Impact of Urbanisation on LULC: A case study on Panaji Smart City

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PREFACE

Urbanization is when more and more people move to cities. This study examines the impact of urbanization on land use and land cover (LULC) dynamics in the smart city Panaji, Goa, India. Cities are growing rapidly and Panaji, Goa, India is no exception. It strives to be a smart city, using technology to make things work better. But as the city grows environment will change. This study examines how the city develops and how it affects the territory and nature around it. We want to understand how this growth happens and what it means for the environment.

The study focuses on analyzing trends in built-up area and land area, aiming to understand the relationship between urban development and environmental changes. Furthermore, this study aims to explore the balance between economic growth and environmental sustainability in the context of Panaji's smart city initiatives. Through interdisciplinary analysis, this study seeks to shed light on the process to achieve balanced and sustainable urban development in Panaji and similar urban contexts.

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ABSTRACT

This research work examines the impact of Urbanisation on Land Use and Land Cover (LULC) dynamics in the Smart City Panaji, Goa, India. Using remote sensing data and Geographic Information System (GIS) analysis, this study examines trends in built-up areas and land cover for the period 1995 to 2023. This study aims to understand the spatial and temporal patterns of urban expansion and vegetation change in the city. In addition, the thesis also explores the balance between Economic Growth and Environmental Sustainability in the development of smart city Panaji. It seeks to identify the relationship between urbanization, economic growth and environmental impact. These results contribute to the understanding of the dynamics of urbanization and their implications for sustainable development in Panaji and similar contexts. Ultimately, the study aims to inform the decision-making process to achieve a harmonious balance between economic progress and environmental management in the Panaji Smart City.

Keywords: Urbanisation, Land Use and Land Cover LULC, Smart City Remote Sensing, Geographic information System (GIS), Economic Growth, Environment Sustainability

CHAPTER 1: INTRODUCTION

1.1 Background

Urbanization is characterized by the concentration of people in relatively small areas and is recognized as an inevitable historical process. In recent decades, the growth and expansion of urban areas have been the largest in the world, mainly due to population growth and economic development Chen et al., (2014). In 2018, the urban population of the world reached approximately 55% of the total population, and this share will rise to approximately 68% (UN 2018). In 1975, about 21.3% of India's population lived in cities, compared to about 28.3% in 2003 (UN 2004). The degree of urbanization is highest in developing countries like India. According to the 2011 Census of India, the urban population of the country was approximately 377 million (31.16%) and the urban growth rate was approximately 31.8%. Urbanisation has been increasing in a very rapid way, the increase in urbanisation is because of the increasing population (Pradhan 2004). Population growth has an impact on resources and land use patterns, which begin to decline as a result of people building more homes and people moving to cities in search of employment due to the increased economic and job opportunities they offer(Rahman et al.2011b). The construction of infrastructure is necessary to address population growth and improve urban living conditions. Zeug and Eckert (2010).

With the growing urban population, there is a greater need for housing and other infrastructure that caters to their needs. The growth of the urban population leads to the expansion of urban areas and urban sprawl, which causes a number of serious environmental, health and climate problems. Mohan et al. 2011; Zhou et al., (2004).

The growth of cities is accompanied by changes in both the socio-economic and physical components of the landscape Duttaet al. (2015). One of the most significant challenges facing cities today, particularly in developing countries like India is the unplanned and unprecedented growth that has been experienced. Zhao et al. (2019). The growth of built-up land in urban areas occurs in line with population growth and economic development. The built-up area is expanding at the expense of natural land cover types such as water bodies, vegetation, fields and wetlands, etc. As the population grows, the use of natural resources also grows as people's needs are unfinishable and human beings ought to use more resources for their living purpose. Building of new houses, apartment, roads, bridges effects the land use pattern as there is much use of land on the earth surface. The use of Land also effects the cultivated land, biodiversity land, ecology and it also affects the earth surroundings such as the surface runoff, decrease groundwater level, water and soil pollutants. Urbanisation, the process of population migration from rural to urban areas, has a profound impact on the natural environment, especially soil, water and land surface temperature (LST). As cities grow, they consume large amounts of land to develop infrastructure, residential areas and commercial space. This rapid expansion often results in the conversion of agricultural land, forests and other natural habitats into built-up areas, leading to habitat loss, fragmentation and reduced biodiversity. In addition, urbanisation changes the hydrological cycle, affecting water bodies such as rivers, lakes and wetlands. Stemn & Kumi-Boateng, (2020).

Improving the waterproofing of surfaces such as roads, buildings and sidewalks disrupts natural drainage patterns, leading to problems such as urban flooding, reduced groundwater recharge and water pollution. O'Driscoll et al., (2010). These changes can have significant consequences for water quality, aquatic ecosystems, and the availability of freshwater resources to meet human and ecological needs. Dibaba & Leta,(2019).

As cities grow, they tend to absorb and retain more heat than surrounding rural areas, due to factors such as an increase in concrete and asphalt surfaces, and a decrease in vegetation cover and an increase in human activities. Stemn& Kumi-Boateng, (2020). This leads to high temperatures in urban areas, leading to many environmental and public health concerns, including heat-related illnesses, energy consumption for cooling, and exacerbation of heat air pollution. Baram et al., (2021).

The environmental problems also occur due to urbanisation, biodiversity loss is perhaps the most serious. The urban expansion that occurs in forests, wetlands and agricultural systems only leads to land clearing and habitat fragmentation. The natural habitat of our world tends to decrease as there is more use of land by the people. As the cities evolve people tend to buy luxuries products such as cars, this indeed increase the air pollution which as a direct impact on the surrounding areas.National Research Council, 2000; Rabalais, (2002); Rabalais et al., (2002). Another effect of urban development is the reduction of green space, as more areas are developed for residential and industrial use, less space is left for natural areas such as parks and gardens.Power, (2001)

One of the most effective ways to reduce the negative effects of urbanisation is to promote social inclusion and reduce inequality by promoting economic growth. This may include efforts to provide housing for low-income families and create community spaces that bring people together.

Cities also have to deal with large amounts of waste generated by their residents, from organic food waste to packaging and construction materials. This requires careful management of landfills and other waste treatment facilities to prevent environmental damage and public health risks. Human activities in urban areas put a significant pressure on water bodies, which is particularly harmful to these bodies of water(UN-Habitat 2012). The water quality has degraded with time due to urbanisation that ultimately leads to increased sedimentation there by also increasing the pollutant in run-off. Direct pressures created by urbanisation tend to be concentrated around cities and result from the conversion of surrounding land, often agricultural, into urban infrastructure.

This leads to a direct loss of services provided by agricultural lands, including food production and carbon storage. World Bank Group,(2015). It can also lead to degradation and reduced ecological function of neighboring lands due to the effects of proximity to cities, through impacts such as anthropogenic disturbance, noise pollution and reduced air quality.Arsiso et al.,(2018).

Human settlements typically expand to meet the additional housing demands of a growing population and its socio-economic activities. This means the consumption of land, a limited resource needed for many other services. The efficiency of this development relative to population dynamics is key to conserving land and natural capital that may be degraded. Duttaet al.(2015)

The remote sensing technique provides a wide scope to map and monitor the urban growth and their consequences. To monitor the spatial and temporal pattern of urban expansion, multi-temporal satellite data have been used in the studies. Mohamed and Worku (2019; Li et al. (2018); Nguyen et al. (2018); Dutta et al. (2015); Rahman et al. (2012); Maktav and Erbek(2005).

The use of Geospatial technology in this study helps to identify the geographical data pertaining to environmental factors. It can be used to identity the agricultural land, forest, built up areas and the changes happening on the Land. Shalaby and Tateishi (2007; Rogan and Chen(2003). Geographic information system (GIS) mapping and analysis helps to identify the ecological area, habitat, environmental factors, built up, and population distribution. The use of Remote sensing helps to gather the data about the particular area which to study. Through GIS techniques it can be identified the changes happening in through the past years and the recent years

Understanding the impact of urbanisation on land, water and LST is important for sustainable urban planning and management.

An extensive literature review points out the following definitions, processes and challenges of the smart city initiative taken up by the Government of India. Neirotti et al (2014) has identified the importance of smart use of technologies to provide improved services to the citizens and thus improve their life quality. A smart city is one which has the potential to incorporate and efficiently use the latest technology to provide better services Paolo Neirotti, (2014). „A smart city is a system of systems – water, power, transportation, emergency response, built environment, etc. – with each one affecting all the others‟ Berst, (2015). During the last twenty years, the world has emerged as a competitive stage to usher developments into its cities, countries have come out to improve their infrastructures, providing the best services concerning environment, social and 18 economic conditions Freeman, (2017).

The study aims to analyse the impact of rising urbanisation on vegetation, water bodies and Land surface temperature. Like other cities in India, Panaji has been selected as a Smart city started in 2015 in Goa, under the smart cities mission through a "City challenge competition". As Panaji has a diverse tourism destination and also the beaches which attracts the tourists, it is full of heritage architecture. Panaji City is spread over an area of just 812 hectares and is a leading tourist destination for both domestic and international tourists and is home to essential infrastructure to support tourism activities. According to Ministry of Tourism data in 2011, Tiswadi taluka, where Panaji is located, received 6.90 lakh domestic tourists and 4.45 lakh foreign tourists. Panaji is one of the major tourist spots in the taluka and receives a large number of tourists throughout the year. Increasing tourism and rapid urbanization are putting pressure on the city's infrastructure, posing a major threat to the city's natural resources and ecosystems, such as mangroves, soil khazan and sand dunes. The city also has a rich heritage and several protected historical sites. All of these factors, along with future risks posed by climate change, make Panaji extremely vulnerable. With the aim of promoting economic growth and improving the quality of life of its citizens, the Indian government launched the Smart Cities Mission in 2015 with a plan to build 100 smart cities across the country. Mission to promote technology as a means to support local development and create smart outcomes for people. Smart cities need to be equipped with basic infrastructure through smart solutions.

Some of the possible attributes of smart cities would be ensuring electricity and water supply, better sanitation and solid waste management, efficient urban mobility and public transport, strong IT connectivity, e-governance and citizen participation as well as citizen safety. Panaji was selected as a smart city following a fast-track selection process. It also implements the AMRUT program. In addition to the government's Smart City Mission and the AMRUT programme, several non-governmental initiatives have given Panaji the opportunity to develop in an environmentally sustainable approach and enhance resilience against Climate Change. Ultimately, integrating the principles of sustainability and resilience into urban development can help create more livable, healthier and more environmentally friendly cities for current and future generations. Panaji's transformation into a smart city is likely to have a positive impact on its economic growth. Smart city initiatives often involve the integration of technology and infrastructure to enhance various aspects of urban life, including transportation, energy efficiency, waste management, and public services. By investing in these areas, Panaji can attract businesses, improve the quality of life for its residents, and stimulate economic development. Additionally, smart city projects can create employment opportunities, foster innovation, and attract investment, further contributing to the city's economic growth.

1.2. Objectives

The topic of this study is to identify the changes in the Built Up, Vegetation, water and LST. As urbanisation has been increasing it is also affecting the surrounding areas and also the resources are decreases.

1. To analyse the trends of built-up area and vegetation in Panaji Smart city.
2. To understand the tradeoff between Economic Growth and Environment.

1.3. Research Question

1. Is Panaji as a Smart City achieving a balance between Economic growth and Environmental Sustainability?

1.4. Research Gap

The gap in research is to examine the scenarios for urban development and environmental sustainability in Panaji Smart City.

1.5. Scope of the study

The scope of the study includes the current trends and dynamics of vegetation, water resources and LST in Panaji Smart City, the purpose of the research is to find the interaction and impact of these factors on sustainable development. This may involve analyzing data, using remote sensing techniques to gain insight into urban growth patterns and environmental change.

Chapter 2: Literature Review

2.1 Introduction

Literature review discusses the research work done on the issues related to the environmental factors such as vegetation, water and it focuses on urbanisation impacts on environment and the development of economic activities are also increasing.

2.2 Review of related literature

The physical and socioeconomic process of urban sprawl is the conversion of rural areas into cities (Jat et al. 2008). This process gradually transforms the social and physical landscape from having a rural to an urban character, in addition to manifesting itself as a rise in the land ceiling. India is anticipated to experience significant rural-urban shifts in the upcoming years (Mushore et al.2017; Tang et al. 2007). Countless research works have measured and examined the extent and effects of rural-urban transitions. India's national spatial policy neither qualifies nor outlines the location of urban limits or the potential expansion of cities suggested by (Fazal 2000; Jiang et al. 2007). Some rural communities are becoming urban areas due to urbanisation, while others remain rural. The spatial difference in this transformation varies, requiring more spatiotemporal data for accurate mapping. Urban heat islands (UHIs) are shown to result from the growth of rural areas, with high surface temperatures in agricultural and forest lands. Recent advancements in thermal remote sensing, GIS, and statistical methods have improved the monitoring and analysis of UHIs, influencing policy makers to promote sustainable urban development. Jeganathan et al. (2016). The main cause of urban population growth in India is livelihood opportunities in urban areas, which attract people from rural areas. The change in LU/LC in urban areas is the result of urban residents using natural, socio-economic factors over time and space. landscape. Dutta et al. (2015).

Remote sensing technology provides a wide range of tools and techniques as well as the availability of satellite data at different spatial and temporal scales has enabled the monitoring and quantification of regional expansion. urban areas and land use changes. At the same time, mapping built-up areas has proven to be easier and more accurate using land use indices (NDBI, NDVI, DBI, etc.) Bouhennache et al. (2018); Zhouet al. (2014); Kumar et al. (2012); He et al. (2010); Xu (2008). Land use and land cover maps for three years were prepared using Arc-GIS 10. land use and cover maps were cross-checked with field information using high-resolution images. Mohammady et al. (2015).Another type of information is supplementary data, which was added from 4,444 field surveys to verify the LULC classes. NDVI (normalized difference vegetation index) maps for the years 2008, 2014 and 2017 were estimated to be from LISS-III and Landsat satellite images. 4,444 Normalized Difference Vegetation Index (NDVI) map of 4,444 measured in 2008, 2014 and 2017 using 4,444 spatial analysis raster calculation tools. Rosenfield and Fitzpatirck-Lins (1986); Riebsame et al. (1994); Ruiz-Luna and Berlanga-Robles (2003); Owojori and Xie (2005); Yuan et al. (2005). Urbanization in watersheds increases impervious surface area, leading to reduced infiltration capacity and increased runoff. Reducing infiltration into aquifers may also reduce groundwater recharge. Therefore, it is necessary to evaluate the impact of urbanization on water resources and hydrogeological characteristics of urbanized river basins on environmental sustainability. “GIS". techniques were developed to map and monitor urban growth, land use/cover, and hydrogeomorphic features. Assessment of land-use and land-cover changes in Pangari watershed area (MS), India, based on the remote sensing and GIS techniques paper, study the fundamental relationship between the (built-up) urban area and how it changes its land use/cover, morphology and relationships between different components of the urban hydrological cycle (runoff). and (groundwater recharge). A study was conducted on two urbanized river basins, Anasagar and Khanpura, covering a large part of Ajmer city of the state of Rajasthan (India). The process of urbanization of the natural environment causes the artificialization of flow axes and natural water flows in urban areas. Algeria was affected by these phenomena and especially the Algiers region, the political and economic capital of the country. The expansion of urbanization in the Collines foothills and the Algiers Massif, with the presence of small river basins, has led to significant changes in land use. The objective of this treatment is to study the evolution of land use and impervious surfaces due to the growth of urbanisation. The research aims to assess land use changes due to urbanisation in Wuhan and Western Sydney over 30 years, using Landsat images to classify different land categories and determine the extent of land use fragmentation. Different SRM models have been developed, including subpixel/pixel spatial attraction models, Hopfield neural networks, and Markov random field-based models. The Artificial Neural Networks Predicted Wavelet Transform (ANN WT) method is used in this particular study by Mertens et al. (2004).Land use and land cover change (LULCC) is a significant global environmental issue, impacting climate, ecosystems, biodiversity, and human activities. Human impacts on the Earth's surface have increased in the past two decades, driven by socio-economic and biophysical factors. The Citarum watershed in Java is facing serious threats due to rapid urbanization, forest changes, and agricultural intensification, leading to a decline in water quality. Monitoring LULCC in the watershed is crucial to prevent further degradation. This study used GIS and remote sensing techniques to track LULCC in the upper Citarum watershed . Infrastructure is vital in managing the increasing population and creating better urban living spaces. Water bodies in cities are facing stress from human activities, altering their hydrological role. Evaluating the impact of land use changes on water bodies' hydrology at urban, catchment, and water body scales is crucial but challenging due to methodological limitations. This literature review summarizes various methods used to study the effects of urbanization on waterways. Brar and Chandel (2012) utilized Survey of India topography and Landsat satellite data to analyze wetlands in Punjab. Suriya and Mudgal (2012) found a 63.79% reduction in watersheds in Adyar Basin, India. Zope et al (2015) studied watershed loss in Mumbai. Traditional methods of distinguishing built and unbuilt areas have limitations, with accuracy typically below 80%. Various studies have used multiple classification methods to improve accuracy, with some achieving around 85%. The normalized difference shape index (NDBI) has been proposed as a simple process for automatic mapping of populated areas, based on the spectral response of built-up areas in satellite images. However, limitations exist, as certain types of vegetation can have higher reflectance in the mid-infrared wavelength range, leading to mixed data. To address this, the author suggests an index-based built-in index (IBI) as a more effective method for identifying built-up land in satellite imagery.The integrated watershed management approach focuses on balancing the needs of people and the environment while securing ecosystem services and natural diversity. It takes into account the needs of society and the environment amidst population pressure and demands for higher productivity. The evolution of watershed management, potential uses of new technologies, current issues, and the future of watershed management and research are discussed in this article, along with case studies from. Dianchi Lake in China is a prime example of a water body that has been negatively affected by rapid industrialization and urbanization in the surrounding area since the country's economic reform in 1978. The main objective of this study is to investigate the spatio-temporal patterns and mechanisms of land use/land cover changes in the Dianchi Lake Basin after China's economic reform using remote sensing, GIS, and landscape measurement techniques. Basin analysis is crucial in hydrological studies for various purposes like groundwater potential assessment and environmental assessment. Physiographic characteristics of watersheds such as size, shape, slope, outflow density, and inclusions play a significant role in hydrological phenomena. SRTM data and GIS techniques are effective tools for computational morphometric analysis. The Wailapalli watershed in Andhra Pradesh was analyzed using these methods.

2.2 Techniques used in Remote Sensing and GIS

The study used the LST derivation method in line with the LANDSAT Science Data Users Manual to analyse urban spatial patterns and changes. Urbanisation was found to be fragmented, with suburban and urban settlements increasing while rural settlements decreased. The expansion includes low density fragment and ribbon extension, impacting socioeconomic factors and transportation needs. This expansion may be exceeding the area's capacity, leading to environmental degradation. The study uses Landsat Thematic Mapper (TM) data from 1991 and 2011, Enhanced Thematic Mapper (ETM) data from 2001, and operational data from Terrestrial Imagers/Thermal Infrared Sensors (OLI/TIRS) from 2019 have in use to exploit urban areas. To extract (map) the built-up area, built-in index (IBI) based indicators were used to extract the built-up area. The built-up area extracted from is then used to calculate the built-up density/urban compactness ratio. Kappa statistic is used to evaluate accuracy, linear regression technique is applied to evaluate the space-time relationship between population and built-up area. Some studies suggest the methodology they asussed are that the satellite images were calculated by assigning markers to each pixel and dividing the area into four classes based on the specific numerical values (DN) of the modified landscape elements. Land use and land cover maps for three years were prepared using Arc-GIS 10. Land use and land cover maps were cross-verified with ground-truth information using high-resolution images. Another type of information, which is added from field surveys to verify LULC classes. NDVI (normalized difference vegetation index) maps for 2008, 2014 and 2017 were estimated from LISS-III and Landsat satellite images.

When calculating NDVI values, the output is displayed on a grayscale raster map with an index ranging from 1 to −1. The images from Wuhan were taken during September or October when vegetation was dense, with similar conditions in Sydney during early spring. A 5–6-year timeframe was considered adequate to assess land use changes in both cities, consistent with previous studies. The datasets included images from Landsat 5 TM and Landsat 8 OLI sensors, downloaded from the USGS Earth Explorer website.

According to the studies discussed in the introductory section, the focus was primarily on the administrative boundary scale or the watershed boundary scale, rather than a combination of the two. Therefore, this study aims to assess the impact of urbanization on reservoir hydrology at three different scales: (a) fully urbanized urban extent, (b) catchment area, and (c) micro watershed extent. Remote sensing (RS) technology utilizes electromagnetic radiation to gather information and images of land and water surfaces. This data source allows for the study, identification, classification, and monitoring of various watershed components such as land use, physiography, soil distribution, and drainage characteristics. RS, often used in conjunction with GIS, can provide spatial input data for watershed management models, especially in remote areas. Singh and Woolhiser (2002) highlighted GIS's importance in hydrological simulation models for assessing human activities' impacts on water bodies. Prenzel et al. demonstrated the effectiveness of these methods in extracting thematic land and surface change data in an Indonesian basin. Land use/land cover classification is essential for planning at both national and city levels to address issues such as uncontrolled development, environmental degradation, loss of agricultural land, wetland destruction, and loss of important habitats for fish and wildlife. Classification is a complex process that involves categorizing objects based on relationships. Land use/land cover classification maps for the years 1974, 1988, 1998, and 2008 were created for the Dianchi basin. Evaluation using a confusion matrix based on ROI data and high-resolution images showed classification accuracies of 78.85%, 88.94%, 92.36%, and 94.44% for the respective years. Resampling of 1974 images to 30m resolution slightly lowered accuracy. Overall, the results meet LULCC monitoring needs in the Dianchi Basin. Regional expansion of built-up area from 1991 to 2019. Spatio-temporal pattern analysis of built-up area in Surat shows continuous expansion of built-up area according to in all directions and in all areas except central area . The highest increase in built-up area from 1991 to 2019 of was observed in the South West Zone (844.76%), followed by the West Zone with (693.11%) and the South Zone is (623.79%), while the lowest increase was recorded were observed in the central region. At the regional level, there was variation in the increase in built-up area during each decade, as some residential areas had the highest increase from 1991 to 2001. but the lowest increase from 2011 to 2019 and about 4,444. The final classified land use map shows a matrix of changes for areas that vary from one category to another between the specified dates. In addition, the total area of land use and land cover is expressed in units of hectares and the proportion of each type of land use and land cover between different periods is shown in Results of the classification method. Monitoring shows a general decrease in agricultural land and an increase in unused, built-up land and water areas in 2008, 2014 and 2017, representing agricultural land was converted into wasteland in the catchment area (244). Areas developed for human habitation are classified as urban settlements, including all types of built-up areas, such as buildings, transport facilities, peanuts, commercial and industrial facilities, public recreational services associated with water, vegetation and paved roads. The results indicate that the rate of land development is greater than the rate of population growth. The results of mapping land use dynamics in the two river basins Wadi Koriche and Wadi Kniss show changes in space and time over the past 60 years. At the Wadi Koriche River basin level, the results show an increase in the area occupied by buildings by 13.the socio-economic and political transformation has led to a significant increase in the surface area of the built environment, to the detriment of vegetation and to the development of roads, causing damage to natural river beds.

At various sites, total suspended solids (TSS) and turbidity levels varied significantly, with TSS ranging from 217 to 5296 mg/L and turbidity from 245 to 3032 NTU. In Jahangirpur, a slum area, TSS levels were 40 times higher than those at the institution's IIT SAC. Physical parameter changes were observed under different conditions, with commercial sites showing differences despite belonging to the same category. Biological quality of effluent was below sewage standards at all sites, except for industrial sites. The study uses remote sensing to assess the environmental impacts of urban growth in Wuhan, China and Western Sydney, Australia. It addresses challenges like mixed pixels in satellite images by utilizing multi-member spectral mixture analysis and super-resolution mapping to create classification maps with higher spatial resolution. The study analyzed land use and land cover (LULC) changes in a specific area between 1997 and 2014, focusing on six main classes: forest, water bodies, urban areas, agriculture, open land, and bush. The results showed significant changes in the proportions of these LULC types during the study period. The forest area decreased by 41% between 1997 and 2005, and by 35% between 2005 and 2014. In contrast, agricultural land increased by 8% between 1997 and 2005, and by 2% between 2005 and 2014 The study introduces a new Index-based Built-up Index (IBI) to quickly identify built-up land characteristics in satellite images by utilizing thematic indexes like SAVI, MNDWI, and NDBI. The efficiency of IBI was validated using Landsat ETM images from Fuzhou City, revealing improved built-up land recognition and reduced background noise. Statistical analysis shows a positive correlation between IBI and surface temperature, indicating its relevance in capturing urban heat island effects.

Chapter 3: METHODOLOGY

3.1. Study Area

Panaji is the capital of the Indian state of Goa and the headquarters of the North Goa district. It used to be the capital of the former Portuguese Indian region. It is located on the banks of the Mandovi River delta in the Tiswadi subdivision (taluka). With a population of 114,759, Panaji is the largest urban area in Goa ahead of Margao and Mormugao. The heart of the city is Praça da Igreja (Church Square), home to the Jardim Garcia de Orta (Municipal Garden) and the Portuguese Baroque Igreja de Nossa Senhora da Imaculada Conceição, originally built in 1541. Other sights include the old and rebuilt Adilshahi. a palace (or Idalção Palace) dating from the 16th century, the Menezes Braganza Institute, the Saint Sebastian Chapel and the Fontainhas area, considered the old Latin Quarter, as well as the nearby Miramar Beach. Panaji houses the relics of Saint John Bosco (also known as Don Bosco) at the Don Bosco Oratory until August 21, 2011.One of the most sought-after sights in the capital is the Mahalaxmi Temple located along Dada Vaidya Road (Rua de Saudade during Portuguese times), Mahalaxmi deity is the main object of reverence for all Panjim people irrespective of caste, class, gender or religion.

The famous places of Panaji are 18th June Road (busy street). in the heart of the city and shopping area for tourists and for locals), the Mala area, Miramar Beach and the Cala Academy (a cultural center known for its structure built by architect Charles Correa). Kala Academy is where Goa showcases its art and culture. Panaji lies near the coastal side and it is also famous for the beaches such as Bambolim, Miramar and Dauna Paula.

3.2. Data collected

The data collected for this study is secondary Data from USGS Earth Explorer. The Study examines the Panaji Smart city's environmental health and the economic growth with the use of four major indicators namely Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-up Index (NDBI), Normalized Difference Water Index (NDWI), and Land Surface Temperature (LST). The data for the study was obtained through USGS Earth Explorer.

The time period covered in this study is from (1991 to 2023) a total of 31 years. By taking all the variables into account to see the changes of the dependent variable on the independent variables.

The four indicators used in the study to assess the health of the Panaji Smart city and to assess the changes for 31 years. This study examines the connection between the environmental factors in Panaji. This study understands the interactions and the influence between these variables and help to identify the and understand the connection if there is an increase in built up on vegetation, water and LST.

The use of GIS and Remote sensing is done to analyze the data, downloaded from USGS Earth explorer.

3.3. Methods used in the study

The study uses the method to calculate all the index, vegetation, Built-up, water and Land surface temperature. The GIS tools are used to calculate through Raster calculator following methods are used to calculate:

- (NDVI) Normalized Difference vegetation index is a measure used to assess and monitor the density of green vegetation on the Earth's surface based on satellite imagery.

Landsat 7 data, NDVI = (Band 4 – Band 3) / (Band 4 + Band 3) and for Landsat 8 data, NDVI = (Band 5 – Band 4) / (Band 5 + Band 4).

- (NDWI) Normalized Difference Water Index, is a remote sensing technique used to detect the presence and extent of water bodies in satellite imagery by comparing the reflectance of near-infrared and green light wavelengths.

  Landsat 7 data, NDWI = (Band 4 – Band 5) / (Band 4 + Band 5) and for Landsat 8 data, NDWI = (Band 5 – Band 6) / (Band 5 + Band 6).

- NDBI Normalized Difference Built-Up Index, is a remote sensing method used to identify and analyze urban areas and built-up structures in satellite imagery by comparing the reflectance of near-infrared and shortwave infrared wavelengths.

  Landsat 7 data, NDBI = (Band 5 – Band 4) / (Band 5 + Band 4) and Landsat 8 data, NDBI = (Band 6 – Band 5) / (Band 6 + Band 5).

- (LST) Land surface temperature (LST) refers to the temperature of the Earth's surface as measured remotely from satellites or other platforms. It represents the thermal energy emitted by the land surface and is an important parameter for understanding processes such as urban heat island effect, land-atmosphere interactions, and climate change impacts.

The following steps to calculate LST are:

1. TOA (L) = $M_L * Q_{cal} + A_L$
2. BT = $(K_2 / (\ln (K_1 / L) + 1)) - 273.15$.

3. NDVI = (Band 5 – Band 4) / (Band 5 + Band 4)

4. P_v = Square ((NDVI – $NDVI_{min}$) / ($NDVI_{max}$ – $NDVI_{min}$))

5. $\varepsilon = 0.004 * P_v + 0.986$.

6. LST = (BT / (1 + (0.00115 * BT / 1.4388) * Ln(ε))

After Calculator the Grid Shape file is created and after this the Zonal statistics has been calculated to find the Mean values of all the index. The calculated Zonal statistics is then transferred into Rstudio to find the regression model of each Index.

CHAPTER 4: STUDY AREA: PANAJI SMART CITY

4.1. Introduction

Panaji, the capital of the state of Goa, is among the ninety-eight cities identified as potential smart cities by the Government of India under its flagship Smart Cities initiative. Panaji Municipal Corporation is now competing among 20 selected cities for funding for realization of a smart city. ICLEI Local Governments for Sustainable Development, South Asia is proud to help Panaji city develop a sustainable smart city proposal with the active participation of local stakeholders and citizens. The Panaji Smart City initiative was launched on 14 October 2015 in Panaji, Goa in the presence of Hon. The Deputy Prime Minister of Goa, Shri. Francis D'Souza, Hon'ble MLA - Panaji Constituency, Shri. Sidharth Kuncolienkar and Hon. Panaji Mayor Shri. Shubham Chodankar and other leading experts and citizens of the city. Transportation, Solid waste processing, cultural heritage and culture; Health care and education became priority areas.

Smart City Mission focuses to build convergence, more than ever, to better leverage the opportunities available under national programs such as AMRUT, HRIDAY, Housing for all, Swachh Bharat Mission and all other programs connected to social infrastructure such as Health, Education and Culture. The project involves the preparation of the Panaji Smart City Proposal based on the mission guidelines and through extensive citizen consultation process. The Government of India launched the Smart Cities Mission in 2015 to develop infrastructure and best management practices. This project seeks to assess whether the Panaji Smart City.

The project is in line with the Smart Cities Mission objective of "creating model cities that can initiate planned and rapid urban development along desired lines".

Designing the cities to face the Challenges of Rapid Urbanisation

India's GDP growth rate exceeds 7%, making it one of the fastest developing countries globally. However, this economic growth is challenged by the rapid population growth, particularly in urban areas. The urban population in India is projected to reach 600 million by 2030 and 800 million in the next 20 years. Currently, 30% of the population resides in urban areas, contributing 63% to the GDP. The World Cities Report predicts that 40-50% of India's population will live in urban areas between 2030 and 2050.

The increasing urbanization in India is expected to contribute significantly to the GDP, with 75% predicted to come from urban areas by 2030. However, the lack of adequate infrastructure in cities hinders the development potential of urbanization. Rapid urbanization leads to negative externalities in both urban and rural areas, as migration.

To address these challenges, the Indian government has launched initiatives such as the Smart City Mission and the Atal Mission for Urban Rejuvenation and Transformation (AMRUT). These programs aim to enhance basic infrastructure in cities, promote sustainable growth, and stimulate urban development. The AMRUT Cities Program targets 500 cities to improve infrastructure such as water, sanitation, open spaces, and public transportation. The 100 Smart Cities Mission focuses on modernizing existing mid-sized cities and developing satellite towns of larger cities. Both initiatives require significant investments from the government, with the aim

of attracting funds from various sources including private investors and development banks. Smart governance and regulations are crucial for the success of these programs, requiring institutional and policy reforms. Transparency in management processes is essential for ensuring the effectiveness of urban projects and achieving the desired outcomes of urban development initiatives in India.

A smart city uses ICT to create a sustainable urban environment with each city developing its own concept and plan. The World Economic Forum's Urban Development Program focuses on India, offering recommendations to accelerate smart city deployment and strengthen governance. This includes working with the private sector, improving citizen participation, and streamlining permitting processes. Many states in India have already improved their permitting processes to attract foreign investments and drive industrial and GDP growth. Smart solutions in areas like environmental protection, health, transport, and waste management will lead to job growth, particularly in IT and IS. Overall, smart city projects aim to improve the quality of life, create a more sustainable environment, and boost economic growth through technology-driven solutions.

The government selects Indian cities as part of the smart cities mission through the 'Urban Challenge Competition', which creates identity connection and bonds with the local community. The public, ULBs and the state government will work as a team to apply for the tender process and receive resources support thereby increasing awareness of the program and related projects.

The Smart Cities Mission aims to develop at least two smart cities in every India 29 state where cities with more than a million inhabitants can become potential smart cities; In addition, it is believed that state capitals, heritage cities and conurbations can be smart cities. The Smart City Mission focuses on sustainable and inclusive\development and the idea is to look at compact areas, create a replicable model that acts as a beacon for other aspirants Option. Panaji city meets the selection criteria as it is the state capital and a heritage city. There are nearly 900 heritage structures in and around Panaji, according to statistics from Goa Heritage Action Group (Heritage Conservation Phase 1 - Heritage Conservation Phase 1 - Inventory and Classification of Heritage

Structures in Panaji, 2014). However, according to the Provisional Population Census of India 2011, the population of the state in the metropolitan area is only 114,759. It is also a compact area and its development aims to "create a replicable model that serves as a beacon for other aspiring cities".

Panaji Smart City Objectives:

· Enhance quality of life

· Promote heritage and cultural diversity

· Progress in productive knowledge and economic status

· Introduce environmentally sustainable methods

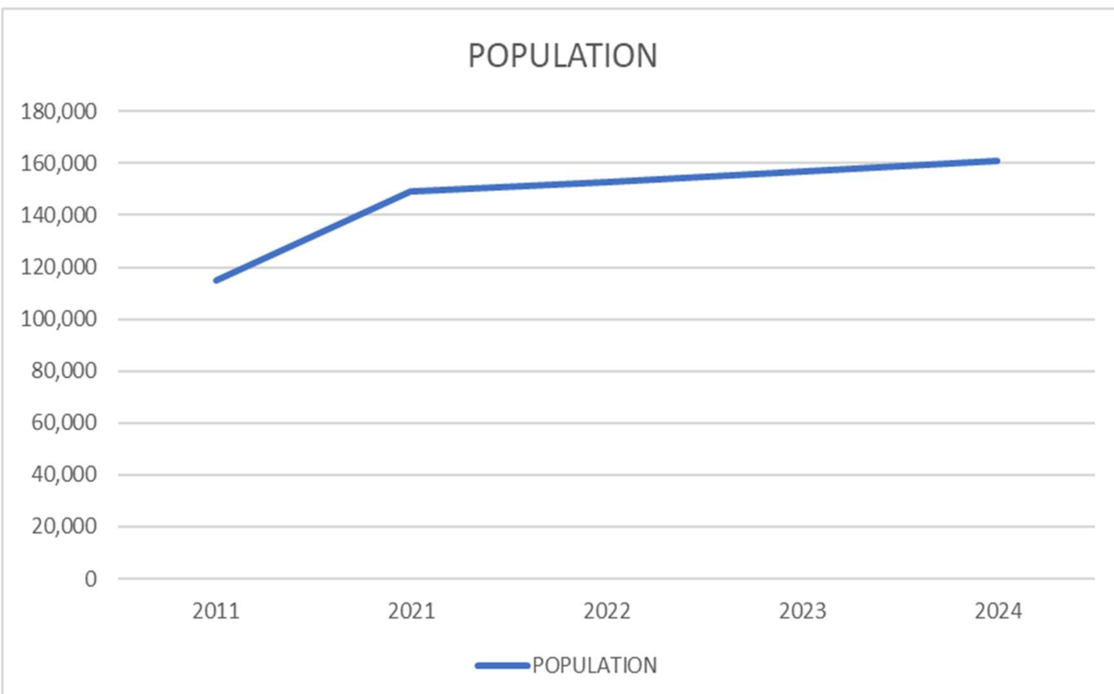
CHAPTER 5: ANALYSIS

5.1. Census data : Panaji City

The population of Panaji city is around 161,000 in 2024. The last census was done in 2011 . The Above table signifies the census data from 2011 to 2024 of Panaji Smart City. The population of Panji city in 2011 was around 114,759 and it gradually increased to 161,000 in 2024 which shows that there is a huge growth in population in Panaji Smart City.

5.1.1. Population Census Graph

Graph No. 5.2. Population Census Graph



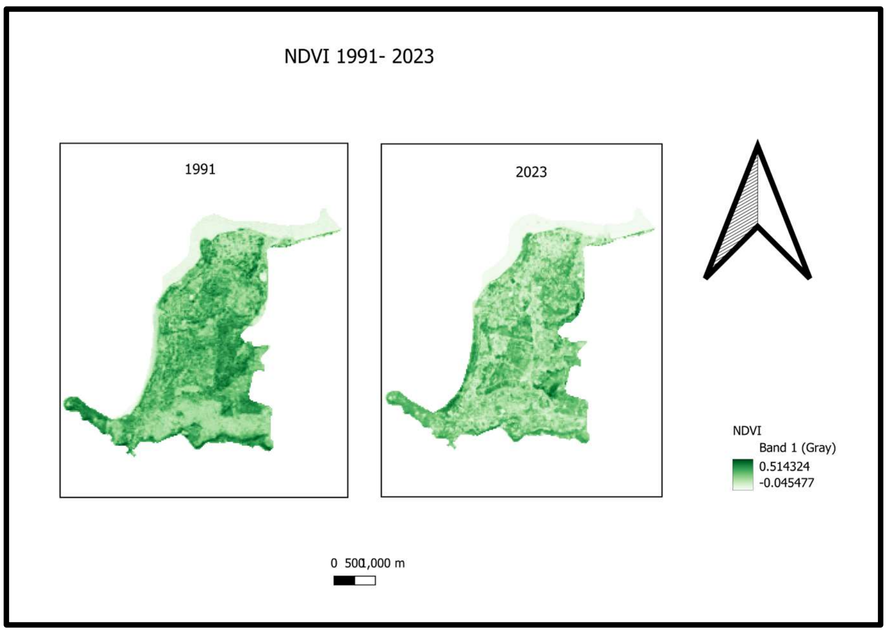
The above graph shows that there is a drastic increase in population from 2011 to 2024. (Census 2011).

As per the census 2011 data, The children (0-6 age) population of Panaji is around 9.43 % of total Panaji UA population which is lower than National Urban average of 10.93 %. Total children in

Panaji Urban region were 10,824 of which male were 5,623 while remaining 5,201 children were female. The sex ratio of female to male in Panaji UA was found higher with a figure of 935 females against national urban average of 926 females per 1000 males. For children (0-6 age), girls were 925 per 1000 boys in Panaji Urban region against national average of 902 girls per 1000 boys.

5.2. Mapping: Vegetation Index, Water Index, Built-up index and Land Surface Temperature.

5.2.1. Map of Normalized Difference Vegetation Index (NDVI)

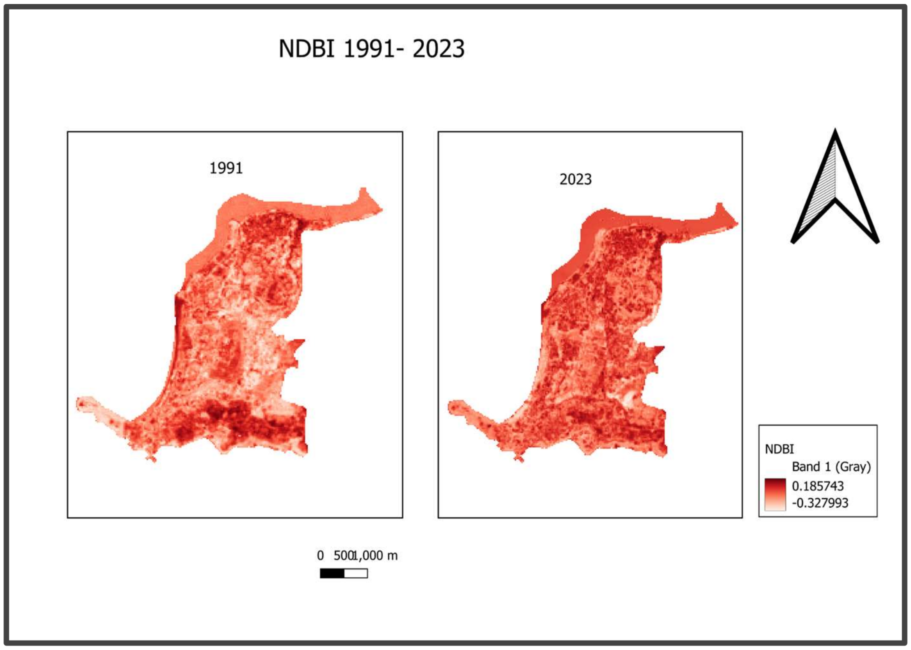


The above Map signifies the Panaji city Vegetation, it shows the maps of 1995 and 2023. The map signifies the difference of vegetation for each year. The dark green shows that there is a good vegetation in 1995 but as the years passed the vegetation tends to decrease as can be seen in 2023.

As there is more human made activities and there is increase in built-up the vegetation tends to decrease. Panaji as a Same city have been evolving over the years and new infrastructure has been taking place to make the Panaji Smart city as a tourist destination and also to increase the economic status of the city from employment, education, Health and many more, in order to build the infrastructure, there is a need to cut the trees so the new infrastructure can come in the places of vegetation, also rural people come in search of jobs in urban area this also increase the economic valuation of the city.

As can be seen in the above map the vegetation in 1995 was denser than the vegetation in 2023. The decrease in vegetation is because of increase in Buildups, the immense pressure on Earth by the human beings have led to change it the Land use Land cover change and there is a significant change in Land pattern as more and more infrastructure, roads are increasing with the increase in population there is more use of land by the Humans. The expansion of built-up areas often leads to the loss of natural vegetation, including forests, wetlands, and green belts. As urbanization encroaches on surrounding natural habitats, ecosystems are fragmented, and biodiversity declines. This loss of green spaces not only reduces the overall area available for vegetation but also disrupts ecological processes such as nutrient cycling and habitat connectivity.

5.2.2. Map of Normalized Difference Built-up Index (NDBI)



The above Map signifies the Panaji city Built-up ,if show the maps for the years 1995, 2000, 2005, 2010, 2015 and 2023. The map signifies the difference of Built-up for each year, as the vegetation tends to decrease shown in the (figure. 5.3.2. Map of Vegetation index) the Built-up level tends to increase with a decrease in vegetation. The white part in the year 1995 shows that there is less built-up but in 2023 the most of the part is covered with built-up areas as can be seen in the map.

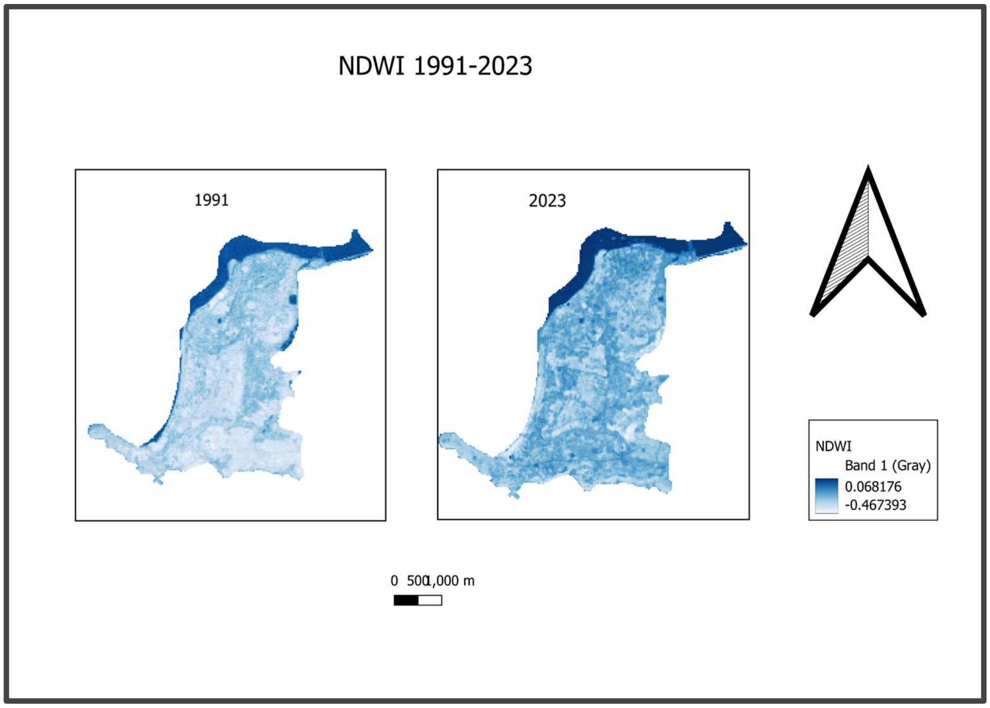
The expansion of built-up areas often leads to the loss of natural vegetation, including forests, wetlands, and green belts. As urbanization has an impact on surrounding natural habitats, ecosystems are fragmented, and biodiversity declines. This loss of green spaces not only reduces the overall area available for vegetation but also disrupts ecological processes such as nutrient cycling and habitat connectivity. Built-up areas are often associated with increased air pollution due to emissions from vehicles, industries, and other sources. Poor air quality can also inhibit plant growth and limit the diversity of plant species, particularly in areas with high pollution levels.

Consequently, urban vegetation may exhibit stunted growth, discoloration, or dieback in response to prolonged exposure to air pollutants.

The rise in economic activities associated with urbanization often drives changes in land use patterns, including the conversion of vegetated areas to built-up areas for residential, commercial, and industrial purposes. As urban populations grow and demand for land increases, natural habitats may be cleared to accommodate infrastructure development and urban expansion. This land use conversion can result in the loss of valuable ecosystem services provided by vegetation, such as carbon sequestration, soil stabilization, and water regulation, with potential implications for local economies and livelihoods dependent on these services.

The expansion of built-up areas can have significant impacts on vegetation health and biodiversity, affecting ecosystems, air quality, and habitat connectivity.

5.2.3. Map of Normalized Difference Water Index (NDWI)



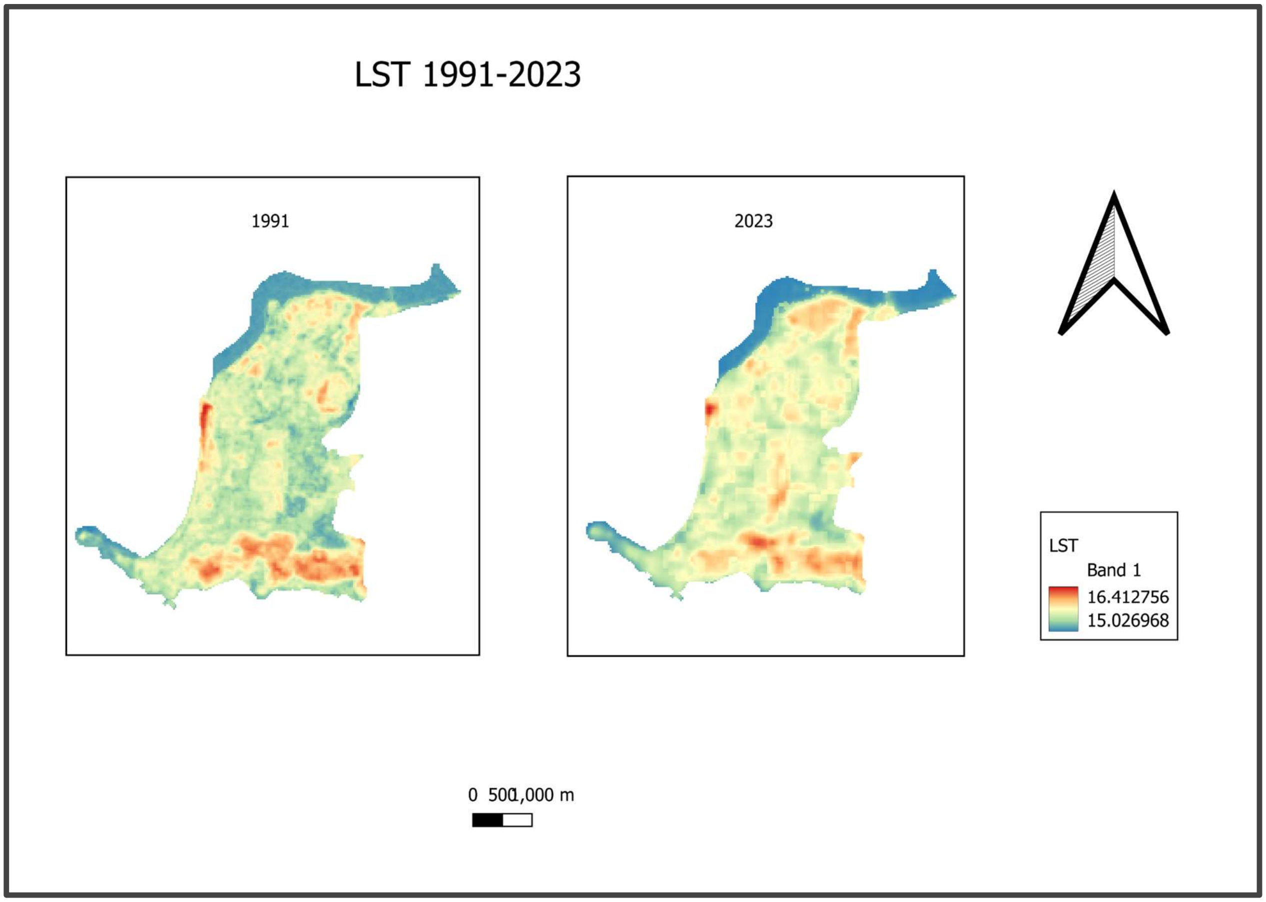
The above Map signifies the Panaji city Vegetation, it shows the maps of 1995 and 2023. The map signifies the difference of water for each year. The dark blue shows that there is water present in 1995 but as the years pass the water level tends to decrease in some parts as can be seen in 2023.

vegetation plays a critical role in intercepting rainfall and reducing surface runoff. When rain falls on vegetated surfaces, plants absorb water through their roots and canopy interception, slowing

down the movement of water over the land. This process helps to recharge groundwater aquifers, reduce soil erosion, and mitigate the risk of flooding by delaying the onset of peak flows. However, in areas where vegetation has been cleared or degraded, such as urbanized or agricultural landscapes, surface runoff increases, leading to more rapid and erosive flows that can exacerbate flooding and sedimentation in water bodies. In the areas where vegetation has been cleared or degraded, such as urbanized or agricultural landscapes, surface runoff increases, leading to more rapid and erosive flows that can exacerbate flooding and sedimentation in water bodies.

The loss of vegetation can have far-reaching consequences for water resources, affecting surface runoff, groundwater recharge, streamflow dynamics, water quality, and ecosystem function. Built-up areas can contribute to water pollution through various mechanisms such as surface runoff, industrial discharge, and sewage effluent. When rain falls on impervious surfaces such as roads, rooftops, and parking lots in built-up areas, it can pick up pollutants such as sediment, heavy metals, nutrients, and contaminants from vehicles and buildings. This polluted runoff can then flow into water bodies such as rivers, lakes, and streams, degrading water quality and compromising the health of aquatic ecosystems.

5.2.4. Map of Land Surface Temperature (LST)



The above map signifies the Panji city Land surface temperature as how increase in urbanisation has led to increase in heat which leads to rise in the surface temperature. In the map it signifies that in 1995 there was low surface temperature whereas, in 2023 as the vegetation decreases and the built-up increases the Land Surface Temperature.

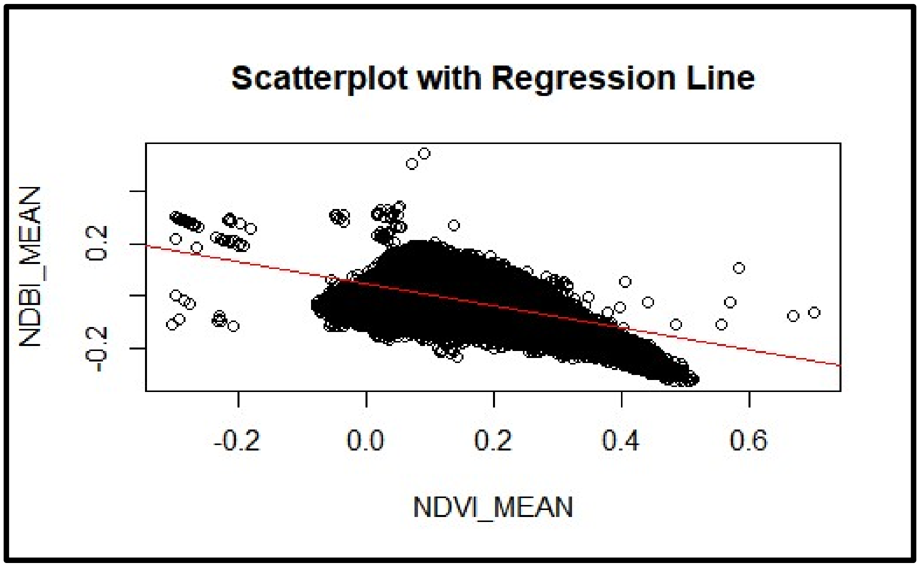
Vegetation plays a crucial role in providing various ecosystem services, including carbon sequestration, air and water purification, soil stabilization, and habitat provision. A decrease in vegetation cover reduces the capacity of ecosystems to provide these services, leading to soil erosion, reduced water quality, and loss of biodiversity. Vegetation helps regulate local microclimates by providing shade, releasing moisture through transpiration, and moderating temperatures. A decrease in vegetation cover results in higher temperatures and reduced humidity, leading to increased heat stress for plants, animals, and humans.

The increase in Land Surface Temperature (LST) in built-up areas exacerbates the urban heat island effect, characterized by higher temperatures compared to surrounding rural areas. Higher LST in built-up areas can worsen air quality by promoting the formation of ground-level ozone and other air pollutants. The increase in LST can exacerbate water stress in built-up areas by accelerating evaporation rates and reducing soil moisture levels. Higher temperatures increase the demand for water for irrigation, landscaping, and cooling purposes, placing pressure on water resources and infrastructure. This can lead to water shortages, increased competition for water resources, and challenges in meeting the water needs of urban populations.

5.3. Regression Model Interpretation

5.3.1. Model 1 -Scatter Plot with Regression line

Scatter Plot No. 5.3.1. Model 1- Scatter Plot



The above scatterplot with a regression line showing the relationship between the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Water Index (NDBI).

In the model described, NDVI is on the X-axis and NDBI is on the Y-axis. The data points are plotted with their NDBI values determining the position on vertical (Y-axis) and their NDVI values determining the position on horizontal (X-axis).

The abline in the scatter plot shows a downward slope which suggests that there is a negative correlation between NDVI and NDBI, as Built-up increase the vegetation decreases. The Built-up has a negative effect on the environment.

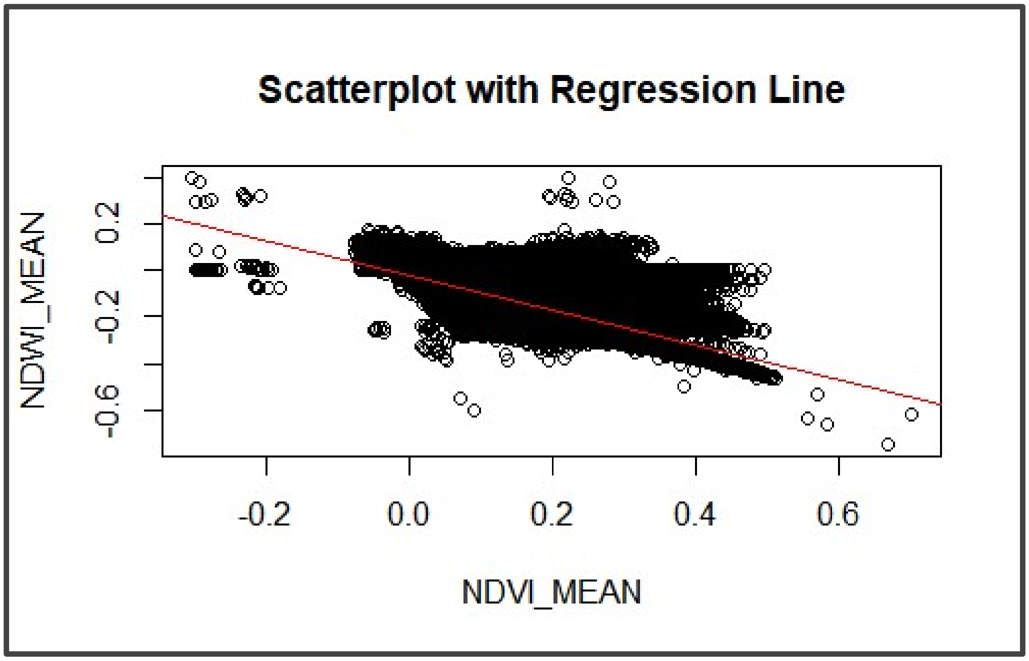
5.3.2. MODEL 1

NDVI_MEAN=$\beta 0+\beta 1$*NDBI_MEAN +ϵ

	Model 1
Constant Standard error	0.1493269 *** 0.0001213
NDBI Standard error	-0.7736656 *** 0.0015763
R SQUARE	0.3271
ADJUSTED R SQUARE	0.3271
OBSERVATION	495568

5.3.3. Model 2 -Scatter Plot with Regression Line

Scatter Plot No. 5.3.3. Model 2- Scatter Plot



The scatterplot shows a relationship between the Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water index (NDWI).

In the model described, NDVI is on the X-axis and NDWI is on the Y-axis. The data points are plotted with their NDWI values determining the position on vertical (Y-axis) and their NDVI values determining the position on horizontal (X-axis).

The abline in the scatter plot shows a downward slope which suggests that there is a negative correlation between NDVI and NDWI, as the vegetation decreases, the water level also decreases. As the level of vegetation tends to decrease due to other factors such as increase in built-up and also due to the setting up of new industrial areas, dumping of garbage has a negative effect on water and vegetation.

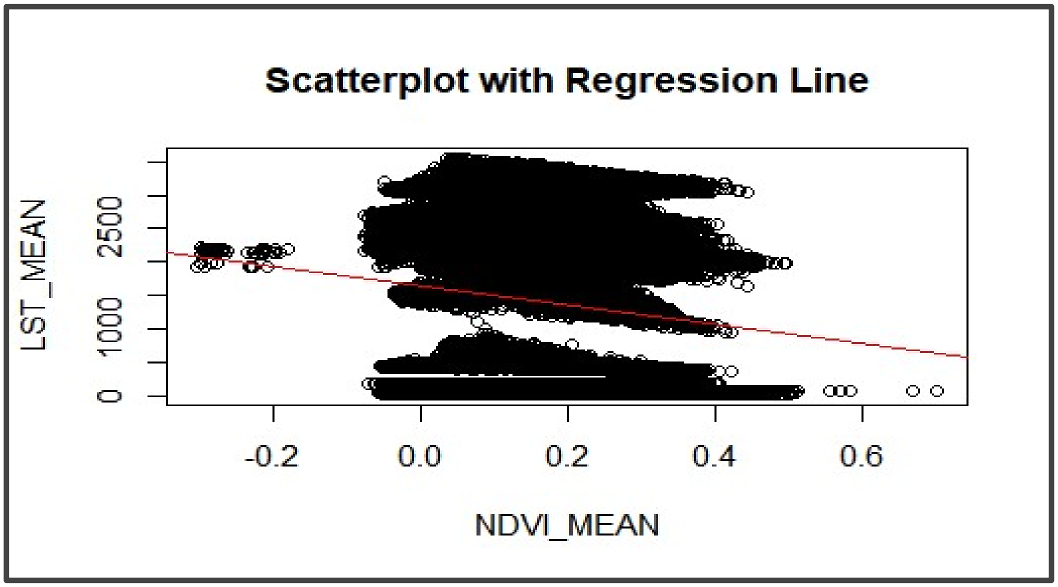
5.3.4. MODEL 2

$NDVI\_MEAN = \beta 0 + \beta 1 * NDWI\_MEAN + \epsilon$

	Model 2
Constant Standard error	0.0604063 0.0001686
NDWI Standard error	-0.7462305 0.0009446
R SQUARE	0.5549
ADJUSTED R SQUARE	0.5549
OBSERVATION	500499

5.3.5. Model 3 - Scatter Plot with Regression Line

Scatter Plot No. 5.3.5. Model 3- Scatter Plot with Regression Line



The scatterplot shows a relationship between the Normalized Difference Vegetation Index (NDVI) and Land surface Temperature (LST)

In the model described, NDVI is on the X-axis and LST is on the Y-axis. The data points are plotted with their LST values determining the position on vertical (Y-axis) and their NDVI values determining the position on horizontal (X-axis).

Areas with higher NDVI (healthy vegetation) tend to have lower LST (cooler temperatures), this is because healthy vegetation can shade the land surface, reducing evaporation and keeping the land cooler. Conversely, areas with lower NDVI (less vegetation) tend to have higher LST (warmer temperatures) due to increased solar radiation reaching the bare soil. The above scatter plot examines that as vegetation level decreases the Land surface temperature increases which creates more heat on the surface.

5.3.6. MODEL 3

NDVI_MEAN=β0+β1*NDWI_MEAN +ϵ

	Model 3
Constant Standard error	1.844e-01 2.001e-04
LST Standard error	-7.886e-06 1.051e-07
R SQUARE	0.01134
ADJUSTED R SQUARE	0.01134
OBSERVATION	491111

5.3.7. MODEL 4

$$NDVI\_MEAN=\beta0+\beta1\times NDBI\_MEAN+\beta2\times NDWI\_MEAN+\beta3\times LST\_MEAN+\epsilon$$

	Model 3
Constant Standar error	2.600e-02 *** 1.298e-04
NDBI Standard error	-7.125e-01 *** 7.573e-04
NDWI Standard error	-7.450e-01 *** 5.752e-04
LST	8.108e-06 *** 4.236e-08
R SQUARE	0.8481
ADJUSTED R SQUARE	0.8481
OBSERVATION	491109

5.3.8. Panel Model

	Panel Model
NDBI Standard error	-7.0847e-01 *** 8.7255e-04
NDWI	-4.9940e-01 *** 7.3811e-04
LST	3.8317e-06 *** 3.1691e-08
R SQUARE	0.730
ADJUSTED R SQUARE	0.72047
OBSERVATION	473758

5.4. Regression Results

The formula used in 5.3.2. regression model 1 is NDVI_MEAN ~ NDBI_MEAN, which indicates that NDVI_MEAN is the dependent variable and NDBI_MEAN the independent variable

The above regression model shows the relation and the interaction between NDBI and NDVI. It shows how the increase in built-up has an impact on the vegetation level. The regression model explains that there is a negative impact of built up on vegetation. Specifically, as the Normalized Difference Built-up Index (NDBI_MEAN) increases, the Normalized Difference Vegetation Index (NDVI_MEAN) tends to decrease.

This implies that areas with higher levels of built-up structures have lower levels of vegetation. This regression model aims to predict the Normalized Difference Built-Up Index (NDBI) based on the Normalized Difference Vegetation Index (NDVI). The coefficient for NDBI_MEAN (-0.7736656) shows the projected change in NDVI_MEAN for a one-unit increase in NDBI_MEAN, while keeping all other variables constant. In this situation, as NDBI_MEAN grows by one unit, NDVI_MEAN is expected to fall by around 0.7736656 units.

The standard error estimates the standard deviation of the estimated coefficient. The p-value associated with this test is less than 0.05, indicating that the coefficient for NDVI_MEAN is statistically significant. The R-squared value (0.3271) indicates that about 32.71% of the variability of NDBI_MEAN can be explained by the linear relationship with NDVI_MEAN. Because the Normalized Difference Vegetation Index (NDVI) is often used to assess vegetation density or greenness, a fall in NDVI_MEAN indicates a decline in vegetation cover. In the model's context, an increase in NDBI_MEAN, which represents built-up areas, indicates the expansion of built-up or urbanized regions. Thus, based on the negative coefficient estimate for NDBI_MEAN, we can conclude that an increase in built-up areas (as represented by higher NDBI_MEAN values) is connected with a decrease in vegetation density or greenness.

The 5.3.4. regression model 2 examines the relationship between the Normalized Difference Vegetation Index (NDVI_MEAN) and the Normalized Difference Water Index (NDWI_MEAN).

In this regression model NDVI_MEAN is a dependent variable and NDWI_MEAN is an independent variable. This model signifies the relation between water availability and vegetation as in howWater availability issues also have an impact on vegetation. As the water availability decreases as increase in Built-up, it also has an impact on surrounding vegetation.

The coefficient for NDWI_MEAN (-0.7462305) represents the estimated change in NDVI_MEAN for a one-unit increase in NDWI_MEAN, holding all other variables constant. In this case, as NDWI_MEAN increases by one unit, NDVI_MEAN is estimated to decrease by approximately 0.7462305 units.

The value for NDWI_MEAN is less than 0.001, indicating that the coefficient is highly significant. This means that there is strong evidence to suggest the relationship between NDWI_MEAN and NDVI_MEAN.

This statistic measures the proportion of variance in NDVI_MEAN that is explained by the independent variable (NDWI_MEAN). In this model, approximately 55.49% of the variance in NDVI_MEAN is explained by NDWI_MEAN.

The model provides valuable insights into the relationship between water content and vegetation density, which can inform decision-making processes related to environmental management, conservation efforts, and sustainable development initiatives.

The 5.3.6. regression model 3 examines the relationship between the Normalized Difference Vegetation Index (NDVI_MEAN) and the Land Surface Temperature (LST_MEAN)

The coefficient for LST_MEAN (-7.886e-06) represents the estimated change in NDVI_MEAN for a one-unit increase in LST_MEAN, holding all other variables constant. In this case, as

LST_MEAN increases by one unit, NDVI_MEAN is estimated to decrease by approximately 7.886e-06 units. The value for LST_MEAN is less than 0.001, indicating that the coefficient is highly significant. As the vegetation has a decline the land surface temperature tends to increase, this leads to more heat present on the surface area. This statistic measures the proportion of variance in NDVI_MEAN that is explained by the independent variable (LST_MEAN). In this model, approximately 1.134% of the variance in NDVI_MEAN is explained by LST_MEAN.

The model suggests that Land Surface Temperature (LST_MEAN) has a significant but negative relationship with NDVI_MEAN. This implies that higher land surface temperatures are associated with Lower vegetation density, as indicated by NDVI_MEAN.

The 5.3.7. regression model 4 is a combination of all the variables and it explores the relationship between the Normalized Difference Vegetation Index (NDVI_MEAN) and three predictor variables: Normalized Difference Built-up Index (NDBI_MEAN), Normalized Difference Water Index (NDWI_MEAN), and Land Surface Temperature (LST_MEAN)

The coefficients indicate that the estimated change in NDVI_MEAN for a one-unit increase in each predictor, holding other predictors constant.

NDBI_MEAN and NDWI_MEAN have negative coefficients, suggesting that higher values of built-up and water are associated with lower vegetation density.

LST_MEAN has a positive coefficient, indicating that higher land surface temperatures are associated with lower vegetation density.

The R-squared value of 0.8481 indicates that approximately 84.81% of the variability in NDVI_MEAN is explained by the three predictor variables in the model.

The 5.3.8. Panel model suggests that the increase in built-up has a negative effect on vegetation, water availability. It also suggests that as built-up increases there is an increase in Land surface temperature and the presence of heat in the low vegetation area increases.

This model seems to analyze the relationship between vegetation indices (especially NDVI - Normalized Difference Vegetation Index) and several environmental variables.

Dependent variable: NDVI_MEAN represents the mean or average of NDVI over the study area or over a period of time. NDVI is a measure of green vegetation density based on the reflection of near-infrared and red light.

Independent variables: NDBI_MEAN: Normalized Difference Index. It is often used to identify settlements or urban areas on satellite images.

NDWI_MEAN: Normalized Difference Water Index. It is used to identify bodies of water. LST_MEAN: Earth's surface temperature. It shows soil temperature, which can be an important factor affecting vegetation health and growth. This is a fixed effects panel data model, Panel data models are used when both cross-sectional data (different units such as regions, cities, etc.) and time series data are available. Fixed effects are used to control for unobserved individual characteristics that are unchanged over time but may affect the dependent variable. The purpose of this model appears to be to understand how population density, water availability, and land surface temperature affects vegetation health.

The coefficients of the independent variables (NDBI_MEAN, NDWI_MEAN and LST_MEAN) indicate the strength and direction of their effect on NDVI_MEAN. Negative NDBI_MEAN and NDWI_MEAN coefficients may suggest that higher values of built-in and water availability are associated with lower vegetation density (which is usually the case).A positive LST_MEAN coefficient suggests that higher soil temperatures are associated with more tall vegetation. density, which may indicate a threshold above which temperatures are harmful to plant health. Overall, this model helps to understand the complex interactions between environmental variables and vegetation health and provides insights that can be valuable in environmental monitoring, land use and ecosystem research.

Chapter 6: Conclusion

In this study, it shows the vegetation dynamics, land surface temperature (LST) and their effects on the environment and urban areas. This study has helped to fulfill the main objective of the study.

The study focuses on the trends of built-up area and vegetation in Panaji Smart city. It also focuses on understanding the tradeoff between Economic growth and environment. Study focuses on whether there is balance between the Economic Growth balancing Environment. As one of the objectives in the initiatives of Panaji Smart City, the objective suggests to introduce environmentally sustainable methods. It gives a clear picture of how the growth in urbanisation given a rise to Economic factors such as job creation, productive knowledge and economic status in all the backgrounds.

The use of GIS techniques and Remote sensing gives the detailed picture of the maps showing the changing in the vegetation, GIS tools used in the study helps to identify the difference in each index present in the study, It shows the difference from 1991 to 2023, which shows a significant change in vegetation as the built-up increases the vegetation index tends the change.

Our results show a complex interaction between vegetation loss, LST increase and their impact on ecosystem health, urban heat island effects and sustainable development. The study found that vegetation plays a crucial role in maintaining ecological balance, regulating microclimate and supply. essential ecosystem services. However, the loss of vegetation in urban areas has increased surface water runoff, reduced infiltration rates, and increased the urban heat island effect.

This has resulted in degraded water quality, hydrological processes and increased heat health risks in built environments. Our research highlights the integration of green infrastructure and sustainable land uses into urban planning frameworks to mitigate adverse impacts. impact of urbanization on vegetation and LST. The study emphasizes the importance of understanding the interactions between vegetation, land surface temperature, and urban environments for fostering sustainable development and livability in cities.

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