the locations have witnessed multiple hazard events in the past. Hence, the multi-hazard risk assessment at the micro-level will be beneficial for planning purposes. An overlay analysis was attempted in GIS to assess the multi-hazard risk in the coastal plains. The integrated assessment shows that the respondents living in the coastal villages of Chennai, Puducherry, Cuddalore, Nagapattinam and Thoothukudi districts perceived very high risks due to likelihood-impact of multiple hazards. Many coastal locations in these districts are reported with more than four very high risk classes. Most respondents in these districts believe they are at very high risk due to cyclones. After the Indian Ocean tsunami in 2004, people all along the coastline were more afraid of tsunami risk. Transport accidents are also noticeably high in these locations. Major flood events have occurred in these districts. The adverse effects on the wetland environment are also witnessed, especially near the major coastal settlements. These region's scoio-economic conditions also make it a hot spot for multiple hazards (Balasubramani et al. 2021). Several studies have also reported that these coastal parts are very prone to coastal hazards (Mahendra et al., 2011; Murali et al., 2013; Muthusankar et al., 2013; Saxena et al., 2013; Parthasarathy et al., 2020; Rehman et al., 2020). Many physical vulnerability analyses have also documented many locations of these districts as highly vulnerable zones (Nitheshnirmal et al. 2018; Balasundareshwaran et al. 2018; Priya Rajan et al. 2019, George et al., 2022).

Unlike model-based physical risk assessments, which are widely and frequently studied, risk assessments through field surveys are complex and challenging. Even though coastal risk assessments were attempted in the coastal plains of Tamil Nadu, such reviews did not cover the entire coast on a relative scale. Therefore, this proxy approach was tried through a wide area public perception survey with the help of many students to fill the gap and to understand the public perceptions of coastal hazards. As disaster is a product of hazard, vulnerability and coping capacity of the affected community, the results of this people-based multi-hazard risk analysis are beneficial for developing plans to increase disaster reliance, especially in the northern coastal plains of Tamil Nadu.

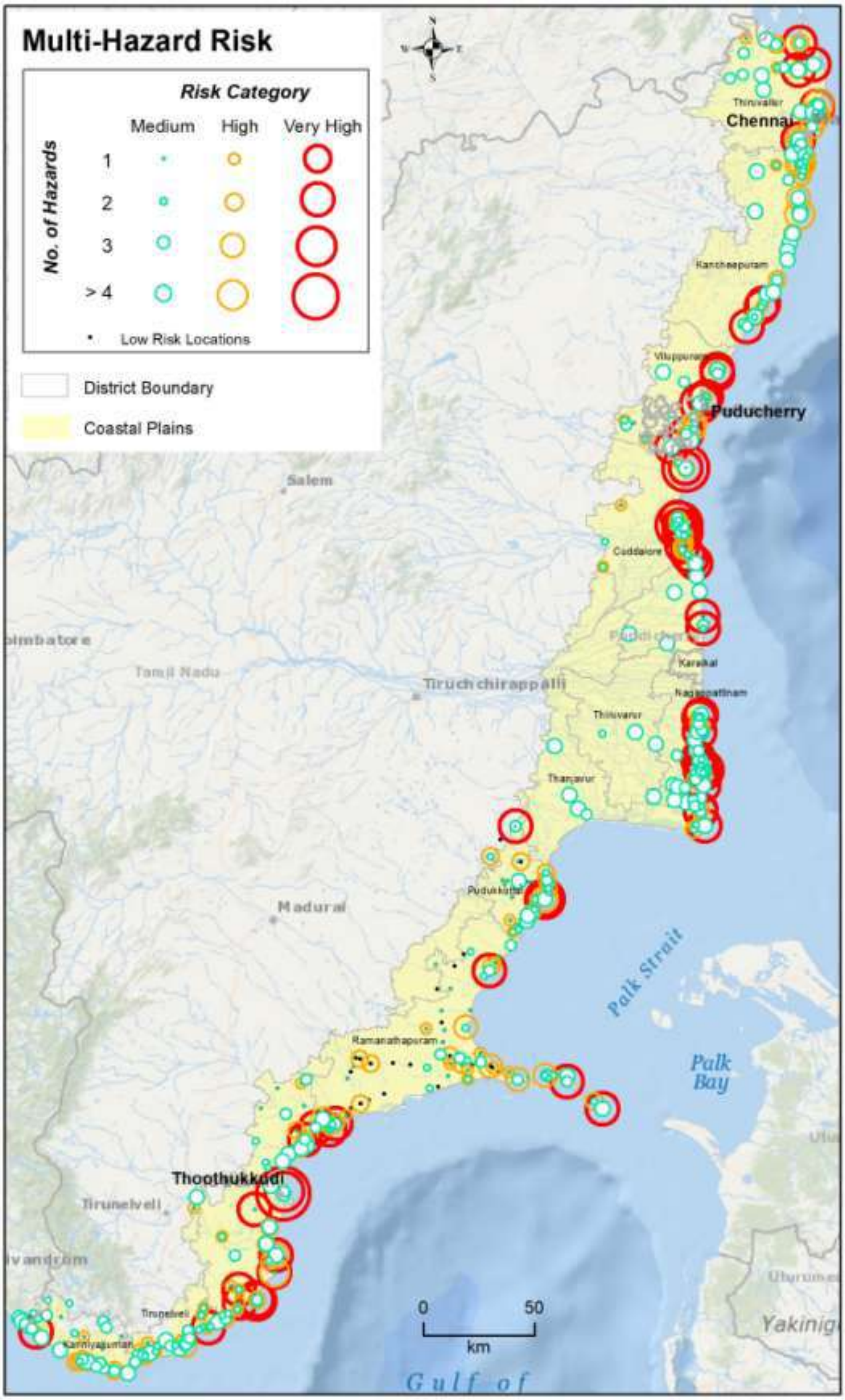

Fig. 3: Spatial distribution of multi-hazard risks in coastal plains of Tamil Nadu

5. Conclusion

The study offers a detailed field survey in the entire coastal plains of Tamil Nadu to reveal likelihood-impacts of multiple hazards with a standard reference scale. The perceptions of the affected communities about multi-hazard risks help understand the severity of coastal disasters better. As the public perception survey was conducted in almost all major settlements of the coastal plains of Tamil Nadu, the study offered a piece of first-hand information to understand the disaster risks in the study area. The spatial pattern generated from the field surveys helped to comprehend the public perceptions of multi-hazard risks and disaster management in coastal Tamil Nadu. The spatial variations presented in the study would help the administrators prepare a local-level plan for mitigation measures, community awareness, and disaster governance. The results of the study would also help to identify priority areas for implementing early warning systems and setting up emergency response centres in very high multi-hazard risk regions, which would greatly help reduce future disaster impacts.

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Lacunae in data availability: Migration studies in India

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Abstract

Out of the three pillars of population studies - birth rate, death rate and migration - migration is least studied, unexplored, and unique one. As the documentation of mobility of human beings is challenging and it needs craftmanship. Demographers around the world have defined the term “migration” in varied contexts but none are universally accepted. Many researchers and population scientists agree that theories and laws underlying the subject are not fulfilling the studies on new age migration problems. One of the major concerns for the researchers in the domain is the data collection and data availability through secondary sources, so as in India too. In India, the data is collected at the national level and at the state level with just the inter-state migration, the block/district level data and intra-state migration get neglected. Data is recorded once in a decade and the questions entitled are arguable. Research suggestions, formulation of policies and all the decisions are based on the available data which is inadequate. Here, the study tries to summarize the lack of data collection tools and the accessibility to data, from the lowest administrative unit to international level, and the problems associated with acquiring the data. Therefore, a detailed literature assessment is carried out. Along with that a detailed survey from the experts and researchers in the domain is carried out to identify the questions that are most suitable to collect the migration data. The profound collection and understanding of the migration data will aid to explore untouched dimension of humans and the demographic patterns.

Keywords: Migration, data sources in India, data collection tools and accessibility.

1. Introduction

Migration, defined as the change of residence from one place to another, is a pivotal aspect of population studies with far-reaching impacts on demography (Census, India). It affects demographic dynamics differently than birth and death rates, making it a subject of significant academic interest. The concept of migration has been explored from various angles, ranging from the practical comparisons drawn by Adam Smith in "The Wealth of Nations" to the seminal work of Ravenstein, who emphasized birthplaces and paved the way for subsequent studies (Adam Smith, 1776; Macisco and Pryor, 1963; Grigg, 1977). This historical perspective highlights the continued relevance of migration studies.

The definition of migration varies across contexts and theories, adding complexity to the field. While it is a well-established aspect of population dynamics, recent research has shown that there are unexplored dimensions of migration that require new data types to be fully understood (Blunt, 2007). Despite migration's profound impacts on various aspects of society, including social, economic, environmental, political, and cultural dimensions, it has often been neglected in favor of more specific field-based studies. Migration studies have failed to receive the attention they deserve despite their pervasive influence (Kevin M. Dunn, 2005).

The field of migration has become increasingly complex with the rising movement of people worldwide, necessitating exploration into new aspects such as permanent versus temporary migration, legal versus undocumented movement, forced versus voluntary migration, and work-related versus non-work-related migration (Kevin M. Dunn, 2005).

For scholars and researchers in the field of migration, the importance of data sources extends beyond their mere existence. Issues of awareness, accessibility, and data regularity also loom large. These concerns are compounded by the variability in definitions, sampling methods, and survey objectives. No single survey comprehensively fulfills the diverse needs of migration researchers (King & Skeldon, 2010; Castles & Miller, 1993, 2009).

Migration scholars are currently divided into two categories: traditional migration researchers who employ quantitative and qualitative methods, and digital demographers who harness computational tools. Integrating these two approaches offers the potential for more comprehensive and efficient migration research (Drouhot et al., 2022).

The advent of the digital age has introduced a new dimension to migration studies, as internet use, social media, and digital tools have directly influenced migration patterns. Innovative data sources, such as web data, social networks, and geolocation data, have been employed to gain insights into migration trends (Messias et al., 2016; Drouhot et al., 2022; Lacus, 2022). This paper aims to contribute to a more comprehensive understanding of migration, its impact, and the challenges associated with data availability.

In the Indian context, a rich history of record-keeping, dating back to the British colonial period, has primarily focused on various administrative and societal aspects. The decennial census, initiated in 1872 and subsequently continued at ten-year intervals until 2011, is a prime example. While these records provide valuable demographic data, they often lack a dedicated focus on migration, necessitating comparative assessments of the available sources.

Despite the rich history of migration studies and the increasing complexities in the field, there is a notable research gap in understanding the multidimensional aspects of migration, particularly in the Indian context. This study seeks to bridge this gap by examining data availability, data sources, and challenges in migration research. The integration of traditional and digital methods provides a unique opportunity to address this gap and gain a more comprehensive understanding of migration patterns and their implications. The proposed study on ‘Lacunae in data availability: Migration studies in India’ is essential in the current global and Indian context, where migration continues to play a significant role in shaping societies and demographics.

2. Objectives & Methodology

This research paper is guided by the following objectives to:

1. Analyze existing migration data sources (Census, DCHB, NSSO, IHDS) to assess the scope and identify gaps in the available information.
2. Evaluate the awareness, accessibility, and data update regularity among migration researchers to understand practical challenges.
3. Examine the specific difficulties encountered during the collection of migration data, highlighting obstacles in the research process.

These objectives serve as the core framework for this study, aiming to address data availability issues in migration research and contribute to a more informed and comprehensive understanding of migration dynamics in India.

2.1. Data sources

The research employs a combination of primary and secondary data sources to thoroughly investigate the scope, accessibility, and limitations of migration-related information. The integration of secondary data analysis and primary surveys offers a comprehensive and nuanced approach to understanding the complexities of migration data availability and the associated challenges. This methodological framework allows for an in-depth evaluation of the current status of migration data in India.

2.1.1. Secondary Sources

The study meticulously examines prominent secondary data sources in India, with a primary focus on the Census and the District Census Handbook (DCHB). These sources have been subjected to detailed scrutiny over the years, and their data content and coverage are thoroughly assessed. Furthermore, the research includes an analysis of other secondary data sources such as the India Human Development Survey (IHDS), National Sample Survey (NSS), and Periodic Labour Force Survey (PLFS). These sources are evaluated based on common criteria, enabling a comprehensive understanding of the information they provide and revealing potential gaps or areas where data may be lacking.

2.1.2. Primary Source

In conjunction with the secondary data analysis, a primary survey was conducted to capture insights and perspectives from experts and practitioners in the field of migration studies. The primary survey participants encompassed academicians, population study experts, officials from relevant institutions, and students specializing in this field. The survey employed a snowball sampling technique, initiating with a select group of respondents and subsequently using their referrals to identify additional participants. This approach facilitated the collection of diverse and well-informed views. The sample size for the primary survey was carefully determined to ensure that it encompassed a comprehensive and representative cross-section of relevant stakeholders.

2.2. Tools, Techniques, and Methods

The research relies on a range of tools and techniques to analyze secondary data sources, encompassing quantitative and qualitative methodologies. Quantitative data are examined through statistical analyses and data visualization, providing an extensive overview of the available data. Qualitative data, derived from academic literature and expert opinions, are subjected to content analysis and thematic coding. The primary survey employs structured questionnaires and interviews, ensuring a systematic approach to data collection. Data validation and cross-verification are integral to the research process, enhancing the credibility and reliability of the findings.

3. Results and Discussion

The Indian census, touted as the world's most extensive data collection effort involving households, is administered by the Office of the Registrar General, India, under the Ministry of Home Affairs. Established in 1881, this monumental undertaking is conducted every decade and serves as the nation's largest data repository, encompassing information at the national level and representing each individual.

The inaugural census was conducted in 1872, with the first comprehensive census transpiring in 1881 during the tenure of the British Viceroy, Lord Mayo. From 1881 to 1941, the census schedules included a solitary query pertaining to migration, primarily focused on the 'birthplace' or 'country of origin' of the respondents. It wasn't until the 1951 census, a mere four years following India's independence in 1947 and the partition that ensued, resulting in significant religious and cultural shifts across the nation, marked by mass movements across the newly drawn borders between India and Pakistan.

In light of the tumultuous events of 1947, the 1951 census introduced a crucial question related to "Displaced Persons," in addition to collecting data on the "birthplace." This question held immense relevance given the prevailing political agreements and the urgent need to track individuals for purposes of resettlement, food distribution, water access, land allocation, and other essential provisions.

The 1961 census introduced another significant addition to the migration section of the schedule, expanding the questionnaire to include a total of three migration-related questions: "Birthplace," "Place of birth” (rural or urban), and "Duration of residence at the current place” (if born elsewhere).

In the 1971 census, the census authorities made a pivotal adjustment to the third question within the schedule. They replaced it with a more detailed inquiry, soliciting information regarding the "Name of District" and "State/Country name." This marked the first instance when the authorities conducted the survey at the micro-level, focusing on the district. The questions this time diverged from the preceding format and encompassed inquiries about the respondent's "last residence" and the "duration of residence at the enumeration place."

In the 1981 census, a groundbreaking development occurred as India sought to delve into the reasons for migration, thereby altering the trajectory of migration studies in the country. This significant shift in approach persisted through the 1991 census.

The 2001 census schedule evolved to become more precise and concise, further refining the migration-related inquiries. In 2011, the census schedule placed a heightened emphasis on capturing migration characteristics and delving into the underlying reasons for migration. Thus, over the years, the evolution of the Indian census not only entailed an increase in the number of migration-related questions but also broadened the scope and depth of migration studies across the nation.

Table 1: Detail of the questions related to migration in Year- wise Census Schedule

Census year	**Question**
1872	1. Race or Nationality or Country of Birth
1881	1. Place of birth
1891	1. Birth district tor country
1901	1. Birthplace
1911	1. District, Province, or country in which born
1921	1.Birth district
1931	1.Birth district or Country
1941	1.Were you born in this district? If not, in what district
1951	1. Birthplace 2. Displaced person
1961	1. A). Birthplace B). Born R/U C). Duration of residence, if born elsewhere
1971	1. Birth Place A). Place of birth B). Rural/Urban C). District D). State/Country 2. Last residence A). Place of last residence B). Rural /Urban C). District D). State /Country 3). Duration of residence at the village or town of enumeration
1981	1. Birth Place A). Place of birth

	B). Rural/Urban C). District D). State/Country 2). Last residence A). Place of last residence B). Rural /Urban C). District D). State /Country 3). Reason for migration from place of last residence 4). Duration of residence at village or town of enumeration
1991	1). Birth Place A). Place of birth B). Rural/Urban C). District D). State/Country 2). Last residence A). Place of last residence B). Rural /Urban C). District D). State /Country 3). Reason for migration from place of last residence 4). Duration of residence at village or town of enumeration
2001	1). Birth place, is the person born in this place/town? Yes/No A). State/Country B). District 2). Place of Last residence, has the person come to this village/town from elsewhere? If yes, give the following particular – A). State/Country B). District C). At the time of migration, was the place of last residence: Rural / Urban D). Reasons for migration E). Duration of stay in this village or town since migration
2011	1). Fill for person born outside this village/town, if within India write the following – birth place, village/town, district, state and if outside India then write the present name of the country 2). Migration characteristics 3). Reason for migration 4). Duration of stay in this village/town since migration

Source: Census of India, Office of Registrar General and Census Commissioner

The District Census Handbook (DCHB), an integral component of the Census, serves as a comprehensive repository of detailed information about districts, encompassing vital aspects such as demography, the workforce, essential amenities, educational institutions, medical facilities, and more. Concurrently, various government departments require statistical data for their respective purposes, leading to the release of data by entities such as the National Sample Survey Organization (NSSO) and the Periodic Labor Force Survey (PLFS). A notable distinction lies in the fact that while NSSO and PLFS operate on samples, the Census and DCHB strive to enumerate every individual.

The National Sample Survey (NSS) and the Periodic Labor Force Survey (PLFS) have been integral endeavors in India's statistical landscape since their initiation in 1950. Operating under the aegis of the Ministry of Statistics and Program Implementation, these surveys were conceptualized to gather socio-economic data, including insights into the labor force and industries. Additionally, they encompass the crucial aspect of crop prices, contributing to the maintenance of price equilibrium in both rural and urban domains. A significant development occurred in 2017 when a separate study, namely the PLFS, exclusively focused on the labor force, was launched. The overarching goal of both NSS and PLFS is to facilitate informed planning, policy formulation, decision-making, and provide valuable resources for academicians, researchers, and scholars in various fields (table. 2).

Table 2: Detailed questions on migration in PLFS schedule of 2020-2021.

PLFS (Year)	Questions/Criteria
2020-2021	1. Age 2. Whether present place of enumeration differs from last usual place of residence 3. Whether moved to the present place of enumeration after march 2020 4. Whether the present place of enumeration was usual place of residence any time in the past 5. Location of the last usual place of residence (mention state as well) 6. Reasons for migration- a). New/ better Job opportunities b). Loss of job/closure of unit c). Migration of parent/earning member of the family d). To pursue studies. e). Marriage f). Natural disaster g). Social/political issues h). Displacement by development project i). Health related reasons

	k). Acquisition of own house/flat l). Housing problems m). Post-retirement n). Others 7. Whether intends to move out from the present place of enumeration 8. Usual Principal activity status of the household members before leaving the last usual place of residence. 9. Occupation group

Source: PLFS, report on Migration in India, 2020-21

The National Family Health Survey (NFHS) serves as a valuable source of health-related data, offering insights into male, female, and child health indicators. Despite being sample-based, NFHS remains a prominent and influential data source, playing a crucial role in health policy formulation.

The India Human Development Survey (IHDS) is a collaborative effort involving scholars from various institutes, including the University of Maryland, National Council of Applied Economic Research, Indiana University, and the University of Michigan. IHDS is known for its regular publications on diverse topics such as health, women's issues, children, and occupational data. The survey has also ventured into the field of migration research, embarking on this journey since 2005 (table.3).

To gain a comprehensive understanding of the available data sources and their respective strengths, a comparative analysis of these sources on various parameters is presented in the following table.4.

Table 3: Detailed questions used in various IHDS survey

Year	**Questions**
2005	1. How many years ago did your family first come to this village/town/city? If more than 90 years = “forever” If less than 90 years = write the count of the years 2.From where did the family come? a). Same state b). Another state c). Another country (including Pakistan/Bangladesh) 3. Was this another village/town/city a). Same b). another village c). another town d). another large city 4. Number of non - resident family member a). Gender b). Age c). Marital status d). State of residence

	e). No. of years outside f). Occupation g). Money (no/sent/received) h). How much money sent/received by the non-resident member in past 12 months. i). Husband/Wife/Parents/Student 5. Do any people come to this village from outside to work during the year? Where do people mostly come from for work? 6. Do any people leave the village to find seasonal work during the year? How many people leave during a usual year? What type of work they do who leave the village?
2011-12 (Panel data)	Same questions as were in IHDS 1

Source: Schedule of IHDS1 and IHDS 2

Table 4: Comparison among the data sources that deal with migration

Criteria	**Census**	**DCHB**	**IHDS**	**NSS**	**PLFS**
1.When it started	1881	1951	2005	1950	2017
2.Focus on	Population	Population	Health, women	Socio-economic aspects, crop statistics	Labor force
3.Place of birth	Yes	Yes	Yes		Yes
4.How to count	1.Place of birth 2.Place of last residence	Same as Census	Each member even they split or got married		
5.Whom to count based on stay out of the origin place	0-9 years of stay	NA	Does not consider. stay less than 6 months as long-term migration		6 months or more than 6 months
5.Universe	Total	Total	Sample	Sample	Sample
6. Unit of Data collection	National > State>District	State>District	India>State> District>Village	Internal migration	Villages>blocks

7. Reasons for migration	1.Job/Employment 2.Business 3.Marriage 4.Education 5.Others	-NA	1. Marriage 2. Work/Job 3. Education 4.Join family 5. Others		14 reasons have noted

Source: official schedules of the respective data source

In pursuit of fulfilling the second and third research objectives, a pilot study was conducted using a snowball sampling approach, targeting experts, professors, and students specializing in the field of migration. This approach involved telephonic interviews with experts (10 samples) and surveys administered to students (47 samples), utilizing identical sets of questions.

The survey encompassed diverse inquiries designed to gauge multiple aspects:

- Awareness of Existing Data Sources: To discern the level of familiarity with current data sources, given that a recurring pattern in the literature indicated limited utilization of such sources.
- Accessibility and Data Regularity: In light of the common challenges identified in relevant studies, this facet was explored, acknowledging the issues pertaining to data accessibility and consistency.
- Need for Additional Questions in Existing Schedules: Recognizing the expanding dimensions of migration, there arises an exigency to introduce supplementary questions within the existing data sources.
- Challenges Encountered in Migration Studies: Migration's interdisciplinary nature and inherent complexity make it a challenging subject to capture comprehensively. Therefore, the study aimed to identify and catalogue the common challenges encountered by researchers in this domain.

These parameters collectively informed the research by shedding light on the awareness, accessibility, and utility of existing data sources, as well as the evolving needs in the field of migration research and the challenges confronted by scholars and practitioners.

Table 5: Awareness about the migration related data among experts and students

Data source	Teachers/Experts (%)	Students (%)
Census	100	92.9
NSS/PLFS	100	64.3
IHDS	0	64
DCHB	20	35.7
Other govt & NGO’s report	0	42.9

Table 6: Accessibility and regularity of the available migration data for experts and students.

Available of Migration Data	Accessibility (%)		Regularity (%)	
	Yes	No	Yes	No
Experts	50	50	24.3	75.7
Student	14.3	85.7	21.4	78.6

Table 7: Need for more question to be added in the schedule.

Need to add more questions	Yes (%)	No (%)
Experts	100	-
Students	42.9	57.1

Table 8: Issues related to accessing data and migration related studies

Issues	Experts (%)	Students (%)
Financial problem	50	53.8
Difficulty in tracing the migrants	50	76.9
Cooperation by migrants	0	69.2
Socio-cultural problems	50	76.9
Secondary data availability	100	53.8
Range of information carried by the data	50	61.5

Being recognized as the largest data source in India, there remain untapped opportunities to broaden the scope of migration data and enhance its significance. Historically, the response to significant events and crises has been largely reactive, with necessary measures taken only post facto. Recent years have borne witness to various forms of migration, such as the cases of Syria, Iran, and, most notably, the far-reaching impacts of the COVID-19 pandemic. The latter event, which reverberated throughout the nation, is poised to leave a profound imprint on the upcoming Census.

While literature underscores the greater importance of internal migration compared to international migration, the latter typically garners more visibility. This underscores the critical need for detailed, micro-level data to decode the trends, patterns, and underlying causes of migration. The challenge with micro-level data, particularly within the framework of Census, is that although district-level data is available, it often lacks granular insights into the specific reasons behind migration. District Census Handbook (DCHB), a publication of Census, is a valuable resource, offering comprehensive data on various aspects, including facilities, education, healthcare, land use, and electricity, in each Indian district. Additionally, India conducts the National Sample Survey (NSS), which focuses on socio-economic aspects, rural-urban crop prices, and internal migration. A recent development is the Periodic Labor Force Survey (PLFS), concentrating on the labor force, its working conditions, needs, and sectors. The emphasis on labor conditions is particularly pertinent, as the pursuit of employment remains a primary driver of migration. The private sector has also made significant contributions to the field, with the India Human Development Survey (IHDS) serving as an exemplary initiative led by scholars and institutes. IHDS delves into various aspects of population studies, including women, children, and, notably, migration. Given the pivotal role of women in nearly half of all migration in India, the study pays special attention to the implications of marriage-induced female migration.

The 21st century has witnessed accelerated global development, unleashing new challenges and dimensions for researchers to explore and address. However, migration data sources, including Census, DCHB, NSS/PLFS, and IHDS in India, often suffer from a lack of awareness. Experts predominantly favor Census and PLFS as the most reliable sources, while students also cite IHDS and NGO reports. It is imperative to acquire awareness and knowledge about international data sources, such as the International Organization for Migration (IOM), UNSTATS, and PASSPORT, which, while valuable, prove to be insufficient in isolation.

Accessibility and regularity of data are recurring issues in migration studies. While experts indicate moderate ease of access, students, by contrast, express significantly more difficulties in obtaining the data. An ongoing survey is crucial, yet a surprising finding indicates that approximately 70% of respondents perceive migration data to be irregular.

As ascertained from the table. Nos. 5, 6, 7 & 8, challenges encountered in the field of migration studies extend beyond data accessibility and regularity. The financial burden of data collection poses a considerable problem, with 53% of students and 52% of experts highlighting monetary constraints. This financial aspect encompasses various elements, including the procurement of secondary data, travel expenses, accommodation near the field of study, and, at times, remuneration for intermediaries facilitating interactions with the study's subjects.

Reaching out to migrants and successfully tracing them present additional hurdles, with 50% of experts and a noteworthy 76% of students acknowledging these challenges. The subsequent step of engaging in productive conversations with migrants necessitates skilled training, impeccable communication abilities, patience, and powers of persuasion. Interestingly, experts appear to face fewer issues with migrant cooperation (69%) than students, possibly attributed to trust and training disparities. Students often struggle to gain the trust of individuals or families, which is essential for them to open up about personal matters.

Effective communication extends beyond language proficiency, encompassing cultural aspects such as attire, grooming, eating habits, and other customs. Migrants are keen observers and these subtleties are noted; therefore, researchers must strive to connect seamlessly with their subjects. The gender dimension looms large in discussions concerning migrant women, who account for a significant portion of all migrations, not just in India, but globally. Research on migrant women necessitates heightened sensitivity at every juncture.

Comprehensive studies demand more than primary data; they require validation through secondary sources and previous works. The availability of secondary data, as previously discussed, varies. Another formidable challenge lies in framing pertinent questions to extract information that is not only relevant but also rich in qualitative insights. Data richness and relevance are fundamental to comprehending the complexities and implications of migration.

4. Suggestions

The following recommendations aim to enhance the existing data sources and their coverage in migration studies. These recommendations, bolstered by the insights from the study, aim to enrich migration data sources and analysis, ultimately contributing to a more comprehensive and nuanced understanding of the intricacies of migration patterns, impacts, and policy requirements.

4.1. Census

1. Include a question that inquiries about the number of times an individual have changed their usual place of residence, especially when it involves moving out of the current district. This would provide insights into the extent of migration experienced by individuals.
2. In support of the previous suggestion, include a follow-up question that captures the names of the place's individuals have previously resided in. This information can be valuable for understanding chain migration patterns and migration corridors.
3. Add a question that assesses how many times an individual has changed their occupation since their first migration. This can help unravel the relationship between career changes and migration experiences.
4. For female respondents, consider managing data on changes in their last residence due to marriage separately. Marital migration is a significant dimension of internal migration that merits distinct analysis.

4.2. NFHS (National Family Health Survey)

5. Introduce a question that distinguishes between local residents and migrants among respondents. If a respondent is identified as a migrant, gather information about their origin place. This additional data can facilitate the tracing of health conditions and the assessment of whether health has improved since migration. Such data can contribute to a more nuanced understanding of health indicators.
6. Justify the inclusion of this migrant status question within NFHS by highlighting its relevance to population studies, particularly in the context of health indicators.

4.3. Additional Observations and Recommendations

7. Consider the possibility of conducting a separate dedicated survey or report along with the general census focused exclusively on migration. Such a comprehensive approach can provide more in-depth insights into the multifaceted aspects of

migration, alleviating some of the limitations posed by existing general-purpose surveys.

8. Recognize the need for policy development specifically addressing migration. The complexity and dynamic nature of migration warrant a policy framework that can adapt to changing migration patterns, providing support and guidance to policymakers, researchers, and other stakeholders.

5. Conclusion

In summary, the increasing global demand for data, transcending various fields, underscores the vital role of comprehensive data collection in migration studies. The impact of migration on demographic dynamics and related aspects necessitates a thorough understanding of this phenomenon. To this end, this study has scrutinized existing data sources in India, assigning significant weight to the exhaustive Census data. However, migration extends beyond international borders and encompasses internal movements within states and districts, which demand microlevel data. While Census and District Census Handbook (DCHB) address these aspects, their decennial data collection cycle hinders real-time responses. The evolving field of migration research presents a host of complexities, ranging from financial constraints to socio-cultural nuances, linguistic barriers, gender-specific dimensions, trust issues, and data quality. Expert opinions and the feedback of students, integral to this research, have contributed to essential suggestions for enhancing current knowledge sources. By acknowledging these gaps and actively striving to fill them, we seek to better equip ourselves to explore migration studies comprehensively and effectively in an ever-evolving global landscape.

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Mapping The Vegetation Dynamics in the Coastal Region of Cauvery Delta Using Remote Sensing Time Series Data

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Abstract

Wetland vegetation's seasonal fluctuations display dynamic patterns that are driven by elements like temperature, the availability of water, and nutrient levels. With implications for conservation and management, these changes have an impact on species composition, biomass, and overall ecosystem function. Seasonal change and the alternation of the vegetation may display a positive or negative trend, which depends upon seasonal changes in environmental factors and the coastal processes. In this study, we utilized open-source multispectral Sentinel-2 data grouped for four seasons (Winter – Jan to Feb; Summer – Mar to May; Southwest Monsoon – June to Sept; and Northeast Monsoon – Oct to Dec) for each year from 2017 to 2022 understand the inter-annual and intra-annual vegetation dynamics. The remote sensing time series data are processed in Google Earth Engine, a cloud-based platform, to gather information for geographical research and visualization. Normalized Difference Vegetation Index (NDVI) was calculated and extracted for each season/year. Sens slope Q statistics have been calculated for time series data to understand the negative/positive trend. Seasonal dependencies can be shown in the NDVI time-series analysis of the study area, with positive trends during the northeast monsoon and negative trends throughout southeast monsoon. The study results show NDVI Sen’s slope, 2017 southwest monsoon have shown the high value of 249.069 and the NDVI 2022 gave the low value of 113.1977 during the summer. For all years, northeast monsoon season NDVI shows that the vegetation cover has been rising with Q value 10.874 and on the other hand southwest monsoon season shows an extensive decrease in vegetation cover and indicating negative trend over time in between 2017 and 2022.

Keywords: Wetland vegetation, Vegetation Indices, Sentinel-2, Google Earth Engine, Remote Sensing Time Series.

1. Introduction

The coastal wetlands are playing a crucial role in our earth. In a wetland the species diversity and ecological process have very divergent and unique characteristics resemble to other habitats. They perform an fundamental function in carbon reduction (energy fixation), Nutrient assimilation, Geochemical cycling, Water storage, Sediment stabilization, and as a nursery habitat for fish and invertebrate (Hardisky et al., 1986). In the present day many factors are causes the degradation of coastal wetland habitat it include, expanded urbanization, population growth, and environmental degradation, etc. coastal wetlands worldwide are confronted with many challenges, wetland loss and degradation have become a global issue (Liang et al., 2020). Wetlands are a great source of global biodiversity within the major climatic belts due to the evolved collection of animals and plants (Alam, 2014). Wetlands are rich in both aquatic and marine species, a wide variety of species live in wetlands. Birds, Mammals, Crabs, Mollusks, Reptiles, Amphibians and, of course, wetlands are home to many types of fishes (World Wildlife Fund, n.d.). The types of flora communities include: Mangrove, Mangrove associates (plants that occur in the coastal environment and are also found within mangrove), Sea grasses, Marine algae (includes phytoplankton and sea weeds), Bacteria, Fungi, Actinomycetes, and Lichens (*Biodiversity watch*, n.d.). Coastal wetland ecosystems are known to be major carbon sinks and belong to main focal areas of global climate change (Gedan et al., 2011). In coastal wetlands which includes coastal vegetation (e.g., cropland, saltmarshes, and mangrove forest), tidal flats, and year-long water, are essential and necessary for future coastal sustainability (Liang et al., 2020). Mangroves are one of the most dominant wide varieties of plant species in coastal wetlands. Natural variations often drive the primary productivity of plant and regulate the presence of terrestrial and aquatic species (Ward et al., 2014). Vegetation is important in stabilizing shorelines from erosion and mitigating the impacts of flooding events especially mangroves (US EPA, 2014). Many complex processes are influencing and controlling the changes that occur on vegetation distinctiveness in a wetland, one of the most predominant processes is surface water inundation. In wetlands the water inundation frequency fluctuates from season to season, therefore coastal wetlands are highly characterized by the seasonal inundation patterns. Accordingly with the seasonal change in the water level alternate the vegetation cover, the alternation of the vegetation may go positive trend or negative trend, it depends upon season or the coastal processes. In fact, in coastal wetlands the relationships between vegetation cover and water level are quite predictable (Wei & Chow-Fraser, 2005). The landscape and the structure of the wetland region is characterized by the process involved in that area by time, also it influences by anthropogenic activity occurs in the area and structure of the local food web and overall biological diversity.

In the present scenario, wide opportunities provided by remote sensing techniques made it easier to carry out all the types of measurements related to hydrological processes. Environmental applications of remote sensing (RS) are living a “Golden era” due to unprecedented data availability and technological capabilities, that enable the assessment of ecosystem dynamics (e.g., land cover change) at broad scales and with high level of detail (van re1es et al, 2021). High spatial resolution provided by Sentinel-2 and Landsat -8 imagery makes the data collection useful for monitoring changes to the wetland landscape. Numerous classification methodologies have been applied to convert remote sensing data into maps that discriminate land classes and surface water inundated areas. A common, relatively simple method is to apply thresholds to remote sensing indices (Brakenridge & Anderson, 2006) In contrast to land classes that are commonly mapped with satellite data, the complex and dynamic interplay between soil, water, and vegetation in wetland ecosystems results in unique land class features with various surface water inundated regimes (Gallant, 2015). The surface water dynamics influences on distribution of wetland vegetation were analyzed in this study based on collection of satellite imageries, those imageries are analyzed by vegetation indices like NDVI. On this onset, to understand the spatio-temporal variation in the vegetation phenology of the coastal regions of Cauvery delta, the following objectives were framed.

- To map the vegetation cover from the remote sensing indices.
- To perform trend analysis on vegetation indices to analysis dynamics.

2. Study Area

Muthupet mangrove forest is located at the southern end of the Cauvery delta on the east coast of India, located at 10°20′N and 79°32′E of South India. Muthupet mangroves relates to the Bay of Bengal in the north and the Gulf of Mannar and the Indian Ocean in the south. Muthupet and nearby villages are traversed by the rivers Paminiyar, Koraiyar, Kilaithankiyar, Marakkakoraiyar, and other tributaries of the Cauvery. Before the rivers meet the sea, they form a lagoon. 68.03 km2 total make up the Muthupet wetland system (Janaki-Raman et al., 2007). The study area has a medium tropical transitional bio-climate, defined by average monthly temperatures over 27°C. The total annual rainfall varies from 1,000 to 1,500 mm. The average humidity of the area is 75 % (Natesan et al., 2014).

A substantial mangrove community lines the lagoon's western and northern borders. Muddy silty terrain devoid of mangroves lines the lagoon's northern and western boundaries. These mangroves are true mangroves. The two dominating species are *Avicennia marina* and *Excoecaria agallocha*, with *Rhizophora* present in a few spots (Natesan et al., 2014). These mangrove forests belong to one of India's most extended mangrove areas and are characterized by semi-diurnal macro-tides., they adapted in coastal region. Beyond Muthupet Lagoon, the mangroves are scattered along the beach. The aim of the study is to condition of wetland vegetation. Because of these reason, Muthupet lagoon area taken is very much apt for this study.

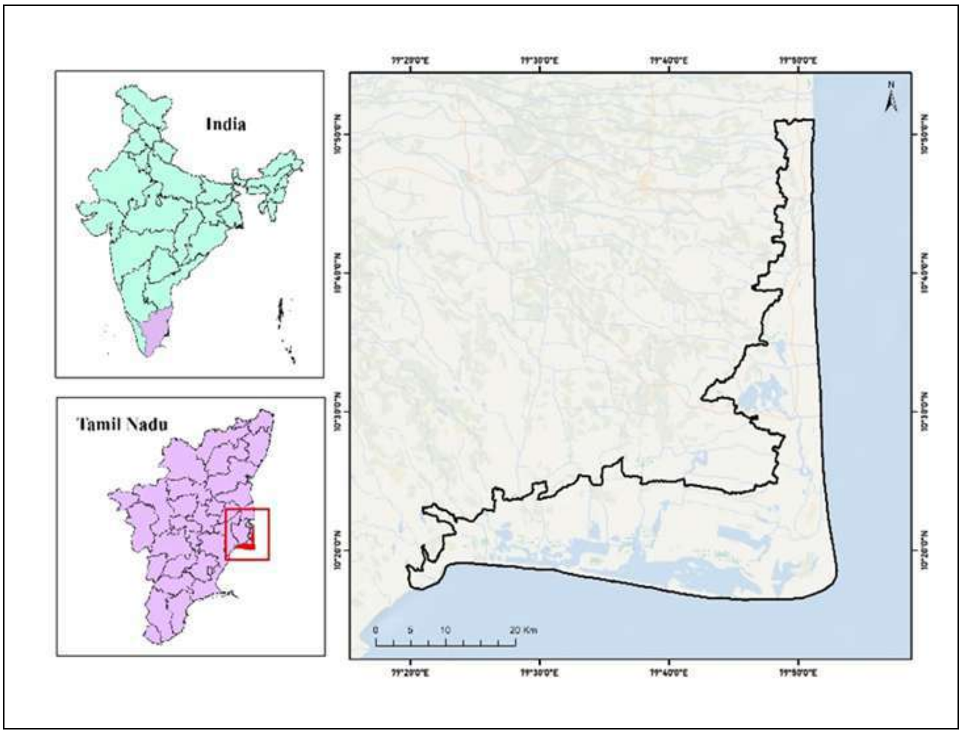


Fig. 1: Study area map

3. Materials and Methods

The Google Earth engine is used to collect data from Sentinel-2 imageries. A cloud-based platform Google Earth Engine (GEE) enables users to access and analyses an enormous quantity of geospatial data. For doing geospatial analysis and developing visualizations. Normalized Differenced Index: Commonly in the red and near-infrared (NIR) sections of the electromagnetic spectrum, are used to determine NDVI. Higher NDVI values denote denser and healthier vegetation. NDVI values range from -1 to 1. Negative numbers denote areas with water or other non-vegetated surfaces, whereas a value of 0 denotes an area with no vegetation.

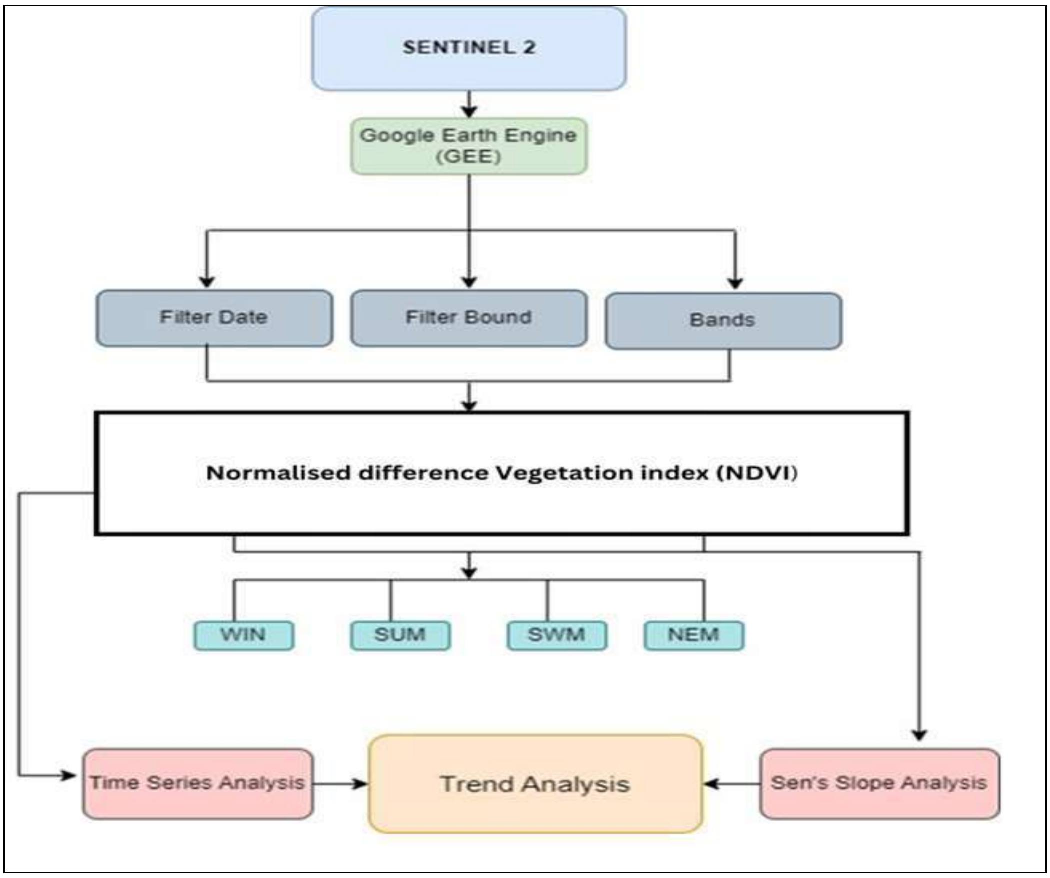


Fig. 2: Methodology flowchart

Downloading the satellite data of these indices I gave filter date, according to the Indian Meteorological Department, there are four seasons: Winter (January to February), summer (March to May), Southwest Monsoon (June to September), and North East Monsoon (October to December). Six years in total are chosen. The download of the data spans the years 2017 through 2022. And the filter bound for all the indices is in the study area. The bands selected for Normalized Difference Vegetation Index are Band 4 (Red) and Band 8 (IR). Two trend analyses were analyzed for Normalized Difference Vegetation Index that are Sen's slope analysis and Time series analysis.

The methodology involves calculating the median of all possible pairwise slopes between observations, which provides a robust estimate of the trend in the data. The Sen's slope is defined as the difference between the median of all slopes and the midpoint of the data series. If the Sen's slope is positive, there is an increasing trend in the data over time, while a negative Sen's slope indicates a decreasing trend. A Sen's slope of zero indicates no trend. I employed time series analysis, a statistical method for analyzing and interpreting data over time.

4. Results and Discussion

4.1 Sen's Slope Analysis NDVI (Seasons)

Table 1: Sen's slope for NDVI (year wise for every season)

YEAR	WIN	SUM	SWM	NEM	Q
2017	193.5296	143.6136	249.069	234.711	20.748
2018	288.7466	159.0683	135.8676	188.445	-28.317
2019	193.6245	92.06107	123.0495	278.7231	29.677
2020	262.6716	133.9476	171.5101	267.3336	19.558
2021	201.2891	140.962	155.818	301.5456	24.137
2022	147.811	113.3385	133.1977	171.6643	13.905

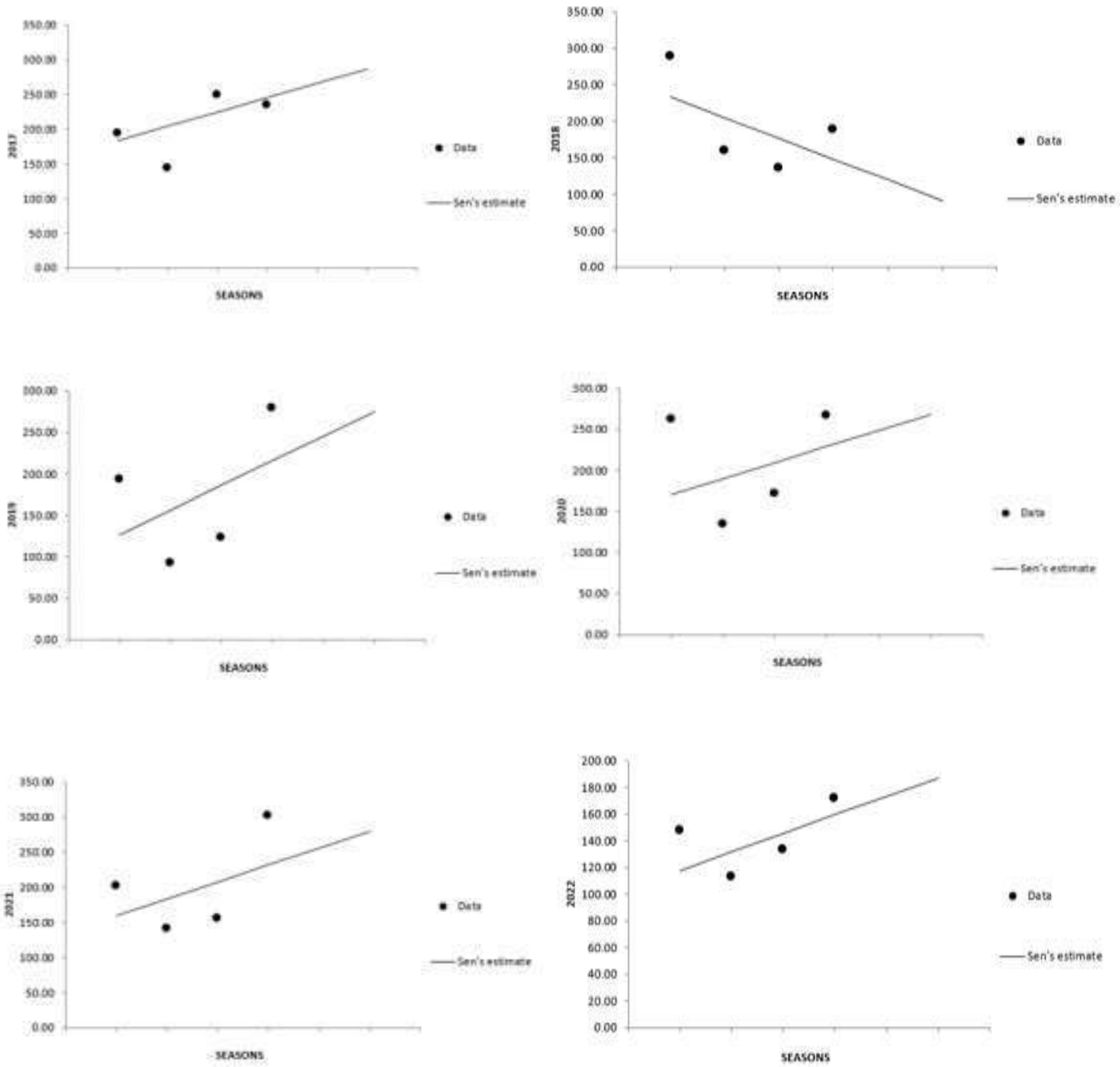


Fig. 3: Sen's slope 2017, Sen's slope 2018, Sen's slope 2019, Sen's slope 2020, Sen's slope 2021, Sen's slope 2022

Sen's slope estimation was used to determine the seasonal change in NDVI of the vegetation from 2017 to 2022 data. Calculations were made for Sen's slope estimation are Trend statistics, Q value, and significance test. Sen's Slope is a nonparametric test initially proposed by Sen PK Estimates of the Regression Coefficient Based on Kendall's tau. The Q is positive it represents an increasing trend, while a negative sign denotes decreasing trend over time. The slope or steepness indicates the value or magnitude of the trend.

4.1.1 NDVI Sen's slope 2017

The NDVI Sen's slope for 2017 all seasons indicates a generally positive trend. Therefore, it indicates the vegetation is increasing. Q is equal to 20.748, a weak decrease in vegetation is seen for 2017 summer season. Positive trend tendencies are present in the winter, southwest monsoon, and northeast seasons. 2017, there is no significant trend observed. Comparing to all other season’s southwest monsoon season have highest NDVI value.

4.1.2 NDVI Sen's slope 2018

The overall slope trend of all seasons in 2018 is negative, and seasonally appropriate vegetation is gradually dwindling. Q value is equal to -28.317. The winter season slightly increased compared to the summer, southwest monsoon, and northeast monsoon seasons in 2018. The Southwest monsoon season is having lowest NDVI value. Generally, the magnitude of the slope is decreasing drastically.

4.1.3 NDVI Sen's slope 2019

The slope trend throughout the entire season is favorable in 2019. When the seasons in 2019 are compared, the NDVI value for the summer and south-west monsoon seasons is significantly lower. However, the NDVI value for the winter and northeast monsoon seasons increased significantly. When comparing the seasons' lowered NDVI values further, the summer season has the lowest NDVI value, which denotes a very low rate of vegetation. The northeast monsoon season has the highest NDVI value compared to other seasons, which implies a high rate of vegetation. Since the Q value is 29.677, the trend's overall magnitude is increasing.

4.1.4 NDVI Sen's slope 2020

Sen's slope's overall trend is positive in 2020. With a Q value of 19.558, the vegetation is rising. The winter season and northeast monsoon seasons have the highest NDVI value, while summer season and southwest monsoon seasons have the lowest. As a result, throughout the winter and northeast monsoon season, there is an increase in vegetation. Additionally, throughout the summer and southwest monsoon seasons, the vegetation declines. The summer season in 2020 had the very lowest rate of vegetation growth, according to the analysis. The positive trend's magnitude is shown by the trend's steepness.

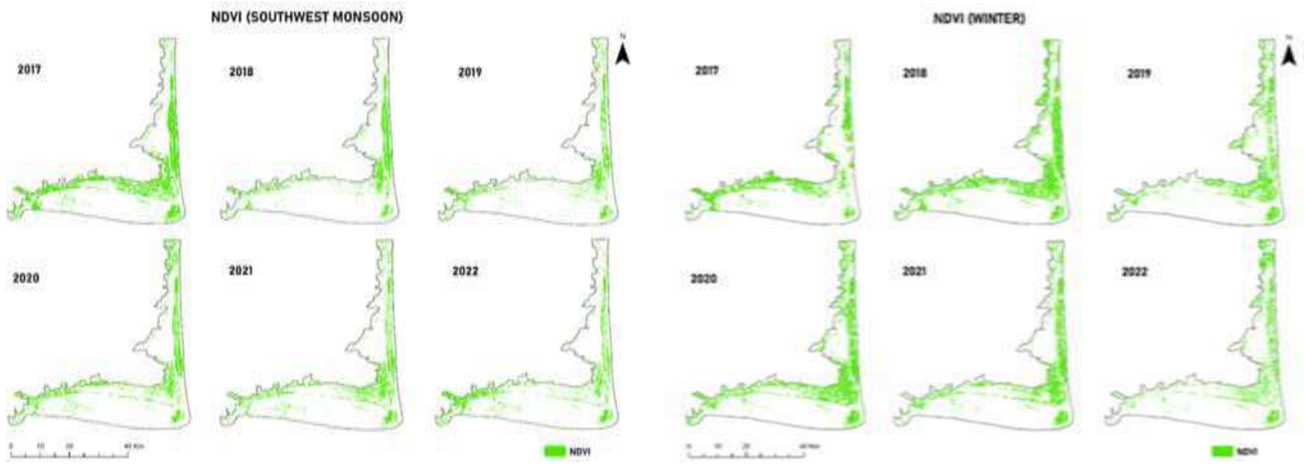
4.1.5 NDVI Sen's slope 2021

All seasons in 2021 the trend line shows positive with Q value of 24.137. In 2021 the Q value is positive it represents an increasing trend. Therefore, the overall vegetation growth is high. Comparing the vegetation variation in between the each seasons the northeast monsoon season the vegetation increased drastically. And all other seasons are normally distributed, there is no much variation observed in winter season, summer season and southwest monsoon season. In 2021 the overall magnitude of the trend line steepness is positive in 2022 the slope trend throughout the entire season is positive.

4.1.6 NDVI Sen's slope 2022

In 2022 the northeast monsoon season has the highest NDVI value which indicates this season is having the high vegetation rate. All other seasons have not much fluctuation in their NDVI value. The Q value is 13.905.the overall vegetation is high, and the magnitude of the trend line slope is positive.

Table 2: Sen’s slope for NDVI (season wise for every year)



YEARS	2017	2018	2019	2020	2021	2022	Q
WIN	193.5296	288.7466	193.6245	262.6716	201.2891	147.811	-13.037
SUM	143.6136	159.0683	92.06107	133.9476	140.962	113.3385	-6.035
SWM	249.069	135.8676	123.0495	171.5101	155.818	133.1977	-15.692
NEM	234.711	188.445	278.7231	267.3336	301.5456	171.6643	10.874

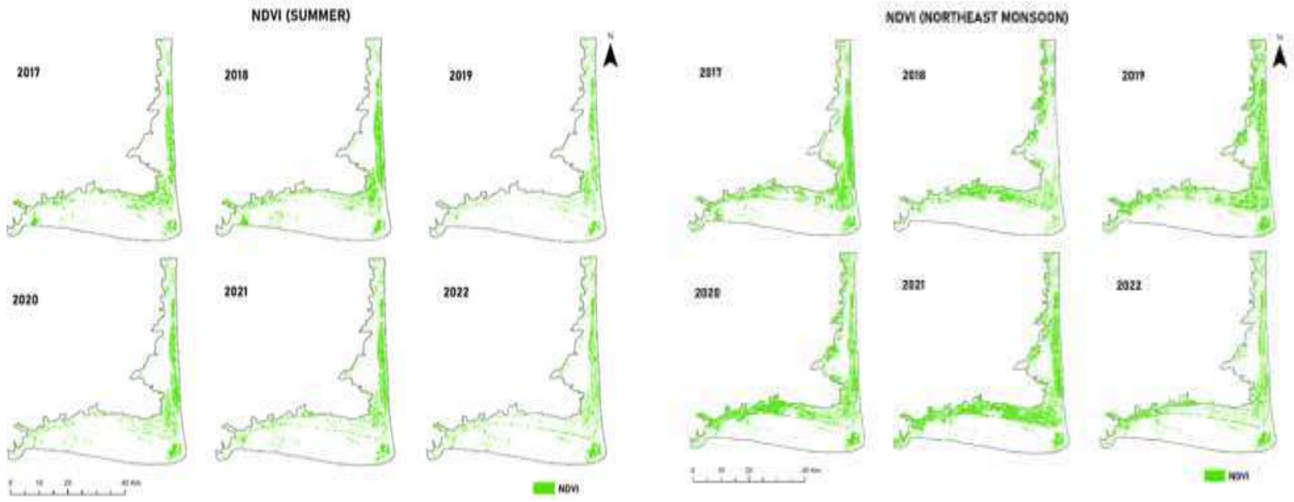
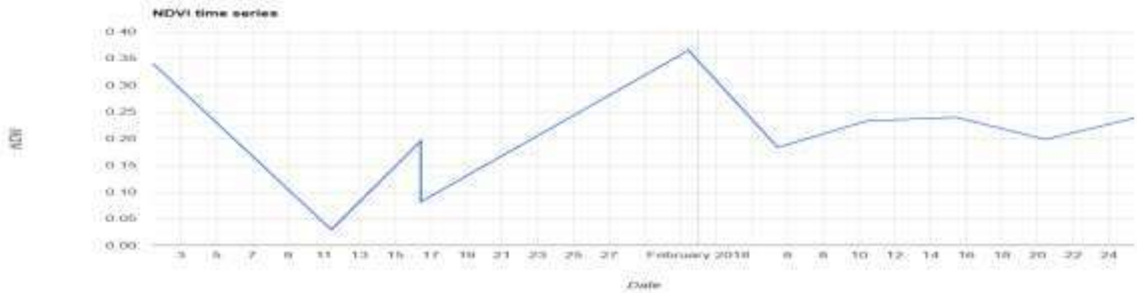
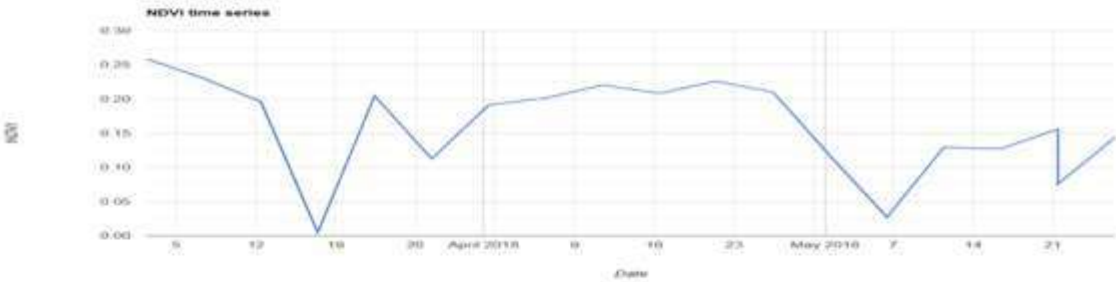
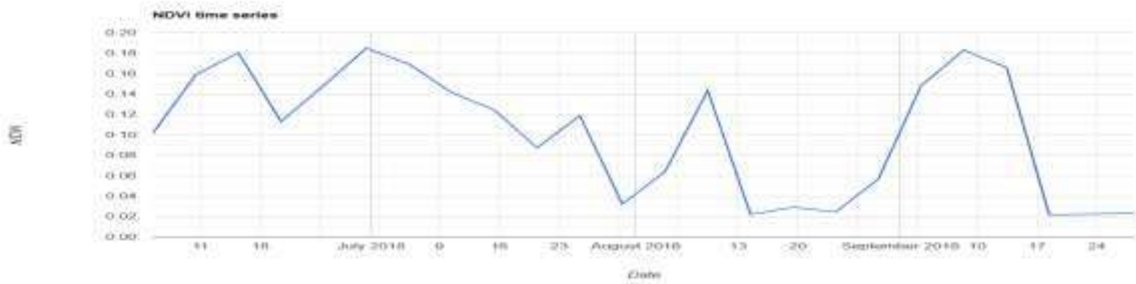


Fig. 4: NDVI for Southwest monsoon, Winter, Summer, and Northeast monsoon

4.2 Time Series Analysis of NDVI 2018







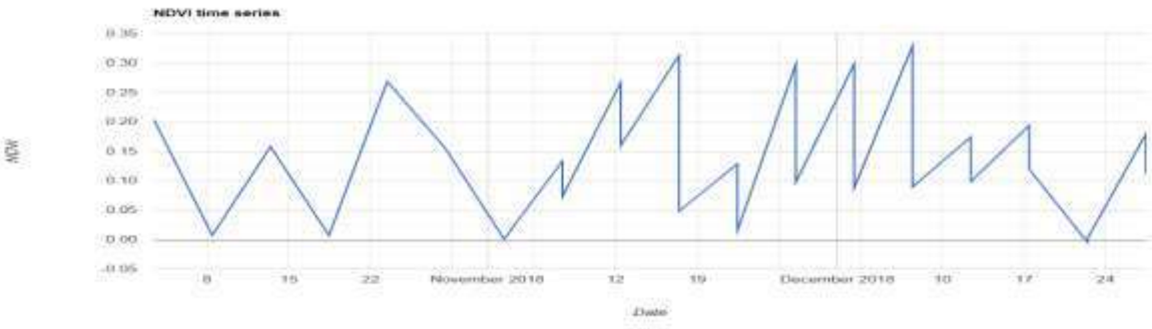


Fig. 5: Time series NDVI 2018 winter season, Time series NDVI 2018 summer season , Time series NDVI 2018southwest monsoon season and Time series NDVI 2018 northeast monsoon season

4.2.1 Time series analysis NDVI winter season

In the first week of January during the winter season, the trend line fell. Later, it reached a minor high in the middle of January, and then the NDVI time series trend line progressively grew in the final days of January, resulting in two peaks occurring in the first month of the winter season. The graph indicates that more variation in vegetation occurred in the month of January, even if there was no significant movement in the line at the beginning of February.

4.2.2 Time series analysis NDVI summer season

The trend line for the summer season began to sharply decline in the middle of March, before reaching its peak on the 22nd day of March. The trend line has a very high value but very little fluctuation since April last week. In the first few days of May, the trend substantially dropped, and after that, it changes very little. At the start of June,

4.2.3 Time series analysis NDVI southwest monsoon season

The trend line for the south-west monsoon season is rising positively. It then fell slightly on June 18 before peaking in the final days of the month. The trend line fluctuated somewhat in the month of July before peaking again in the month of August. The NDVI trend line fluctuates up and down throughout the final month of the southwest monsoon season.

4.2.4 Time series analysis NDVI northeast monsoon season

The trend line fluctuations are particularly large in the 2018 northeast monsoon season. As a result, the vegetation changes according to the season. The variations occur in a positive direction. In this season, a sharp decline in the trend line was seen in the final days of the month of November, and then there was a significant amount of fluctuation in the trend line. Thirteen peak lines are recognized over the entire season.

4.3 Time Series Analysis of NDVI 2022

Fig. 6: Time series NDVI 2022 winter season, Time series NDVI 2022 summer season, Time series NDVI 2022 southwest monsoon season and Time series NDVI 2022 northeast monsoon season

4.3.1 Time series analysis of NDVI winter season

In comparison to previous seasons, the trend line of the time series NDVI 2022's winter season fluctuates substantially. The peaks rise but not much. The peak of the winter season in January reduced drastically between January 21 and February 1. Negative decline peak trend is present. Beginning in February there is a small slope and drop in the peak.

4.3.2 Time series analysis of NDVI summer season

The data reveals a sharp fall in the first week of the three summer months of March, April, and May. The unfavorable trend decreased in the first month of the summer season. However, the trend grew with greater swings once it started to decline. As a result, we are able to infer from this data that vegetation decreased throughout the early weeks of each month before increasing and showing variance.

4.3.3 Time series analysis of NDVI southwest monsoon season

Over the period of the southwest monsoon season, the trend line displays a number of undulations with more high and low peaks. During the early half of the southwest monsoon season, the peak is relatively high, indicating that the vegetation is highly dense. This season, there are more peaks that exhibit declining patterns. Increased peaks have a high value, although inclined peaks experience higher fluctuations.

4.3.4 Time series analysis of NDVI northeast monsoon season

The tendency is downward during the northeast monsoon season. After that, from mid-October through December of last year, the trend had irregular peaks with significant variations. Because of this, the vegetation changes throughout the season.

4.4 Discussion

Based on the Normalized Difference Vegetation Index (NDVI) and Sen's slope analysis in 2017, there was a generally positive trend in vegetation growth across all seasons, although this trend was not statistically significant. The southwest monsoon season had the lowest NDVI value of all seasons, indicating that this season is particularly favorable for vegetation growth in this region. However, in 2018, there was a negative trend in vegetation growth, with the overall

NDVI value decreasing across all seasons. This suggests that seasonally appropriate vegetation is gradually dwindling in the region. In 2019, there was a favorable slope trend throughout the entire season, with the winter season having the highest NDVI value and the summer season having a significantly lower value. This suggests that vegetation growth is dependent on the season in this region. In 2020 and 2021, there was a positive trend in vegetation growth across all seasons, indicating that overall vegetation growth is high in the region. The northeast monsoon season showed a drastic increase in vegetation growth in 2021. In 2022, the overall trend in vegetation growth remained positive, with the northeast monsoon season having the highest NDVI value. However, the winter season showed a negative trend across all years, indicating that vegetation cover is decreasing during this season.

5. Conclusion

The analysis of vegetation dynamics using remote sensing time series data in the study area from 2017 to 2022 has provided valuable insights into the changing landscape of this region. The NDVI suggests that vegetation growth in this region is dependent on the season and varies across years and the northeast monsoon season tends to be particularly favorable for vegetation growth, while the winter season shows a negative trend across all years. The northeast monsoon season shows a consistent positive trend in vegetation growth, and overall vegetation growth is high in recent years. While summer had consistently high values, exhibited a negative trend. However, the southwest monsoon season consistently had negative trends, possibly indicating drought conditions while the northeast monsoon season showed positive trends. The time-series analysis of NDVI peaks provides valuable information about the patterns of vegetation growth and health in the studied region, including seasonal and yearly variations. Overall comparing with the indices in Northeast monsoon season NDVI shows that the vegetation cover has been rising, whereas it stands to be drastically declining in 2022. For all years, Southwest monsoon season shows an extensive decrease in vegetation cover. So, these findings emphasise the significant of monitoring and understanding these processes in order to make informed decisions regarding land management, conservation, and sustainable development.

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Interannual And Intra-annual Surface Water Dynamics in Coastal Regions of Cauvery Delta

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Abstract

A wetland is an area of land that has been inundated or saturated with water. Water for a wetland might originate from an adjacent river or lake. Wetlands may also be formed by seawater, especially in high-tide coastal locations. In this study, the seasonal variations in the Coastal delta region wetlands and surrounding areas were examined. Our research examined how much surface water flooded the coastal delta region wetland and its surrounding over a period of six years, from 2017 to 2022 using Modified Normalized Difference Water Index (MNDWI), a multi-spectral index, are computed for six years of data are utilized to identify the Surface Water Inundation. According to the data, the water inundation is at its highest in the Northeast Monsoon among the four seasons and at its lowest in the Southwest Monsoon. In 2017, 2018, 2019, 2020, 2021, and 2022, the seasonal water inundation was also examined. The outcome indicates that there will be more frequent flooding, which indicates that the most flooding will occur in 2021. The Coastal delta region flooding frequency clearly demonstrated the inconsistent temporal and geographical distribution of surface water.

Keywords: Coastal wetlands, Seasonal Water Inundation, Google Earth Engine, Modified Normalized Difference Water Index, Remote Sensing.

1. Introduction

Wetlands are defined as ‘lands transitional between terrestrial and aquatic eco-systems where the water table is usually at or near the surface or the land is covered by shallow water (Prasad et al.,) While many indigenous people and rural population still depends on local wetlands and water their livelihood most if not all nation now recognize wetlands as one of the world’s most valuable natural resources. According to the definition provided by the Ramsar Convention (Ramsar 2013), wetlands are "areas of marsh, fen, peatland, or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish, or salt, including areas of marine water, the depth of which at low tide does not exceed six meters." In our country, there are many different types of wetlands, including salt marshes, tidal flats, swamps, open water bodies, mangroves, and more. Wetland hydrologic regime (e.g., flooded area and flooding duration) has a direct effect on nutrient dynamics at a watershed scale, but it also impacts greenhouse gas emissions and carbon cycles in the wetlands themselves (Pena et al., 2020). Beside their intrinsic value to specially adapted plants and animals, wetlands produce a wealth of environmental services that directly benefit human societies. Wetland conservation is receiving more attention globally, with Millennium Ecosystem 2005 serving as one example and this international work Programme was created to meet the needs of decision-makers and the public for scientific information regarding the effects of changing ecosystems on human well-being and options for responding to those changes. Wetlands have been purchased as nature preserves, sanctuaries, and wildlife management areas, or they have been recognized as being crucial for storing carbon to lessen the impact of human-induced greenhouse gases on atmospheric temperature or as being worldwide significant for water birds.

1.1. Surface Water Inundation

Surface water inundation in coastal wetlands is a natural process that occurs because of tidal fluctuation, storm surges, and river flooding. Coastal wetlands, which include marshes, swamps, and mangroves, provide valuable ecosystem services such as flood control, water filtration and carbon sequestration. Wetlands and other periodically inundated surface water (SW) areas are hot spots of biodiversity play a crucial role in global climatic, hydrologic, and biogeochemical cycles and provide numerous ecosystem services of value to people (Heimhuber et al., 2017). However, human activities such as coastal development and climate change have altered natural hydrological processes and increased the frequency and intensity of surface water inundation in these wetlands. This leads to the loss of wetlands vegetation and wildlife as well as increased vulnerability to storm damage and erosion.

1.2. Role of Remote Sensing in Surface Water Inundation: Remote sensing can be a valuable tool for detecting and monitoring surface water inundation. Here are some of the ways remote sensing can be used in surface water inundation:

Detecting surface water inundation: Remote sensing data can be used to detect the presence and extent of surface water inundation. Satellite images and aerial photographs can be analyzed to identify areas that are flooded, providing important information for disaster response and management.

Mapping flood extent and dynamics: Remote sensing can be used to create maps that show the extent of surface water inundation, as well as the dynamics of floodwaters. This information can be used to plan and prioritize disaster response efforts and allocate resources effectively.

Monitoring flood progression: Remote sensing can be used to monitor the progression of floods over time, including changes in the extent and severity of inundation. This information can help disaster managers to anticipate the spread of flooding and take preemptive measures to protect affected areas and populations.

Assessing flood damage: Remote sensing can be used to evaluate the harm brought on by surface water flooding, such as harm to crops, buildings, and infrastructure. The recovery efforts and resource allocation can be efficiently prioritized using this information.

The Main objectives of this work are:

- To map the Intrannual surface water inundation trend.
- To map interannual surface water inundation and their inundation frequency.

2. Study Area

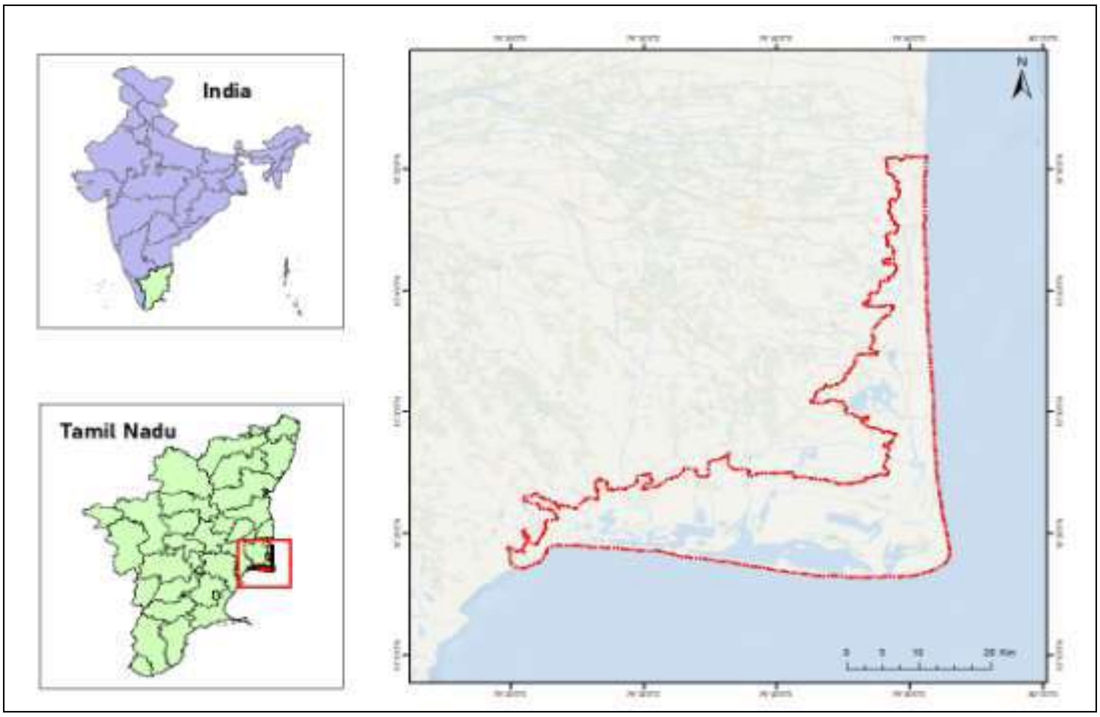

Fig. 1: Study area

3. Materials and Methods

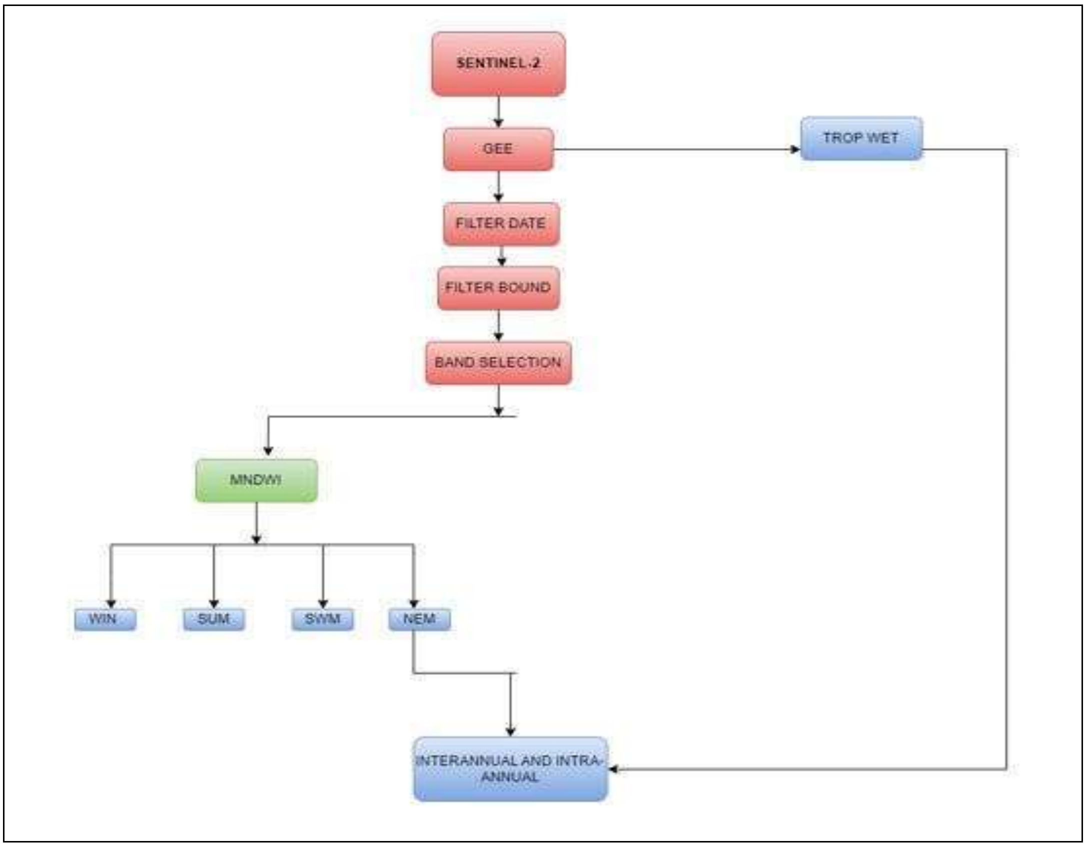

Fig.2: Methodology flowchart

3.1. Data Pre-processing

For this study sentinel 2 data is taken from Google Earth Engine (GEE) and the data like pre-processed data and layer stacked tiff format image will be the output. One major approach was used for the sentinel 2 data, which was acquired from 2017 to 2022 (6 years). There are four seasons in India, according to the Indian Meteorological Department: winter, summer, southwest monsoon, and northeast monsoon. To avoid any errors, the cloud-free image has been taken when downloading the image of the filter date. In this work, MNDWI indices were used to extract water bodies.

3.2. MNDWI- Modified Normalized Difference Water Index

Green and SWIR Bands are used to enhance open water characteristics in the Modified Normalised Difference Water Index (MNDWI). Additionally, it reduced characteristics of urban areas that are frequently associated with open water in indices. Applying MNDWI can enhance open water and improve differentiation within built-up areas and open water features when we are unable to distinguish between built-up areas and such features. In MNDWI index ranges from -1 to 1 wit value close to 0 indicating the absence of water, and value close to -1 indicating the presence of shadow or non-water features. Downloading the data of the MNDWI indices the filter date has been given according to the four season of 2017 to 2022 (6years). The filter bound for these indices of the study area. The bands selected for MNDWI is Band 3 and Band 12.

3.2. TropWet Tool

This tool has improved over existing globally available surface water datasets for mapping the extent of important wetlands. Tool was able to provide frequency inundation maps and able to map flood extent comparable to operational flood risk mapping products. Tropwet Tool also uses information from terrain-based metrics to refine the classification process. It allows for the analysis of wetlands to take place at a temporal and spatial scale that is suitable for informing national and regional scale policies. Tropwet tool can be used to establish seasonal patterns in inundation extent. The performance of Tropwet for mapping open water with this Tool the users are able to make historical assessments of wetland extent and dynamics and provide geographical information to help tackle key environmental and public health challenges (Hardy et al., 2020).

4. Results and Discussion

4.1. MNDWI Interannual and Intra-Annual Dynamics (Season-Wise)

(a) Winter (2017-2022)

The MNDWI value for 2017 was 102 sq.km, indicating a comparatively low amount of water was present throughout the winter months of that year. The MNDWI significantly increased in 2018 to 126.06 sq.km, indicating an increase in the amount of water in the area in the winter. The MNDWI index was 205.63 sq.km in 2022, a modest decline from the previous year, but it was still much higher than the indexes in 2017 and 2019.The data suggests that there has been a significant increase in the presence of water in the region during the winter season from 2017 to 2022, with particularly significant increases observed in 2018, 2020, and 2021. This could be due to various factors such as changes in precipitation patterns or land use practices in the surrounding areas.

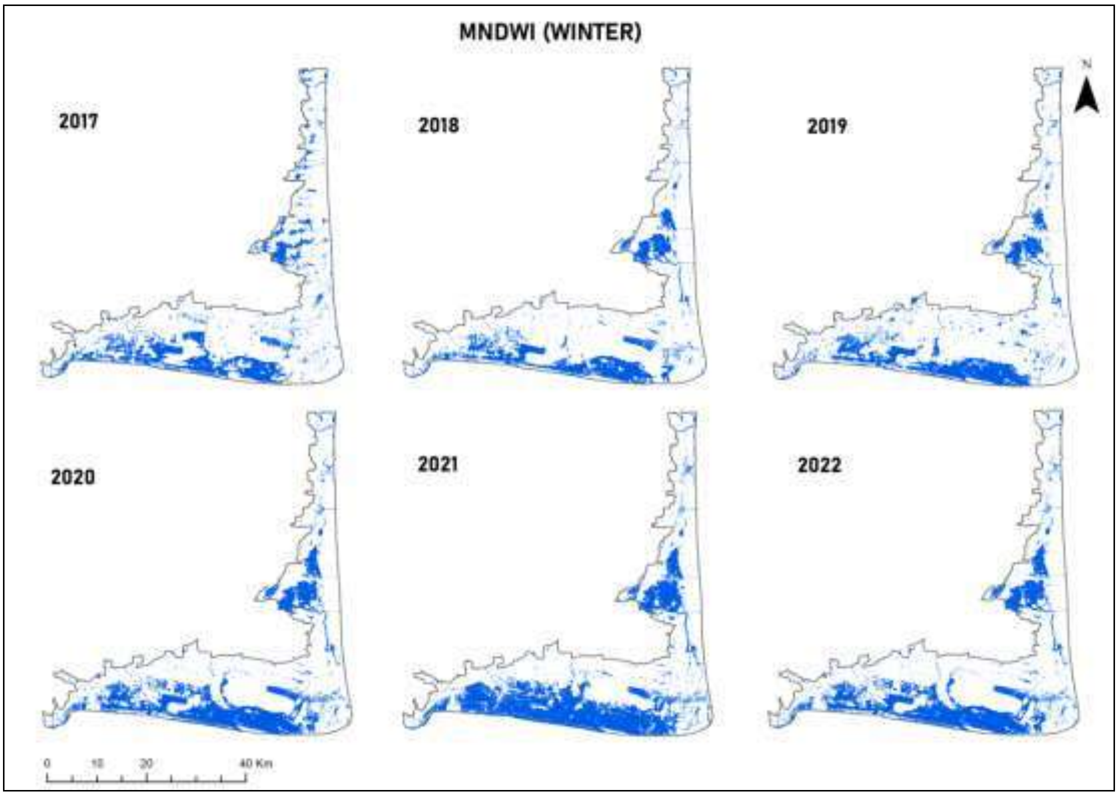

Fig.3: Winter season MNDWI (2017-2022)

(b) Summer (2017-2022)

The MNDWI index for the summer of 2017 was 74.5 sq.km, indicating a low to average presence of water bodies. The MNDWI value for the summer of 2018 was 101.3852, which indicates that there were more water bodies present than in 2017. The MNDWI value for the summer of 2019 was 72.77sq.km, which indicates a decrease in the amount of water bodies compared to the summer of 2018. The MNDWI value for the summer of 2020 was 108.90 sq.km, showing a considerable improvement in the presence of water bodies compared to 2019. The MNDWI value for summer 2021 was 169.48 sq.km, the highest value over the previous six years for the presence of water bodies. The MNDWI value for the summer of 2022 was 175.33 sq.km, which showed a marginal rise around water bodies compared to the previous year. Accordingly, the MNDWI indices showed a general trend of increasing water body presence in the summer from 2017 to 2021, with a little increase in 2022.

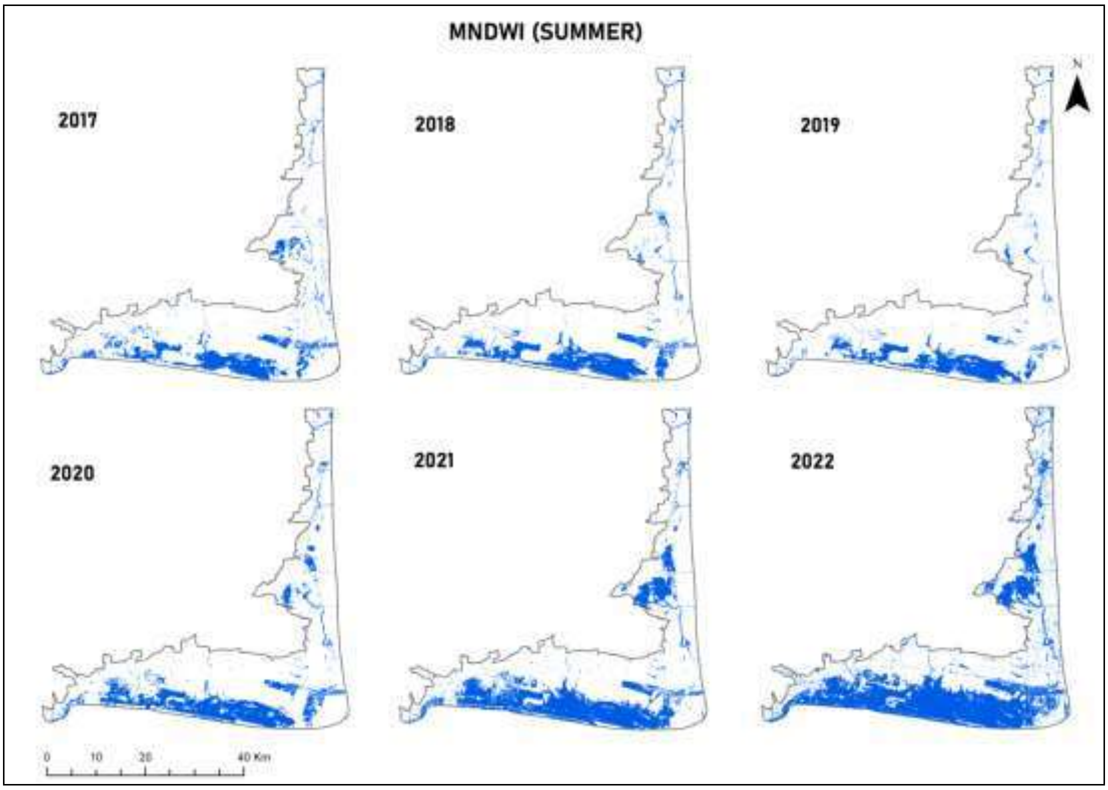

Fig.4: Summer season MNDWI (2017-2022)

(c) Southwest Monsoon (2017-2022)

The MNDWI value for the SWM season of 2017 was 105.63 sq.km, showing the moderate presence of water bodies because of rainfall. The MNDWI index for the 2018 SWM season was 87.49 sq.km, which indicates less water bodies were present than in the previous year. The MNDWI value for the SWM season of 2021 was 185.94 sq.km, which is the highest presence of water bodies during the previous six years. For the SWM season of 2022 was 39.883 sq.km, which showed a considerable decline in the number of water bodies compared to the previous year. According to the MNDWI indices, the SWM season saw an overall rise in surface water inundation from 2017 to 2020, with a minor increase in 2021. However, there was a notable decline in surface water inundation in 2022, which may have been brought on by several variables, including less rainfall, modifications to land use, or climate variability.

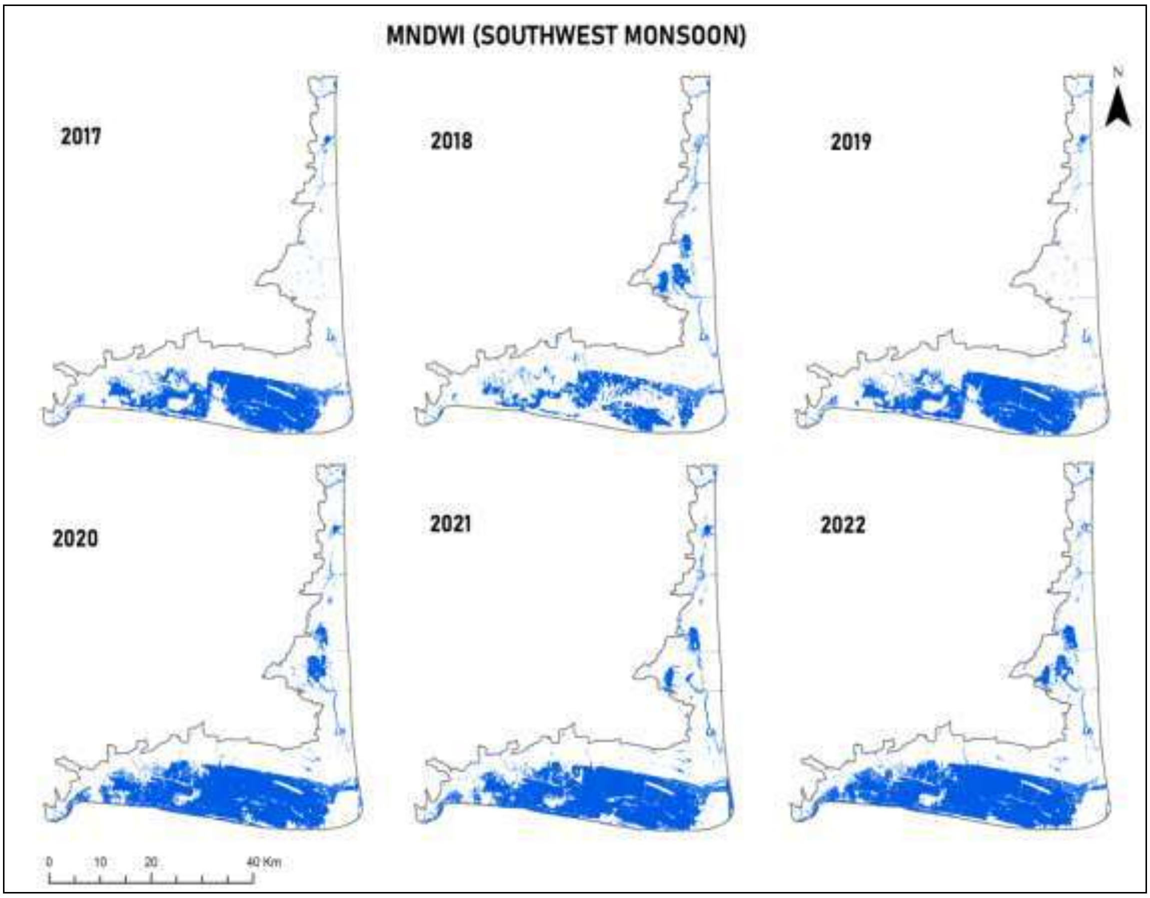

Fig.5: Southwest Monsoon season MNDWI (2017-2022)

(d) Northeast Monsoon (2017-2022)

In NEM the surface water inundation was moderate in 2017 with an area of 305 sq.km. In 2018, the surface water inundation impact reached a high of 318.61sq.km and in 2019 there was a considerable decline in the surface water influence, with a value of 241.25 sq.km. In 2020, the inundation level climbed once more and reached a value of 284.74 sq.km. With an area of 407.46 sq.km, it was increased extremely in 2021 indicating a significant increase in surface water inundation in the region. In 2022, the area under water was 376.97 sq.km, and the MNDWI index value was lower compared to 2021 but still higher than the previous years, indicating a sustained increase in surface water.

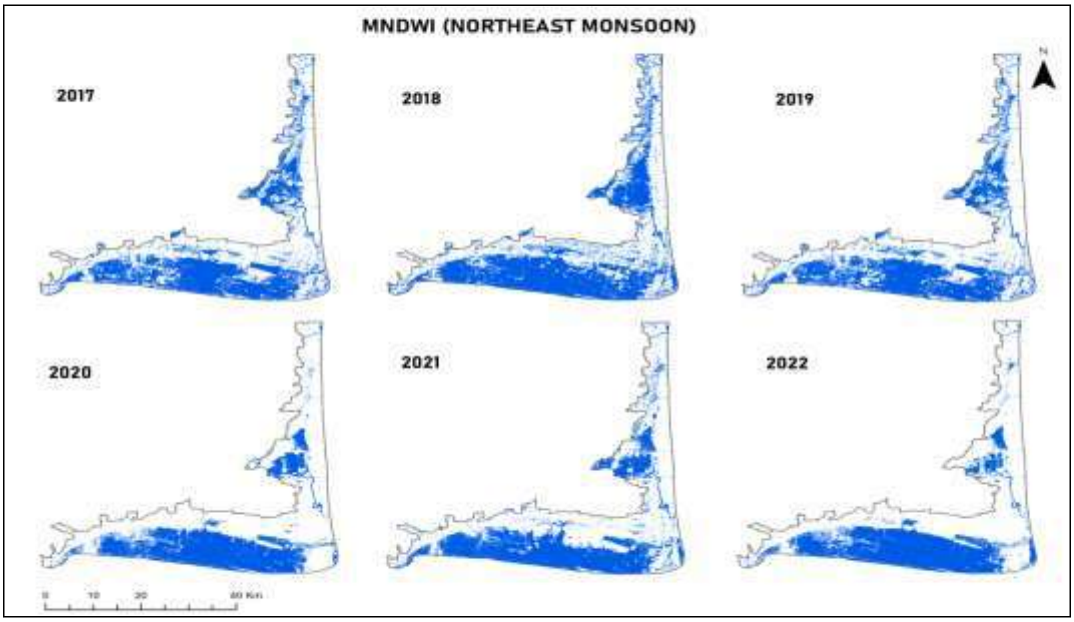

Fig.6: Northeast Monsoon season MNDWI (2017-2022)

4.2. MNDWI (Year-Wise)
(a) 2017

A substantial amount of surface water was present in the area during the winter of 2017, according to the MNDWI index, which was 102 sq.km. The MNDWI index for the summer of 2017 was 74.52 sq.km, which indicates that there was low to moderate surface water present at the time of year. For the 2017 SWM season was 105.63 sq.km, indicating a low level of surface water inundation in the area. The MNDWI value for the 2017 NEM season was 305.65 sq.km, which indicates that surface water inundation was widespread in the area during this season. Surface water inundation was present during the SWM season to a lesser extent than during the NEM season.

(b) 2018

In the year 2018, the highest surface water inundation was observed during the northeast monsoon season, with an MNDWI value of 318.61sq.km. This was followed by the winter season, with an MNDWI value of 126 sq.km. The summer season had the lowest surface water inundation, with an MNDWI value of 101.38 sq.km, while the southwest monsoon season had an MNDWI value of 87.49 sq.km. The data indicate that the northeast monsoon season had the highest water content in the region, while the summer season had the least amount of water.

(c) 2019

In the year 2019, the highest surface water inundation was observed during the northeast monsoon season, with an MNDWI value of 241.25 sq.km. This suggests that the northeast monsoon season had the highest area with water in the region. The southwest monsoon season also had a relatively high level of surface water inundation, with an MNDWI value of

150.7 sq.km. Overall, the statistics indicate that the region's water occurrence was highest during the northeast monsoon and lowest during the southwest monsoon seasons and the surface water inundation over the winter was mild.

(d) 2020

The northeast monsoon season in the year 2020 saw the maximum surface water inundation, with an MNDWI value of 284.74 sq.km. This shows that the northeast monsoon season in the area had the highest water occurrence. With an MNDWI value of 179.62 sq.km, the winter season also experienced a comparatively high surface water inundation. The MNDWI value during the southwest monsoon season was 181.31 sq.km, which is approximately the winter figure. With an MNDWI value of 108.90 sq.km, the summer season experienced the least amount of surface water inundation. According to the data, the winter and northeast monsoon seasons in the area had the most water content, while the summer had the least.

(e) 2021

With an MNDWI outcome of 407.46 sq.km, the northeast monsoon season in 2021 saw the highest surface water inundation. This indicates that the northeast monsoon season in the area had the highest water occurrence. Surface water inundation over the winter reached another reasonably high level. A lower MNDWI value than the winter season, 185.94 sq.km, was recorded for the southwest monsoon season. With an MNDWI value of 169.48 sq.km, the summer season experienced the least amount of surface water inundation.

(f) 2022

The maximum surface water inundation in 2021 was reported during the northeast monsoon season, with an MNDWI value of 407.46 sq.km. This indicates that the northeast monsoon season had the maximum water content in the region. The winter season also saw a rather high amount of surface water inundation, with an MNDWI value of 215.96 sq.km. The southwest monsoon season had an MNDWI value of 185.94 sq.km, which was lower than the winter season. The summer season had the lowest surface water inundation, with an MNDWI of 169.48 sq.km

4.3. Inundation Frequency

(a) 2018

Based on the provided data, it appears to represent the frequency of inundation for the year 2018. The data is broken down into different percentages (0%, 25%, 50%, 75%, and 100%) which likely represent the proportion of time that a given area was inundated during the year**.** According to the map it shows that the 0 frequency of area 290.175149 Sq.km which indicates the no inundation has been found but that there were periods of inundation ranging from 25% to 100% of the time. In the map the dark blue of 100% frequency indicates the 100days permanent inundation which covers an area of 174.118749 Sq.km. The report also contains details regarding the extent of land that was flooded. The area appears to have been smaller as the level of inundation increased and larger at times of 0% inundation (i.e., no flooding occurred). This shows that the flooding was not evenly dispersed over the whole region, but rather was localized in certain areas.

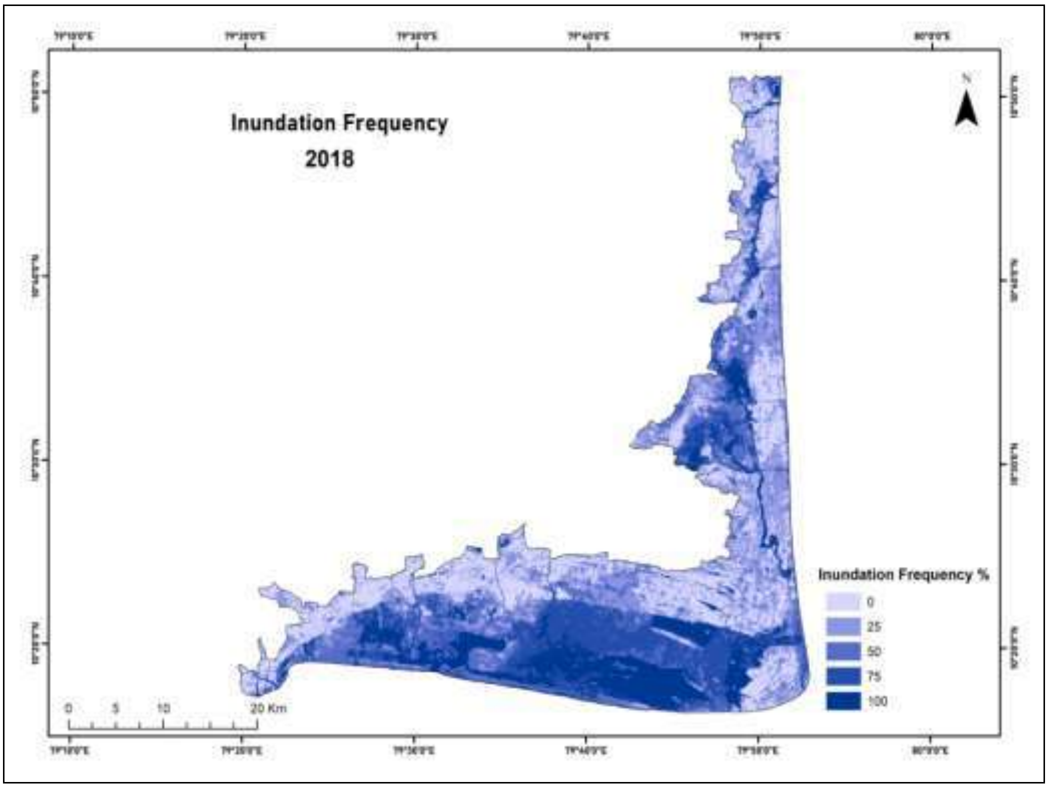

Fig.7: Inundation Frequency 2018

(b) 2019

In 2019, as with the previous data sets, the percentages represent the proportion of the entire region that was flooded, with 0% denoting no water and 100% denoting total inundation. Area covering 328.20 Sq.km is shown as 0% inundation frequency. The 25% inundation frequency shows the area of 180.68 Sq. km that is covered by seasonal water bodies, but the 50% to 70% inundation frequency shows the areas of 156.51 Sq. km in 185 days and 202.66 Sq. km in 275 days that are covered by fluctuations in the water bodies. This would suggest that the water wasn't uniformly distributed over the area, but rather that it was concentrated in a few select locations.

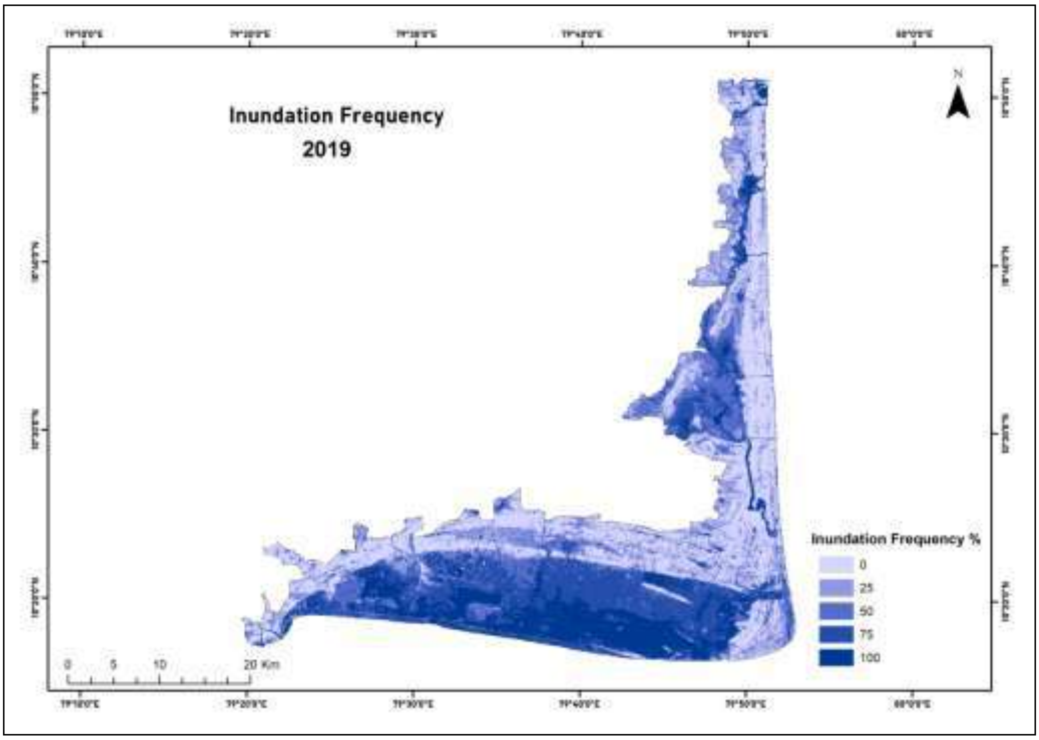

Fig.8: Inundation Frequency 2019

(c) 2020

Based on the above obtained data, it shows the frequency of inundation in 2020. The data is divided into percentages like 0%, 25%, 50%, 75%, and 100%, which most likely indicate the amount of time a certain location was inundated over the year. Each % range is assigned several days, with the greatest duration of inundation being 275 days. The data also provides information on the extent of land impacted by inundation, which appears to have been greatest during times of 100% inundation of area covering 242.53 sq.km and 50% inundation are seen over 122.05 Sq.km. 50% to 70% of the area indicates that the inundation will change over a year as they are not permanent water body.

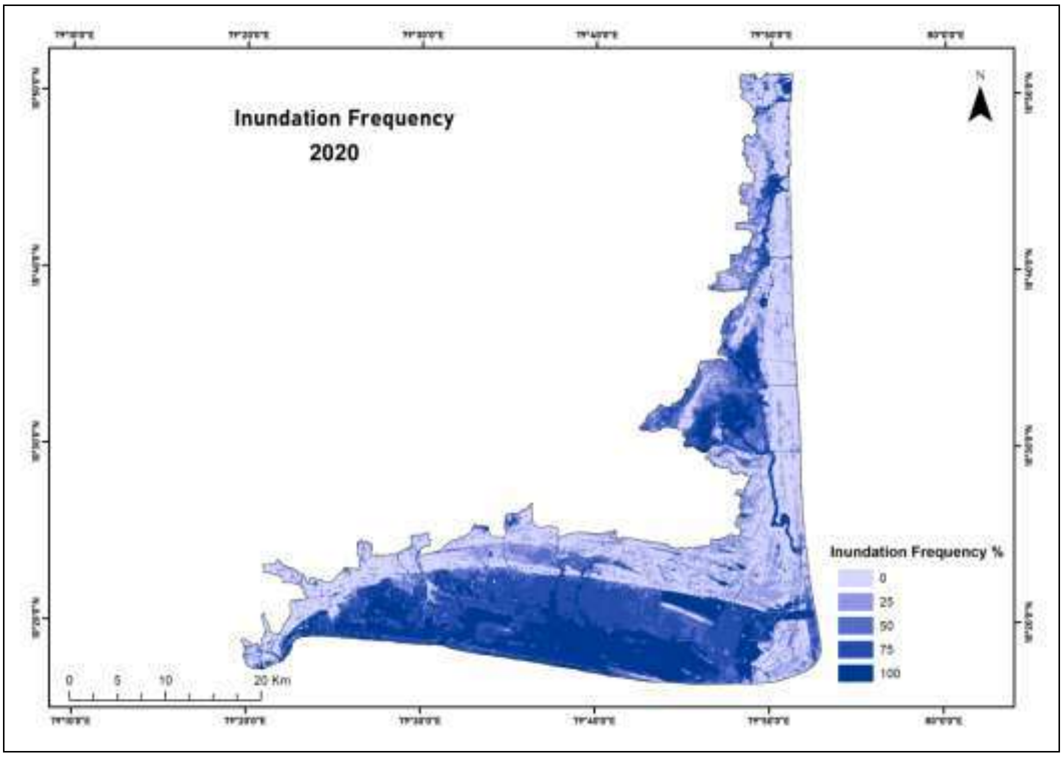

Fig.9: Inundation Frequency 2020

(d) 2021

Based on the above obtained data it shows that the 0% which indicate no water over the area of 364.15 Sq.km whereas from 25% it shows the area with seasonal water bodies. From 50% to 75% which covers an area of 85.81 Sq.km and 105.38 sq.km respectively. The area which covers 339.28 Sq.km depicts 100% inundation frequency of 100days in 365days which indicates that the area is having permanent water body.

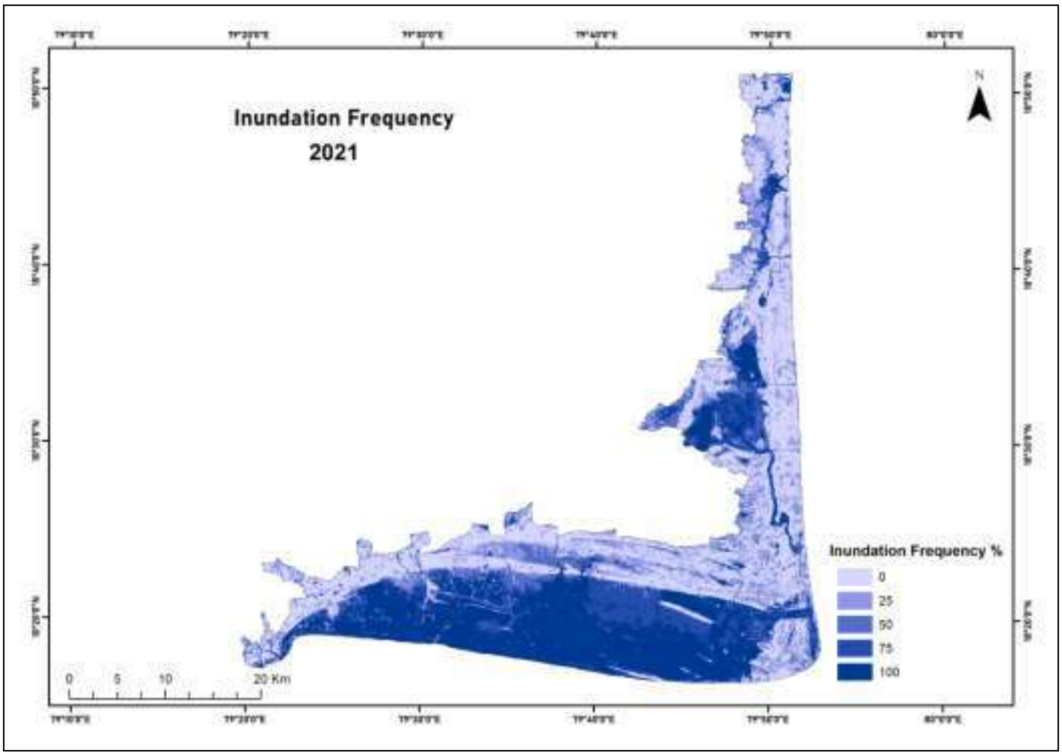

Fig.10: Inundation Frequency 2021

4.4 Inundation Frequency

Based on the mentioned methods, we produced maps of inundation frequency in the Muthupet region for the years 2018 2019, 2020, and 2021. As shown in Figures, the blue bar indicates the area of the inundation area. The darker the color, the higher the inundation frequency, and the lighter the color, the lower the inundation frequency. All other non-inundation regions are masked off in white. The inundation frequency in the Muthupet region clearly showed uneven temporal spatial distribution. In the frequency table it shows the three indices namely frequency in percentage, number of days and area in sq.km. Studying surface water inundation is essential because it enables us to comprehend and control the dangers connected with flooding. We can create efficient flood control policies and construct infrastructure to safeguard lives and property by analyzing trends and the depth of flooding. It also enables us to evaluate how the environment affects ecosystems and water quality, allowing us to put policies in place to reduce ecological harm. Additionally, understanding surface water inundation helps with infrastructure development by ensuring that streets, bridges, and buildings are built to withstand or lessen floods. It also assists attempts to adapt to climate change by analyzing flood patterns and creating methods to increase resilience. It adds to water resource management by evaluating water availability and distribution. In other words, by researching surface water inundation, we can reduce the harmful effects of floods on both natural and human systems, make wise judgements, and put in place efficient regulations.

4.5 Discussion

Surface water inundation result conveys that the changes occur in the water with the six years 2017, 2018, 2019, 2020, 2021 and 2022. In MNDWI indices the summer and winter season exhibited with low level of inundation. While the northeast monsoon season showed the highest inundation value has been observed, whereas in southwest monsoon indicating slow fluctuation of inundation. The water inundation levels in summer season vary between 2020 and 2021, with a substantial increase in 2021. The water inundation levels in southwest monsoon range from 2017 to 2018 and remain relatively consistent, whereas in northeast monsoon season the degree of water inundation varies between 2019 and 2022, with a major rise in 2022. Lastly the inundation frequency information indicates that in 2021 the inundation was highest. In MNDWI, according to the Northeast monsoon season has the largest and most frequent water inundation, while the Southwest monsoon has the lowest. On a seasonal basis, the NEM season had the largest surface water inundation in 2021 with an MNDWI value of 407.4696 and in 2022 with an MNDWI value of 376.9794, while the SWM season had the lowest water inundation in 2018 with an MNDWI value of 87.4960 and in 2022 with an MNDWI value of 39.8839. The year 2022 saw the most significant inundation during the winter, with an area of 205. 6321.As the water inundation varies seasonally every six years, it occurs during the summer. The MNDWI value for water inundation in summer was highest in 2022 at 175.3396 and lowest in 2019 at 72.7716. During each year from 2017 to 2022 the highest water inundation can be seen in the year 2021 which indicates the value of 407.4696 MNDWI values whereas the lowest MNDWI value is 39.8839 in the year 2022.

Based on mentioned methods, the maps of inundation frequency in the Study area for the years 2018 2019, 2020, and 2021 where the blue color bar indicates the area of the inundation area. The darker the color, the higher the inundation frequency and the lighter the color, the lower the inundation frequency. All other non-inundation regions are masked off in white. The inundation frequency in the Muthupet region and Thalainayar region clearly showed uneven temporal spatial distribution of surface water. The annual inundation in the region was analyzed with the help of TropWet tool in Google earth engine. The findings show that the inundation in MNDWI is maximum in the year 2021 during the Northeast monsoon and lowest in the year of 2022 in Southeast monsoon. This is mainly due to weather patterns, such as reduced precipitation or a lack of significant weather events during the winter season, could lead to lower water inundation levels. If there were fewer rainfall events in the region, it results in lower water levels and Human activities, such as the construction of reservoirs, dams, or water management systems, can alter the natural water flow and affect inundation levels. If there have been human interventions in the region that regulate or control water levels, it could influence the observed low inundation during the winter season. According to inundation frequency data the year of 2021 experienced higher variation in surface water inundation when flooding was reported in the region. Tropwet tool has been used in Google Earth Engine to monitor the tropical wetlands. It helped to determine the water inundation in an area inter seasonal variation of surface water. The use of Tropwet tool has provided more accurate results in the study.

5. Conclusion

In this study the remote sensing is very important tool for the analysis of Surface water inundation. The whole data was collected from the Google Earth Engine. While using MNDWI indices has been used to enable the identification of water bodies in satellite imagery. Positive values indicate the presence of water, while negative values represent non-water features. By comparing the indices values over time or across areas, changes in water inundation levels can be assessed. Higher positive values indicate increased water inundation, while lower values or negative values correspond to reduced or absent water inundation. As a result, wetland conservation and protection have become critical. The growth of geospatial technology has increased the relevance of wetlands monitoring and protection.

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Measurement of land Surface Temperature and Normalized Difference Vegetation Index Relationship in Salem City, Tamil Nadu, India

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Abstract

The study focuses on monitoring the land surface temperature (LST) and its crucial correlation with the normalized difference vegetation index (NDVI) as key factors in environmental research. Centered on Salem City in Tamil Nadu, the investigation explores the interrelationship between LST and NDVI over four decades, with Landsat images captured at ten-year intervals from 1990 to 2020. The research highlights the close connection between urban green space growth and the temperature of the corresponding city, revealing negative trends in urban green spaces in ward numbers 7 and 52. These areas show an increase in land surface temperature alongside a decline in urban vegetation patches. Correlation analysis underscores a substantial negative association between LST and NDVI, emphasizing the role of surface characteristics in controlling LST. Overall, the study's insights provide valuable guidance for environmental planning in tropical climate cities.

Keywords: LST, NDVI, Urban Green Space, Vegetation, Temperature, and Environment.

1. Introduction

Urbanization processes impose ecological stress at both local and regional levels, with numerous urban areas experiencing significant land conversion to built-up areas in recent years. This transformation directly contributes to the emergence of new hot zones (Krishnan & Ramasamy, 2022a; Kumar & Shekhar, 2015; Narmada & Annaidasan, 2019). Geographical Information System (GIS) and Remote Sensing techniques play a pivotal role in identifying land use/land cover changes and their associated consequences. Various satellite sensors effectively capture these changes using visual-based interpretation, near-infrared (VNIR), and shortwave infrared (SWIR) techniques, which are facilitated through digital image processing methods (Goward et al., 2002; Mushore et al., 2019; Voogt & Oke, 2003; Yue et al., 2007).

Furthermore, the conventional LULC classification algorithms, and spectral indices are used in detecting specific objects from the earth surface i.e. Normalized difference Vegetation Index (NDVI), Land Surface Temperature (LST), Normalized difference built-up index (NDBI) etc. Similarly, ensembles spectral indices are significantly performing with several remote sensing applications such as mapping forest, rocks, and minerals mapping agricultural monitoring, LULC mapping, hazard mapping, and urban heat island (UHI) and monitoring, and ecological assessment etc., In order to identify the urban heat islands and ecological comfort zones, land surface temperature (LST) which may be derived from various remotely sensed data, is frequently used to explore the LST within very small varied metropolitan region, LST can alter dramatically in a large, uniform land surface(Fatemi & Narangifard, 2019; George et al., 2021; Guha & Govil, 2020; Hao et al., 2016).

Different LULC types respond differently in the TIR band, and as result, LST greatly changes in an urban setting. The natural vegetation is rapidly changed by land conversion in the urbanized area, and LST is one of the driving factors for monitoring the vegetations. The seasonal variations of sun's azimuth and elevation influence to changes of LST as well. Therefore, the seasonal change in LST is crucial to any study connected to LULC. The study involving LST must always employ NDVI because it dominates LST derivation methods. NDVI is directly used in the determination of the land surface emissivity and thus is an important factor for LST estimation. Additionally, it established the LULC categories based on the best threshold values for various physical environments. Since it measures vegetation, seasonal variation has a important influence on NDVI (Gui et al., 2019; Kantamaneni et al., 2022; Sannigrahi et al., 2018; Singh et al., 2017; Yao et al., 2018). As a result, LST is influenced by the changing of the seasons. Therefore, the crucial step in LST mapping and monitoring, urban context is the seasonal evaluation of LST and NDVI. The link between LST and NDVI is highly fascinating, and remote sensing researchers are drawn to it from a variety of angles.

Space and time have an important impact on the character and strength of this interaction. Typically, the LST-NDVI association is adverse in tropical environments. The evolving form of LULC through time determines how unfavorable the association (Cui et al., 2018, 2019; Ghobadi et al., 2015; Kikon et al., 2016; Nimish et al., 2020; Yao et al., 2017). Therefore, the various types of land conversion relationship are fluctuation of the LST-NDVI which is very important to study in mixed land surface. Seasonal examination of the LST-NDVI relationship, several studies has been published.

Remotely sensed data is one of the powerful tools to explore the morphometric assessment (Jaganathan et al., 2015; Krishnan & Ramasamy, 2022b). These studies cover a wide range of tropical cities, and findings from numerous illuminating studies on LST-NDVI. The investigations revealed both LST and NDVI have negative connection that changes with the season. Given that the monsoon season has a greater amount of moisture than the summer months, there is a larger negative association during the heavy rainfall. With the alteration of earth's surface types, such correlation may also vary (Correia Filho et al., 2019; Govil et al., 2019; Mahato & Pal, 2018; Mathew et al., 2018; Mushore et al., 2017; Nimish et al., 2020; Yao et al., 2017, 2019; Yuan et al., 2020). For bare land surface, built-up surface, and water surface, vegetation surface creates a significant, link and strength is decreased.

The present study associates with LST and NDVI from Landsat images of four different periods1990, 2000, 2010, and 2020 in Salem city, Tamil Nadu, India. And it is revealed that the urban green space distribution declining since from 1990 and it is exposed urban environment related problems such as Urban Heat Island (UHI) micro climate change.

However, this study has examined impact of land surface temperature and vegetation phenology in Salam city, and it has been monitoring the ward wise since 1990 to 2020. It exposed account of surface temperature with vegetation healthiness of the study area.

2. Study area

Salem city lies in the western part of Tamil Nadu, and it is geographically located between 11◦15′–12◦00′N latitudes and 77◦35′–78◦50′E longitudes. The city has secured an average maximum and minimum temperature of 40◦C and 13◦C. The study area consists of Cauvery, Vashita Nathi, Swedha Nadhi, Sarabhanga Nathi and Thirumanimuthar are flowing across the Salem district, and it is also known for Stanley reservoir and for mango fruit farming.

The study area encompasses significant mineral deposits such as magnesite, bauxite, limestone, quartzite, iron ore, and granite, among others. The Cauvery River water is stored in the Stanley Reservoir and is distributed to numerous districts, serving as a primary water source for irrigation in various districts of Tamil Nadu. Salem district is predominantly covered by Archaean crystalline formations, with additional recent alluvial and colluvial deposits found in limited areas of the district.

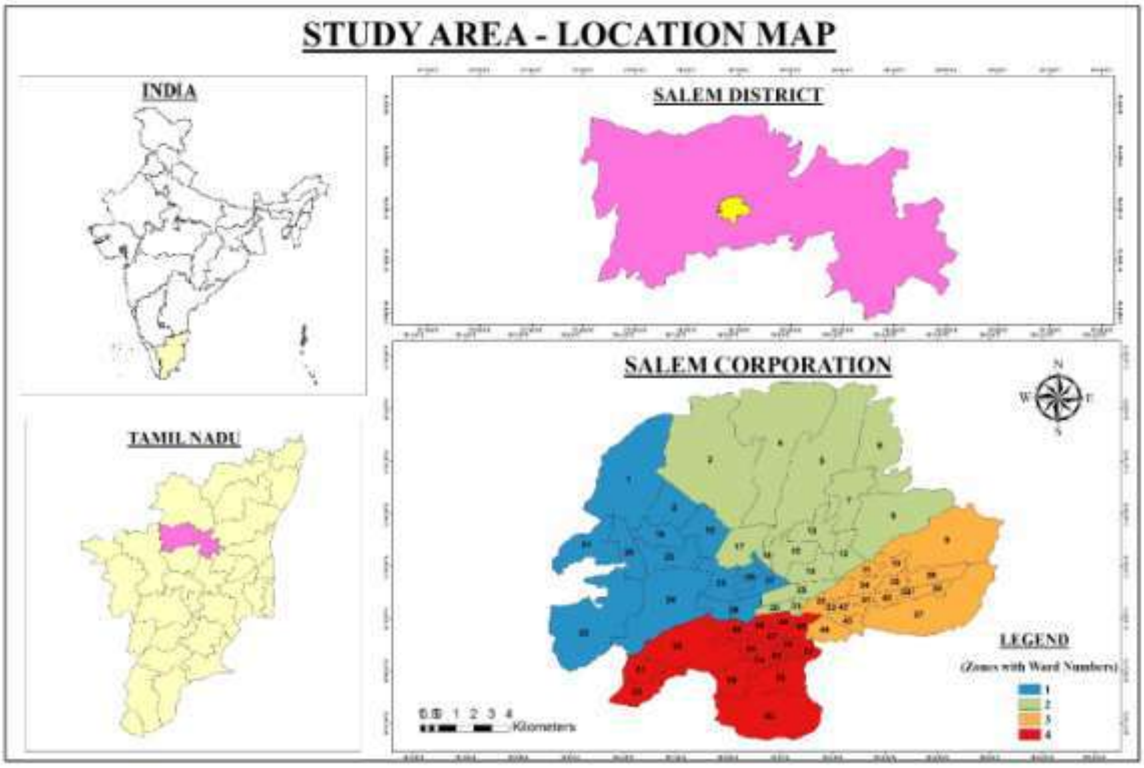

Fig. 1: Study area of the Salem city

3. Methodology

3.1 Extraction process of Land surface Temperature

The current study employs the mono-window algorithm to retrieve land surface temperature (LST) using Landsat images from two different sensors, namely TM and OLI. This process involves the extraction of LST through three essential parameters: ground emissivity, atmospheric transmittance, and effective mean atmospheric temperature. Additionally, the mono-window algorithm is utilized to determine the land surface temperature for the entire city of Salem. The TIR bands are resampled to a 30-meter resolution for application purposes, and all extraction processes and steps are carried out in accordance with the equations specified in previous studies (Govil et al., 2019; Zhao et al., 2017).

$$L\lambda = \text{RadianceMultiBand} \times \text{DN} + \text{RadianceAddBand}$$

Where, $L\lambda$ is spectral radiance (Wm−2 sr−1 mm−1). At sensor brightness temperature is estimated by (Qu et al., 2020);

$$\text{T}B = \frac{\text{K2}}{\text{in}\left(\left(\frac{\text{K1}}{\text{K}\lambda}\right) + 1\right)}$$

Where, $T_B$is brightness of the temperature in Kelvin (K), and $L\lambda$is representing a spectral radiance in $Wm^{-2}\ sr^{-2}mm^{-1}$; *K2* and *K1* are calibration constants. The Landsat 8 data, K1 is 774.89, *K*2 is1312.08 ($Wm^{-2}\ sr^{-2}mm^{-1}$), and Landsat 7 data, K1=666.09, K2=1282.71($Wm^{-2}\ sr^{-2}mm^{-1}$), furthermore Land sat 5 data, K1 is 607.76, K2 is 1260.56 ($Wm^{-2}\ sr^{-2}\ mm^{-1}$).

$$Fv = \left(NDVI - \frac{NDVImin}{NDVImax} - NDVImin\right)2$$

Where, NDVI min represents the minimum value of the Normalized Difference Vegetation Index, whereas Fv is fractional vegetation. The land surface emissivity $'\epsilon'$ estimated with the following equation (Govil et al., 2019).

$$\varepsilon = 0.004 * Fv + 0.986$$

Finally, LST was estimated by the following equation

$$LST = \frac{TB}{1} + \left(\frac{\lambda\sigma TB}{hc}\right) in\ \varepsilon$$

The land surface emissivity ε, was estimated using the NDVI Thresholds methods of each vegetative regions of the image. The following method has been performing to understand the threshold, NDVI < 0.2 for bare soil; NDVI > 0.5 for vegetation; 0.2 <= NDVI <= 0.5 for mixed land with bare soil and vegetation(Hao et al., 2016). ε *is* an estimated from the following equation:

$$\varepsilon = \varepsilon v Fv + \varepsilon s(1 - Fv) + d\varepsilon$$

Where εv is emissivity of respective land surface, and εs is Soil emissivity, Fv is fractional Vegetation, F represents shape of the factor which mean is 0.5, the value of $d\varepsilon$ probably 2% for the land surfaces. The fractional vegetationFv, of each pixel, is determined from the NDVI using equation (Cui et al., 2018).

3.2 Extraction of various types of LULC values through threshold of NDVI

The Normalized Difference Vegetation Index (NDVI) can be utilized to categorize land use and land cover (LULC) types based on threshold values ranging from -1 to +1. These threshold values are indicative of different physical environments. The NDVI thresholds were consistently applied throughout the same season across the study area. The assessment was conducted over four different periods, specifically 1990 to 2020, with each period representing a 10-year interval. The goal was to extract threshold values for different regions within the study area. Table 2 presents the appropriate threshold limits for the Normalized Difference Vegetation Index. An NDVI value above 0.2 signifies vegetation patches, while a value less than 0 indicates water bodies. Threshold values ranging from 0 to -0.2 clearly indicate built-up areas or barren land within the study area (Nimish et al., 2020; Yao et al., 2017).

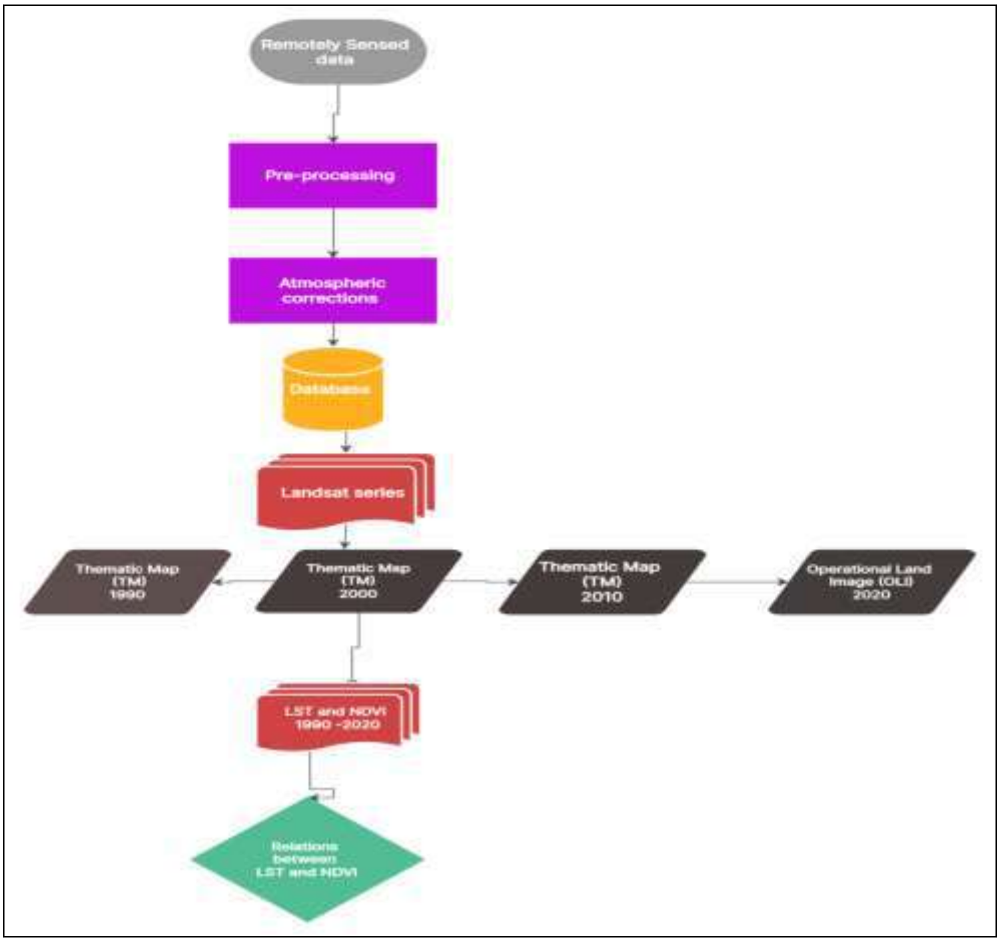

Fig. 2: Methodology flow chart

4. Result and discussions

4.1 Appraisal of Land Surface Temperature in Salem City

An evaluation of Land Surface Temperature (LST) in Salem city, encompassing sixty wards, was conducted with measurements taken from 1990 to 2020 at ten-year intervals. The assessment involved meticulous ward-wise measurements throughout the city, calculating the average land surface temperature using a suitable algorithm. The study provided insights into the context of land surface temperature for each decade, specifically in 1990, 2000, 2010, and 2020. The table below illustrates the significance of LST in Salem city.

Digital image processing data served as the tool for image analysis, employing various algorithms and mathematical-based spectral indices ensembles. These approaches rely on spectral reflectance characteristics, with numerous indices designed to extract information about vegetation. Additionally, various spectral indices are utilized to assess the health status of vegetation using remotely sensed data. The Normalized Difference Vegetation Index (NDVI) is widely employed to evaluate the state of natural vegetation and is effectively involved in quantifying global climate change (Fatemi & Narangifard, 2019; Kantamaneni et al., 2022). NDVI is calculated as the ratio difference between measured canopy reflectance in the red and near-infrared bands, respectively. The distribution of natural vegetation serves as a crucial indicator for measuring biophysical status and estimating soil erosion, which can be derived from satellite images using vegetation indices.

Table 2: Extract the LST from remote sensing data

No of wards	LST				NDVI			
	1990	2000	2010	2020	1990	2000	2010	2020
1	28.4	30.4	27.9	30.1	0.06	0.16	0.11	0.14
2	29.2	32.9	27.9	33	-0.01	0.03	0.11	0.14
3	27.1	28.4	23.3	29.3	0.04	0.15	0.25	0.15
4	28.8	28.4	26.7	28.1	0.04	0.2	0.28	0.16
5	28.4	28.8	25.8	28.8	0.13	0.23	0.44	0.25
6	30	33.7	27.5	33.1	0.04	0.06	0.27	0.16
7	27.1	28.8	27.1	29.3	0.46	0.42	0.26	0.26
8	27.9	29.6	26.3	30.1	0.02	0.21	0.43	0.28
9	27.1	28.8	26.7	27.8	0.19	0.36	0.35	0.31
10	29.2	32.1	29.2	31	0.07	0.09	0.13	0.19
11	28.8	30	27.1	30.1	0.09	0.12	0.2	0.18
12	27.5	31.2	27.5	32.1	0.13	0.1	0.03	0.23
13	27.9	30	27.9	29.6	0.13	0.08	0.16	0.17
14	28.8	30.8	27.9	35.1	0.09	0.26	0.33	0.15
15	27.1	29.6	27.9	31.8	0.18	0.11	0.12	0.14
16	28.4	30.4	28.8	29	0.02	-0.02	-0.01	0.1
17	27.5	28.8	28.4	29	0.16	0.09	0.07	0.15
18	28.4	31.2	28.4	29.8	0.17	0.22	0.2	0.22
19	27.5	31.2	28.4	30.8	0.08	0.05	0.1	0.14

20	27.1	28.4	27.5	28.1	0.39	0.41	0.42	0.38
21	27.1	30.4	26.7	27.2	0.22	0.26	0.37	0.23
22	27.1	32.9	28.8	29.2	0.07	0.25	0.27	0.22
23	27.9	30.8	28.8	29.7	0.1	-0.01	0.04	0.08
24	27.1	31.2	29.2	30.1	0.2	0.09	0.18	0.41
25	30.4	33.3	30.4	31.5	-0.01	0.02	0.09	0.12
26	28.4	30	29.2	30.2	0.05	0.03	0.02	0.15
27	29.6	31.6	29.6	30.8	0.01	0	0	0.11
28	28.4	30.4	29.2	31.1	0.01	0.08	0.06	0.14
29	28.8	30.4	27.9	28.2	0.14	0.22	-0.01	0.12
30	29.6	31.6	30	31.1	-0.02	-0.03	-0.02	0.08
31	29.2	31.2	29.2	29	0.03	0.11	0.2	0.23
32	29.2	30.8	29.6	29.2	-0.03	-0.04	-0.03	0.1
33	30	31.6	29.2	29.2	-0.03	-0.02	-0.04	0.09
34	29.6	32.5	30	32	0.02	0.02	0.01	0.1
35	27.1	28.8	28.4	29.9	0.25	0.3	0.1	0.15
36	29.2	31.6	29.6	30.2	0.02	0.06	0.03	0.11
37	26.3	28.8	26.3	31.1	0.21	0.12	0.41	0.26
38	29.6	31.2	29.2	30.1	0.09	0.02	0	0.11
39	29.2	32.1	29.2	31.1	0.02	0.04	-0.01	0.1
40	27.9	30.4	28.4	29.2	0.05	0.06	0.06	0.11
41	29.2	31.6	29.2	29.2	0.02	0.04	0.01	0.15
42	29.2	31.6	29.2	19.5	0.04	0	-0.01	0.1
43	29.6	30.8	29.2	30.2	0.04	0	0.03	0.11
44	29.2	32.5	29.6	29.2	0.01	0.02	0.03	0.1
45	29.6	31.6	29.6	31.1	-0.03	-0.02	-0.04	0.09
46	29.2	31.2	29.6	32	-0.03	-0.01	-0.02	0.07
47	27.9	31.2	29.2	32	0.02	0.06	0.05	0.1
48	29.2	31.2	29.2	29.2	0.04	0.06	0.08	0.17
49	26.7	27.9	29.2	30.9	0.15	0.33	0.07	0.12
50	27.5	30.8	27.1	31.1	0.04	0.08	0.13	0.12
51	25.4	28.4	29.6	29.4	0.24	0.25	0.28	0.34
52	25.4	27.1	26.3	30.2	0.36	0.36	0.25	0.27
53	28.8	31.6	30	29.1	0.01	0.02	0.07	0.18
54	28.8	31.2	28.8	29.2	0.13	0.14	0	0.09
55	30	31.6	28.8	30.7	0.02	0	0.02	0.11
56	29.2	31.6	29.2	30.2	0.04	0.02	0.04	0.11
57	29.2	31.2	30	31.6	0.02	0	0.04	0.1
58	30	31.2	29.6	29.1	-0.01	-0.02	-0.01	0.09
59	28.8	31.6	28.8	30.2	0.11	0.08	0.08	0.12
60	28.4	31.2	27.9	30.2	-0.02	0.05	0.04	0.13

4.2 Extraction of Land Surface Temperature from Remote Sensing Data

Land surface temperature serves as a crucial physical parameter for assessing the climatic conditions of the city. These data are derived from Landsat images using mono-window algorithms, providing insights into the current context of Salem city. The measurement of land surface temperature is conducted ward-wise, revealing the highest recorded temperatures and their associated factors (Kumar & Shekhar, 2015; Voogt & Oke, 2003; Yue et al., 2007). The study further presents the evolution of land surface temperature in Salem city from 1990 to 2020.

In 1990, the estimated land surface temperature ranged between 23.68 to 30.86 Celsius across Salem city. Notably, certain wards, namely Ward numbers 6, 25, 55, and 58, exhibited temperatures above 30 degrees Celsius. Conversely, the lowest land surface temperatures were observed in wards 51 and 52. The indices used encompass values from -1 to +1, incorporating all vegetative objects, including water bodies. The threshold for vegetation ranges from 0.2 to 0.5, indicating the status of natural vegetation on the Earth's surface. The subsequent figures clearly depict vegetation distribution or cover from 1990 to 2020.

Vegetation values extracted from Landsat images TM and OLI from 1990 to 2020 indicate different threshold ranges that signify various land covers. Values less than 0.2 indicate bare soil, values less than 0.5 represent mixed land with bare soil and vegetation, and values greater than 0.5 indicate complete vegetation and its healthiness. In 1990, the highest vegetation cover recorded a reflectance of 0.63 percent, while the lowest reflectance was -0.24 percent. Similarly, the highest urban green spaces covered 0.64 percent, with the lowest vegetation cover recorded at -0.21 percent reflectance. In addition, the highest green cover of the city was observed at 0.61 percent reflectance, while the lowest green cover recorded -0.09 percent (Correia Filho et al., 2019; Govil et al., 2019; Mushore et al., 2017; Yao et al., 2019; Yuan et al., 2020; Zhao et al., 2017).

In the recent year 2020, urban green land covered 0.47 percent of reflectance, while the lowest values were documented at -0.02 percent reflectance. The overall study indicates a gradual decline in urban green spaces from 1990 to 2020.

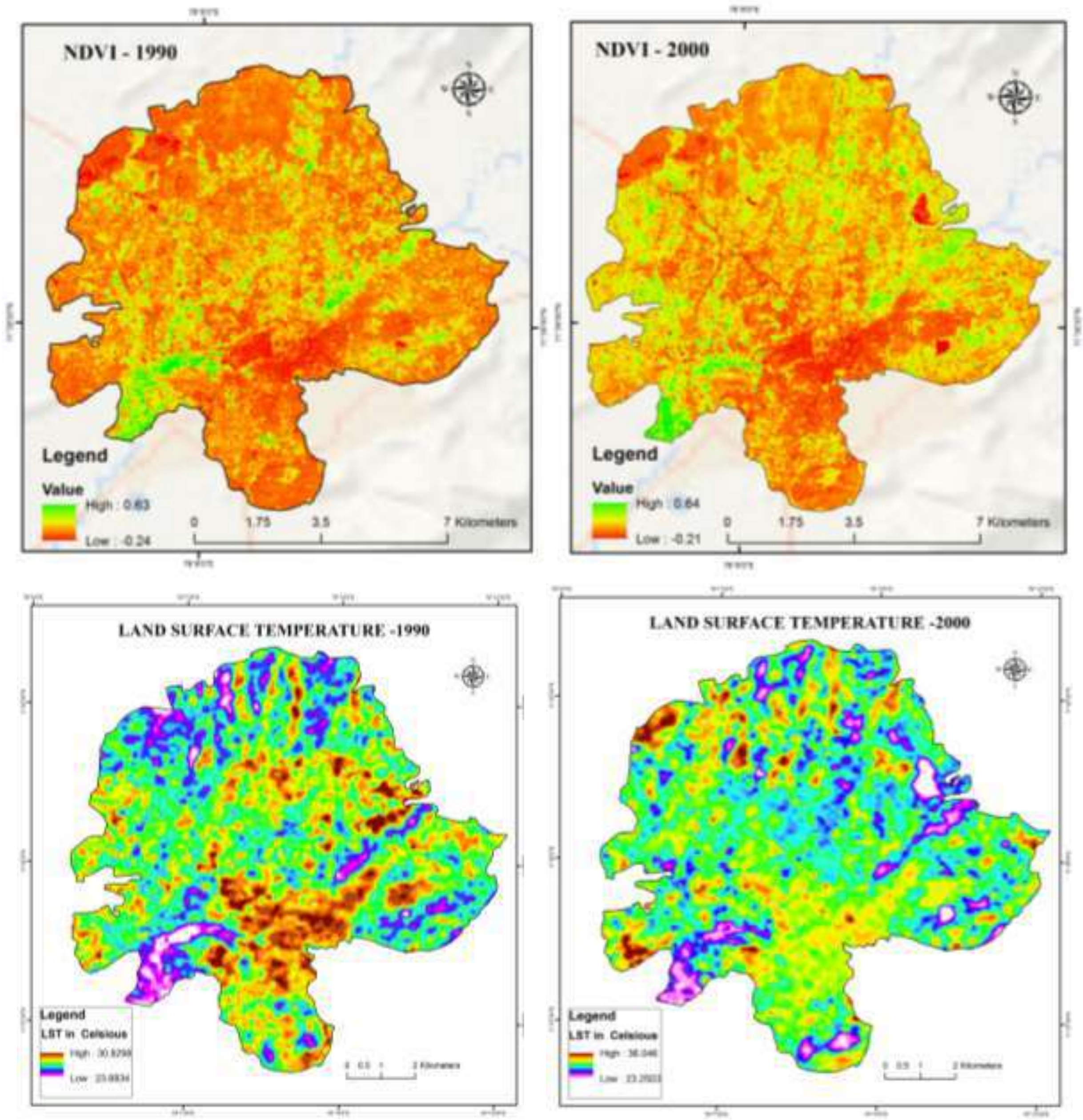

Fig. 3: NDVI and LST 1990 - 2010

4.3 Relationship between NDVI and LST

The land surface temperature is an important factor which gives severe implications to the urban areas, whereas an urban green space is one of the significant factors of the urban temperature. However, the present results exhibits condition of the land surface temperature and Normalized Difference Vegetation Index, and it shows that the distribution of vegetation cover and present status of Salem city heat emission based upon the land surface temperature (Fatemi & Narangifard, 2019; Guha & Govil, 2020; Hao et al., 2016; Krishnan & Ramasamy, 2022b; Kumar & Shekhar, 2015; Mushore et al., 2019; Singh et al., 2017). Nevertheless, the results revealed that the potential of land surface temperature and vegetation covers through by respective indices, it exposed the green vegetation cover registered less LST (Table), likewise scrub with barren lands are secured the moderate LST, and built-up with barren lands are registered the highest LST. The green areas and water areas are characterized by a relatively stable range of LST.

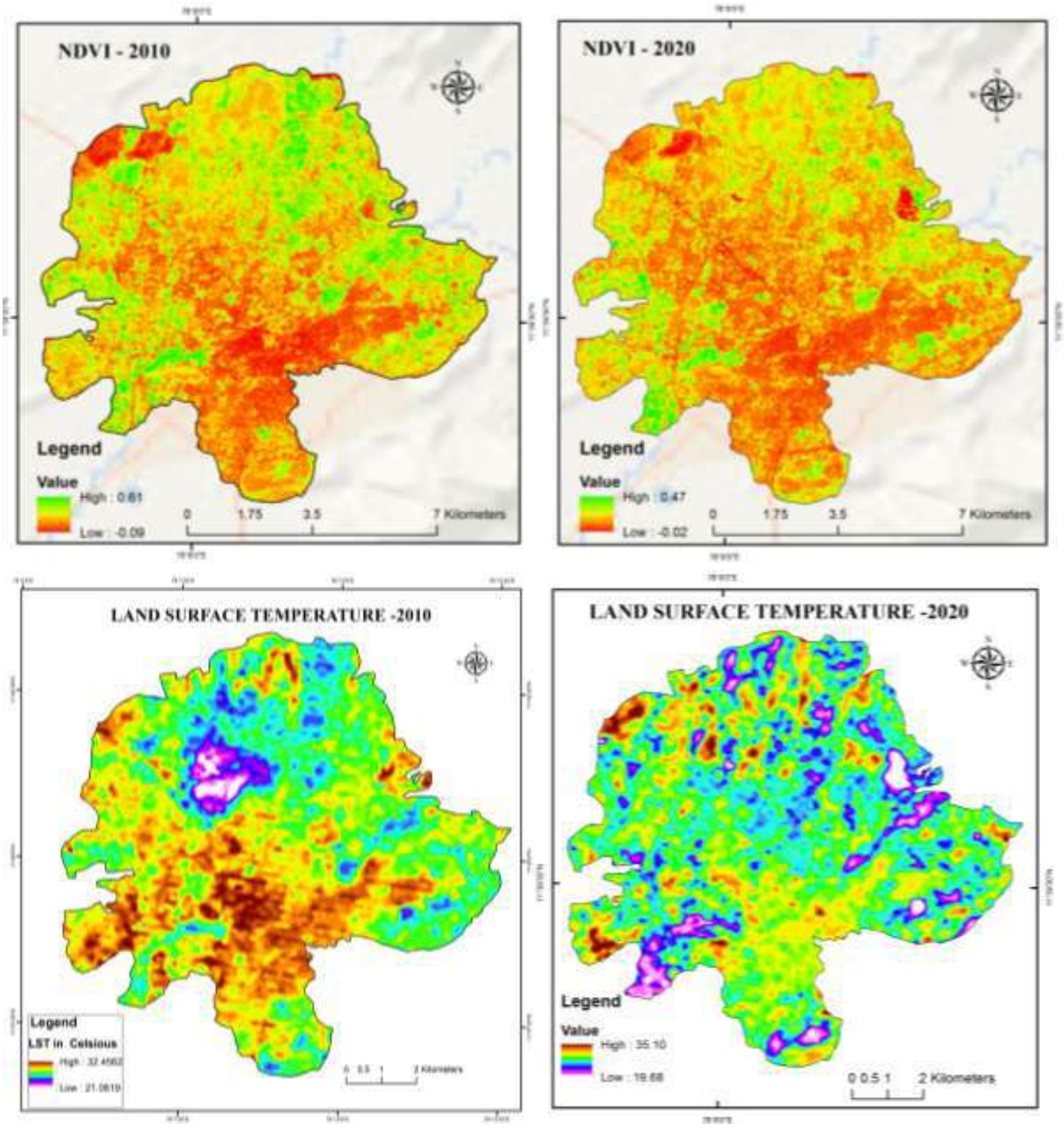

Fig. 4: NDVI and LST 2010 -2020

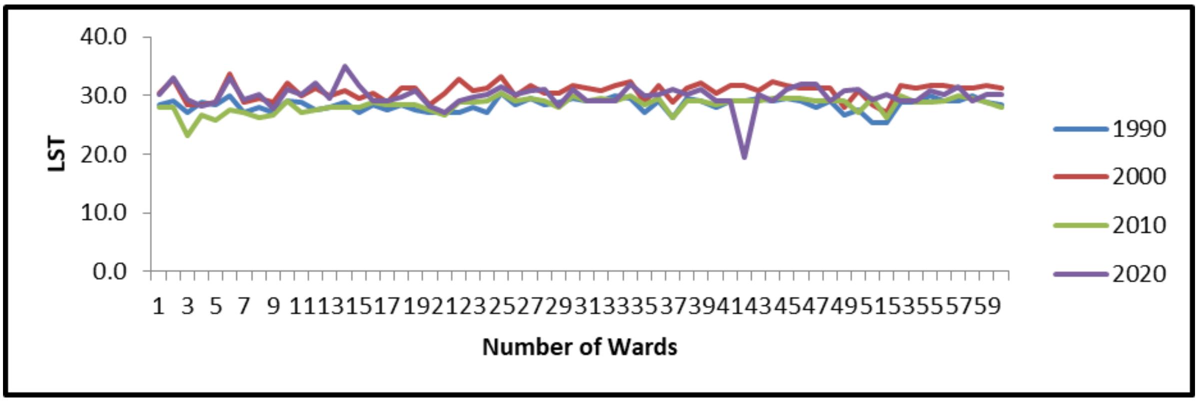

Fig. 5: LST Distribution 1990-2020

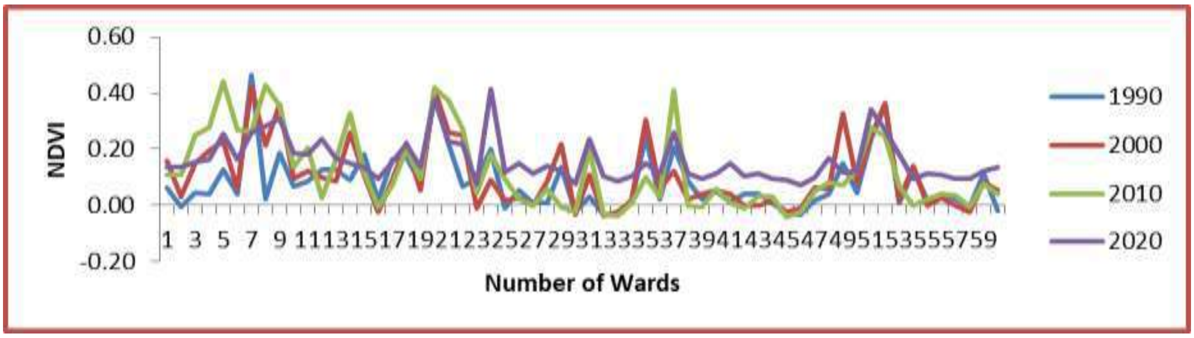

Fig. 6: Vegetation Distribution 1990-2020

In 2000, there are many wards are secured the more than 30 degrees Celsius, and it evidently exhibits that the constructed materials are played a major role for increasing the temperature on the surface. Ranges of land surface temperature between 23.25 to 36.04 degree Celsius, and substantially, lowest land surface temperature extracting the across the Salem city. Likewise, LST value of 2010 was extracted from the 21.06 to 32.45 degree Celsius (Fatemi & Narangifard, 2019; Mushore et al., 2019). In addition, most of the wards are secured the 28 degrees Celsius, and very few wards are documented the above 30 degree Celsius. Ultimately, the recent decade revealed the context of the land surface temperature from 19.6 to 35.10 degree Celsius, whereas few wards are registered the above 35 degree Celsius, especially 14 wards is a highest LST was documented, and the lowest land surface temperature is recorded in 42ndward were registered in the Salem city (Gui et al., 2019; Kikon et al., 2016; Sannigrahi et al., 2018; Yao et al., 2018). The study exposed the Land surface temperature gradually increased from the 1990 to 2020, major causes is due to the urbanization land surface temperature increased rapidly in the Salem city (Annaidasan, 2017).

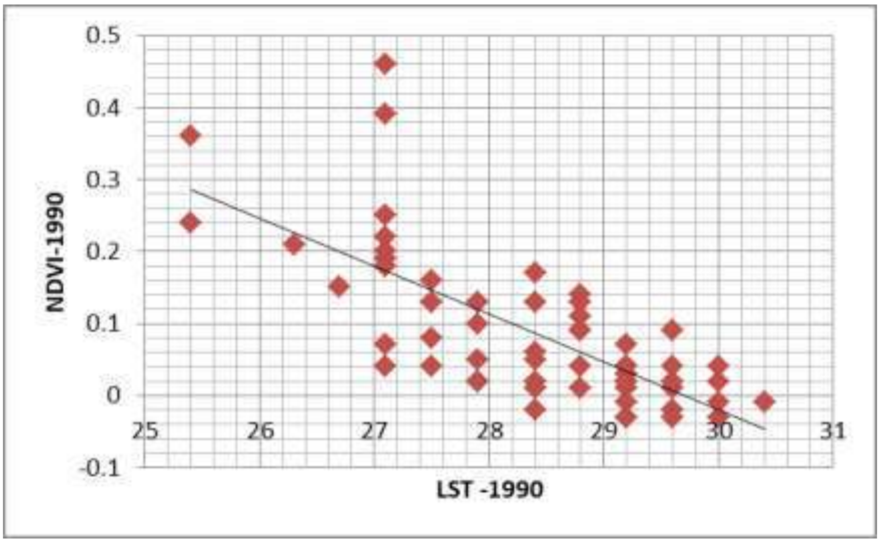

Fig. 7: Relations between LST and NDVI in 1990

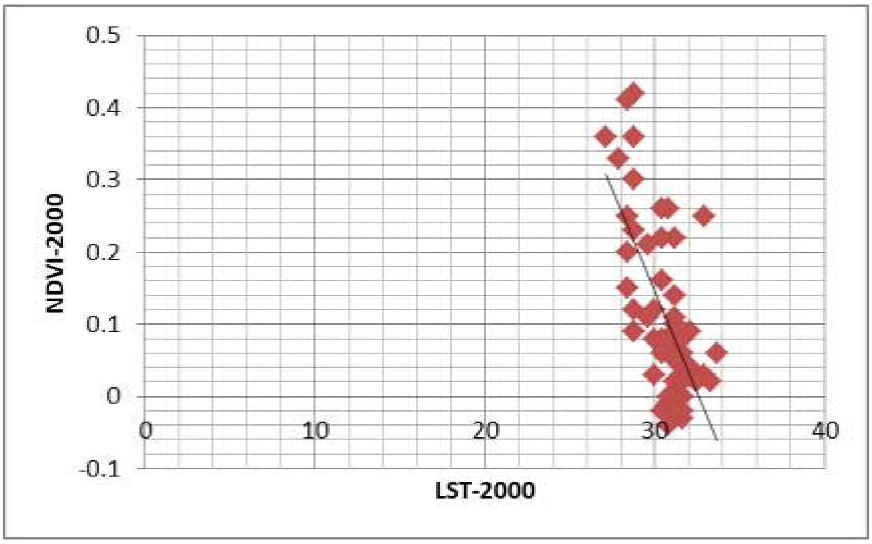

Fig. 8: Relations between LST and NDVI in 2000

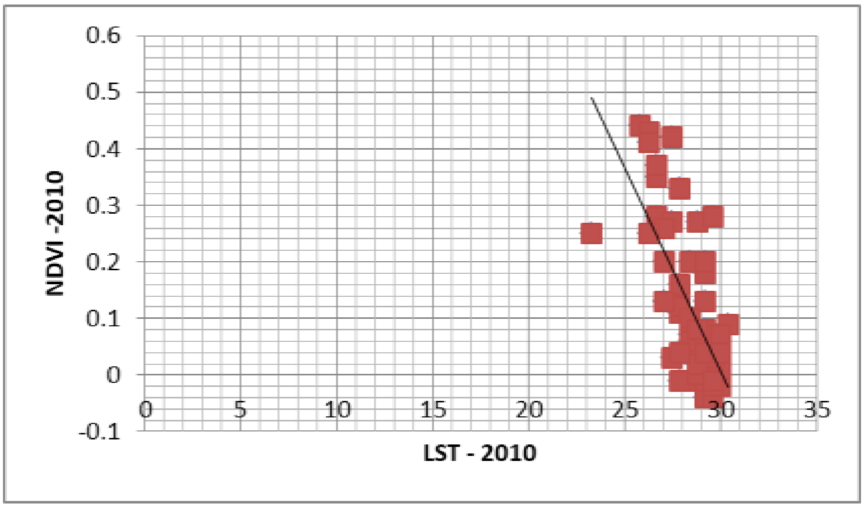

Fig. 9: Relations between LST and NDVI in 2010

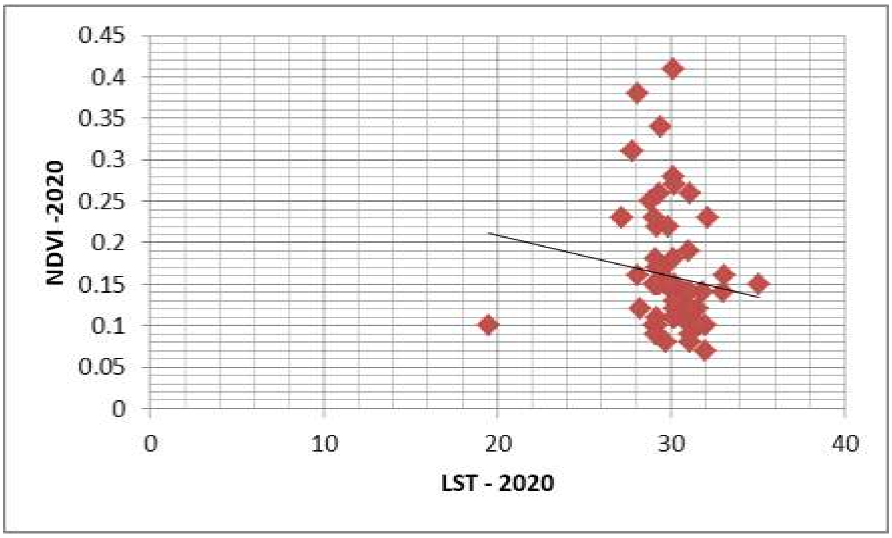

Fig. 10: Relations between LST and NDVI in 2010

5. Conclusion

This study explores into the spatial relationship between Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI) in Salem City, a rapidly growing urban center in Tamil Nadu, India, across the periods of 1990, 2000, 2010, and 2020. Utilizing the mono-window algorithm for LST extraction, the analysis reveals a gradual temperature increase in recent years. The close connection between the growth of urban green spaces and the city's temperature is evident, with Wards 7 and 52 displaying a negative correlation, signifying a reduction in green spaces as land surface temperature rises. The study establishes a notable negative association between LST and NDVI, underscoring the impact of temperature on vegetation. Comparison of LST and NDVI indicates higher LST values in built-up and vegetated areas, including Salem's core and suburban regions, while NDVI peaks in urban green spaces, parks, colleges, near wetlands, and agricultural areas. These results highlight significant changes in urban vegetation linked to the rising LST trend. The findings underscore the influence of climate change on Salem City, with rapid industrialization and urbanization contributing to observable microclimate changes in the city.

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