A

PROJECT

ON

“Satellite Insights into Green Spaces: Towards Sustainable Cities”

Under SDG-15 “Life On Land”

SUBMITTED TO

THE DEPARTMENT OF STATISTICS,

VEER NARMAD SOUTH GUJARAT UNIVERSITY, SURAT.

IN PARTIAL FULFILLMENT OF THE AWARD OF THE DEGREE OF

MASTER OF SCIENCE IN APPLIED STATISTICS

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Certificate

DEPARTMENT OF STATISTICS
VEER NARMAD SOUTH GUJARAT UNIVERSITY, SURAT

This is to certify that the project report entitled "SATELLITE INSIGHTS INTO GREEN SPACES: TOWARDS SUSTAINABLE CITIES", under ***SDG Goal 15: Life on Land****, submitted to the Department of Statistics, V.N.S.G.Uni., Surat, Gujarat, India, in partial fulfilment of the degree of M. Sc. (Applied Statistics) is a record of work carried out by "CHOVATIYA BANSIR JAYANTIBHAI (Roll No. 6), PAVASIYA NISHTHA RAJESHBHAI (Roll No. 27), PRAJAPATI BHOOMIT SHAILESHKUMAR (Roll No. 28), PRAJAPATI MEERA MANOJBHAI (Roll No. 29)" students of M. Sc. Applied Statistics (Semester-IV) for the academic year 2023-24 under my supervision and guidance.*

All sources of information/data have been duly acknowledged. No part of their analysis work has been submitted elsewhere for the award of any other degree.

Place: - Surat
Date:-

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THIS PROJECT IS

DEDICATED

TO

THE DEPARTMENT OF

STATISTICS

ALL OUR PROFESSORS

OUR GUIDE

OUR GROUP

AND

OUR CLASSMATES

ACKNOWLEDGMENT

We would like to express our sincere gratitude to all those who played a significant role in the successful completion of our project. First and foremost, we are grateful to **Dr. Arti J. Rajyaguru**, the head of the Department of Statistics at VNSGU, Surat. We also extend our heartfelt thanks to our project guide, Sahil Merai, for his guidance, support, and encouragement. Additionally, we express our thanks to the faculty members for their valuable feedback and assistance, which greatly contributed to the quality and success of our project.

Moreover, we would like to thank our classmates and friends for their collaboration and support during this project. Their insights and encouragement were invaluable to us. Lastly, we thank our families for their unwavering encouragement and understanding throughout our academic pursuits.

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<u>DECLARATION</u>

We, Students of M.Sc. (Applied Statistics Sem-IV) of the Department of Statistics at Veer Narmad South Gujarat University, Surat, here by declare that We have done our project work, entitled "SDG-15 LIFE ON LAND" under the guidance of **<u>Mr. Sahil Merai</u>** during academic year 2023-24. The information submitted here is true and original to the best of our knowledge.

This academic report is submitted only to the Department of Statistics, VNSGU, Surat and is used for academic purpose only.

We also declare here by that this same report will not be utilized for any other degree / diploma course and fellowship.

Date: -

Place: - Surat

BANSIR CHOVATIYA

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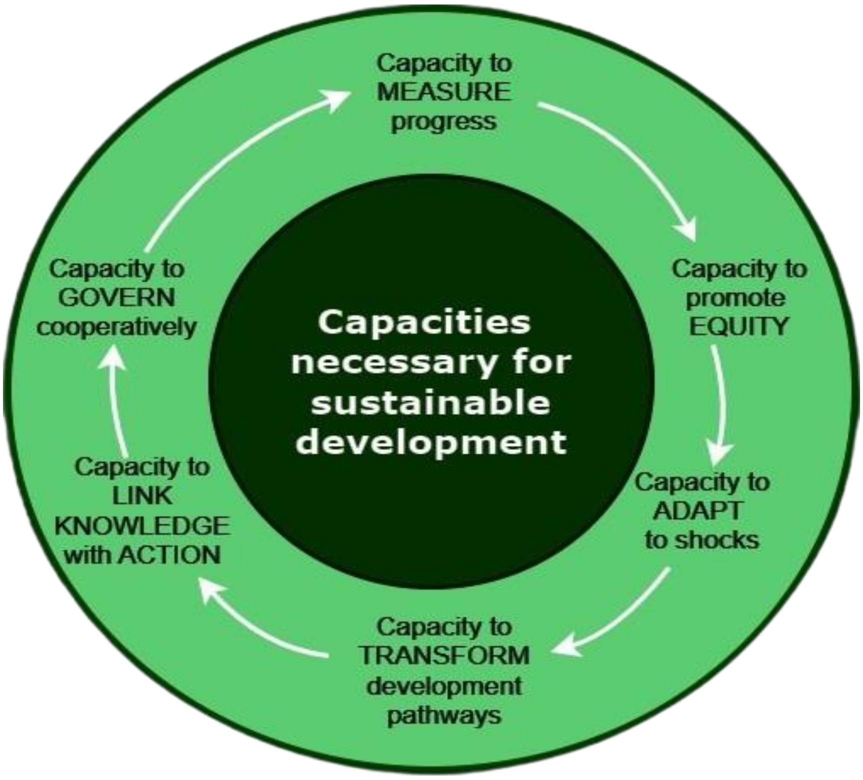
15 LIFE ON LAND

SUSTAINABLE DEVELOPMENT

Sustainable development is an organizing principle that aims to meet human development goals while also enabling natural systems to provide necessary natural resources and ecosystem services to humans. Sustainable development tries to find a balance between **Economic Development, Environmental Protection, And Social Well-Being.**



Sustainable development is how we should live today to ensure a better tomorrow. It's defined as "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs". Sustainable development requires six central capacities.

1. Capacity to **MEASURE** progress

2. Capacity to measure **EQUITY**

3. Capacity to **ADAPT** to shocks

4. Capacity to **TRANSFORM** development pathways

5. Capacity to **LINK KNOWLEDGE** with **ACTION**

6. Capacity to **GOVERN** cooperatively

SUSTAINABLE DEVELOPMENT GOALS

Sustainable development was first institutionalized with the Rio Process initiated at the 1992 Earth Summit in Rio de Janeiro. The 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, provides a shared blueprint for peace and prosperity for people and the planet, now and into the future. At its heart are the 17 Sustainable Development Goals (SDGs), which are an urgent call for action by all countries developed and developing in a global partnership. They recognize that ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth all while tackling climate change and working to preserve our oceans and forests.

WE CONTRIBUTE TO SUSTAINABLE DEVELOPMENT

- Biodiversity Conservation
- Urban Green Spaces
- Sustainable Urbanization
- Resilience to Climate Change

INTRODUCTION

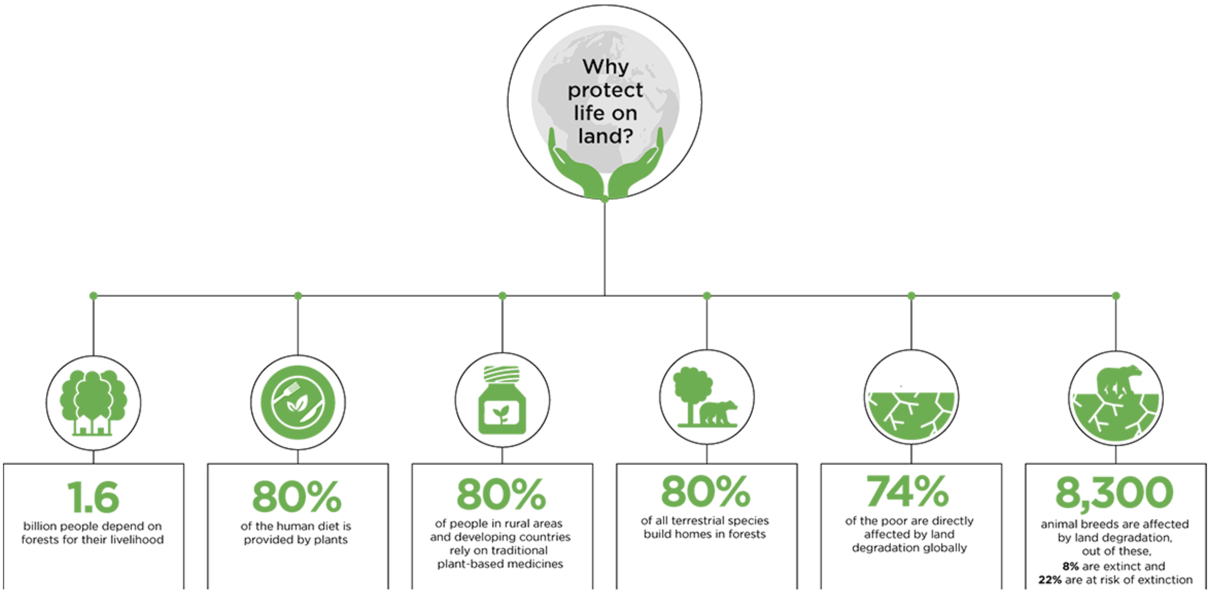
In the pursuit of sustainable development, the interconnectedness of goals underscores the need for holistic approaches to research and action. This study embarks on a multidimensional analysis of urban sustainability, leveraging satellite imagery to assess the intricate balance between built-up and green spaces within cities. We use satellite data to evaluate vegetation distribution and health, **measuring the vegetation to built-up ratio and elasticity to understand urban green space dynamics**. While our primary focus aligns with Goal 15 - Life on Land, aiming to safeguard terrestrial ecosystems, the implications of our research extend far beyond this solitary objective.

By delving into the land use patterns of urban environments, our research contributes to Goal 11 - Sustainable Cities and Communities, striving to foster inclusive, safe, and resilient urban spaces. Furthermore, our analysis of urban green spaces and built-up areas sheds light on their role in mitigating urban heat island effects and enhancing climate resilience, thereby intersecting with Goal 13 - Climate Action.

Moreover, the significance of urban green spaces transcends environmental considerations; they also play a pivotal role in promoting the physical and mental well-being of city dwellers, aligning with the aspirations of Goal 3 - Good Health and Well-being. Additionally, our commitment to collaboration and data sharing underscores the importance of Goal 17 - Partnerships for the Goals, as we recognize the collective effort required to achieve sustainable development objectives.

Preserving life on land is imperative for achieving sustainable development goals. **Target 15.1 calls for the conservation, restoration, and sustainable use of terrestrial and inland freshwater ecosystems.** Meanwhile, **Target 15.2 emphasizes the promotion of sustainable management of forests, halting deforestation, restoring degraded forests, and significantly increasing afforestation and reforestation globally.** Additionally, **Target 15.A-underscores the mobilization and enhancement of financial resources for the implementation of sustainable forest management.** This project aims to explore strategies and initiatives that contribute to these targets, safeguarding biodiversity, promoting ecosystem resilience, and fostering sustainable land use practices.

➢ WHY DOES IT MATTER?



Forests provide us with everything we need: air, water, and nourishment. Human life is equally dependent on the Earth and the ocean for food and livelihood. Approximately 1.6 billion people rely on trees for their livelihoods. More than 80% of all terrestrial animals, plants, and insects live in forests. 80 % human diet is provided by plants. 80 % of people in rural areas and developing countries rely on traditional plant-based medicines. 74% of the poor people are directly affected by land degradation globally. 2.6 billion people rely directly on agriculture for a living.

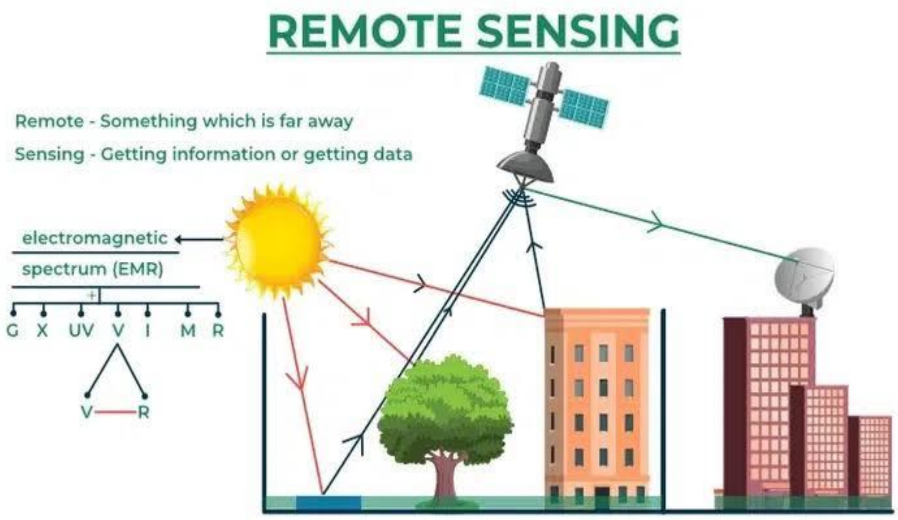
Forests cover around 31% of Earth's land surface. The world's total forest land area is 4.06 billion hectares (10.0 billion acres). Forests are one of the world's major carbon sinks, absorbing carbon from both natural processes and human activity. They also account for 50 percent of plant production.

Each year, the world loses approximately 10 million hectares of forest. This area is the size of Portugal. The loss of trees and other vegetation can lead to climate change, desertification, soil erosion, fewer harvests, flooding, higher greenhouse gas levels in the atmosphere, and a variety of other issues for Indigenous people.

Land conservation strikes a balance between nature and built buildings. It can assist in minimizing air and water pollution, maintain natural resources, and promote natural processes such as soil regeneration and flood prevention. Conserving land can also assist in lessening the effects of climate change. Land conservation can help to provide habitat for native plants and animals, especially endangered species, and biodiversity.

WHAT IS REMOTE SENSING DATA?

Remote sensing data is information about an object or phenomenon collected without making physical contact with it. It can include aerial and satellite photos, as well as data from the Global Positioning System (GPS). Remote sensing data can be collected using platforms such as aircraft, satellites, balloons, rockets, and space shuttles. Sensors collect data on these platforms.



SATELLITE

For our study, we used Satellites for data collection. A satellite is an object that orbits the sun, the earth, or another colossal body. When it comes to satellites, there are two basic categories: natural and man-made. Satellites serve a range of uses, including communication, weather forecasting, navigation, broadcasting, scientific research, and Earth observation. Natural satellites include planets, moons, and comets. The Earth has only one permanent natural satellite: the moon. The four most frequent satellite types are communication, earth observation, navigation, and astronomy. Currently, about 2,500 man-made satellites orbit the Earth.

We study life on land using a Sentinel-2 satellite.

- **Sentinel-2**

Sentinel-2 is a satellite mission that collects high-resolution optical images of Earth's land. It consists of two polar-orbiting satellites that support Copernicus Land Monitoring research. Sentinel-2 achieved overall accuracy between 76% and 84%.

Features:

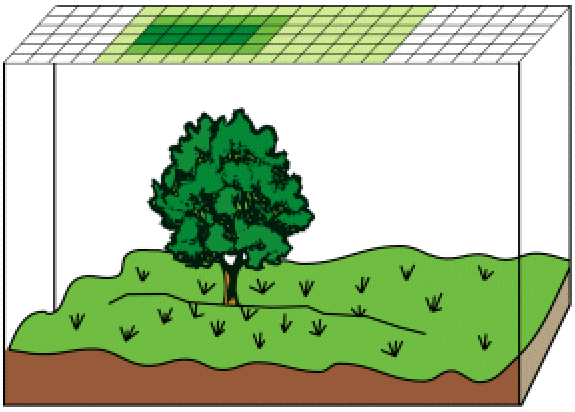
- **Multispectral Imaging:** Sentinel-2 captures data in multiple spectral bands, including visible, near-infrared, and shortwave infrared, allowing for detailed analysis of Earth's surface.
- **High Resolution:** It offers high spatial resolution (10 meters, 20 meters, and 60 meters) to distinguish fine details on the ground.
- **Global Coverage:** Sentinel-2 systematically covers the Earth's land surface, providing global and frequent observations.
- **Repeat Cycle:** The satellite has a short revisit time, meaning it revisits the same area on the Earth's surface frequently.

Applications:

- **Land monitoring:** Sentinel-2 provides high-resolution optical imagery, making it valuable for monitoring changes in land cover, land use, and urban development.
- **Agriculture:** It supports precision agriculture by monitoring crop health, vegetation indices, and crop classification.
- **Natural Disaster management:** It assists in assessing the impact of natural disasters like wildfires, floods, and earthquakes.
- **Water Quality:** The satellite's spectral bands enable the monitoring of water bodies, including assessing water quality and detecting changes in water features.

WHAT IS PIXEL?

The full form of the pixel is "Picture Element." It is also known as "PEL." A screen is made up of a matrix of thousands or millions of pixels. A pixel is represented by a dot or a square on a computer screen. A pixel in its basic form is a number in an array that describes the brightness and color of a point on an image when it is displayed.



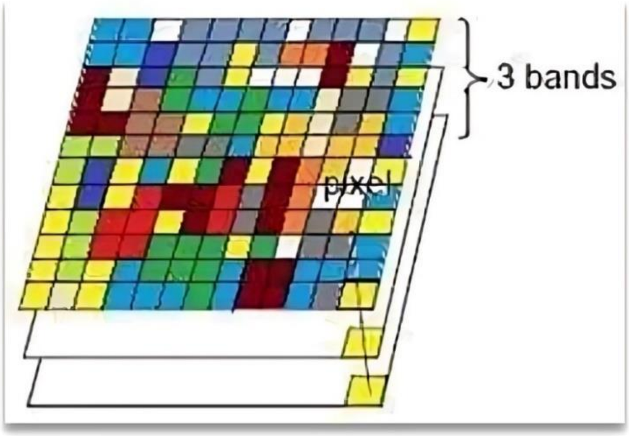
What Does Pixel Mean?

A pixel is the smallest unit of a digital image or graphic that can be displayed and represented on a digital display device. Pixels are combined to form a complete image, video, text, or any visible thing on a computer display.

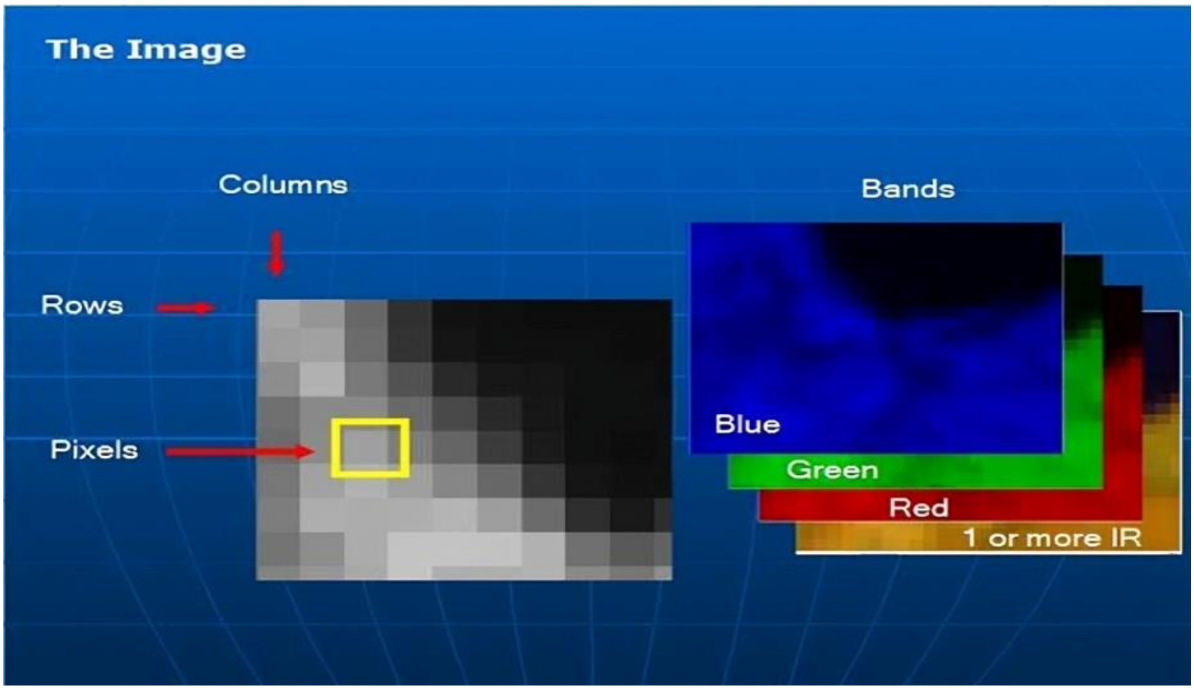
Just like the pictures on your television set, satellite imagery is made up of tiny squares, each of a different grey shade or color. These squares are called pixels and represent the relative reflected light energy recorded for that part of the image. Up to millions of pixels make up an image or video on a device's screen. Each pixel comprises a subpixel that emits a red, green, and blue (RGB) color, which displays at different intensities. Each pixel represents a specific color and brightness value, which collectively form the photograph. The number of pixels in an image sensor determines the resolution and detail captured by the camera.

WHAT IS BANDS?

A band is represented by a single matrix of pixel values, and a raster with multiple bands contains multiple spatially coincident matrices of pixel values representing the same spatial area.



Some images have a single band, or layer which is a measure of a single characteristic, of data, while others have multiple bands. Some sensors may have only 3 or 4 bands, others may have dozens, or hundreds which are called hyperspectral sensors. Many earth-observing satellites include bands that fall within commonly used 'windows', such as “red” or “near-infrared”.



-: Bands for Sentinel-2 :-

Band 1	(B1)	Coastal aerosol
Band 2	(B2)	Blue
Band 3	(B3)	Green
Band 4	(B4)	Red
Band 5	(B5)	Vegetation red edge 1
Band 6	(B6)	Vegetation red edge 2
Band 7	(B7)	Vegetation red edge 3
Band 8	(B8)	Near Infrared (NIR)
Band 8A	(B8A)	Narrow NIR
Band 9	(B9)	Water vapor
Band 10	(B10)	SWIR - Cirrus
Band 11	(B11)	SWIR 1
Band 12	(B12)	SWIR 2

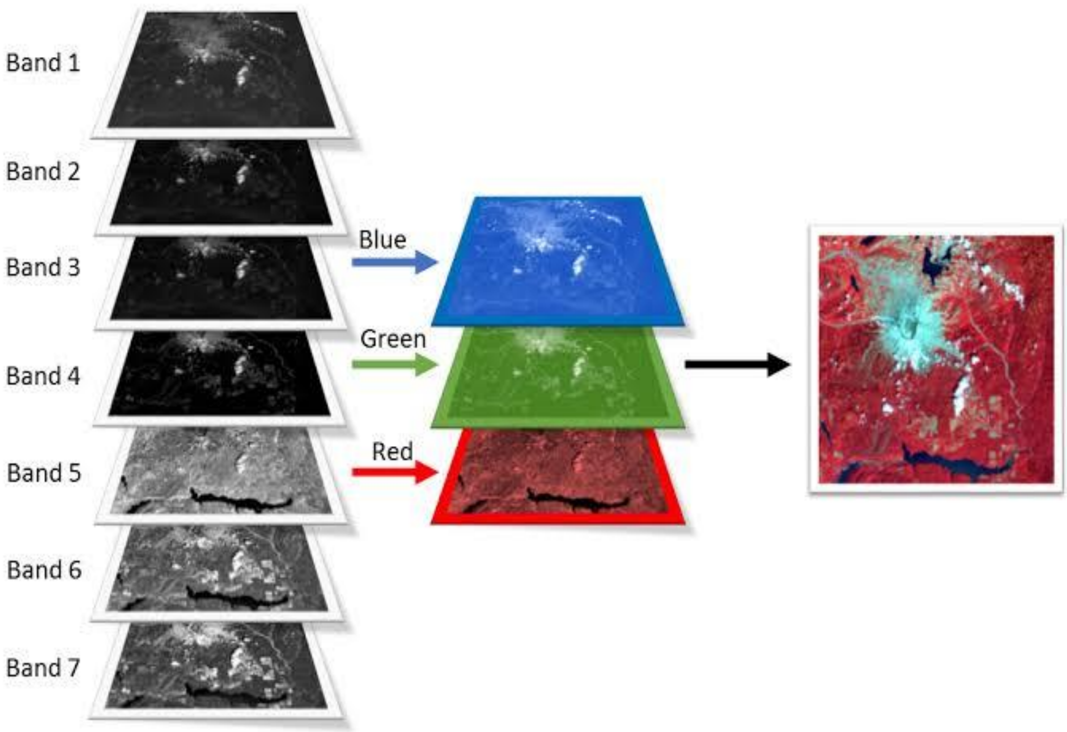
BAND COMBINATION

Bands are often combined in different ways to create images that highlight different features, such as vegetation or water. A *"band combination"* refers to the process of combining different bands or channels of image data to create a composite image.

The most common band combination is Natural Colour which is used to mimic what the human eye would see over a given region, another common combination is Colour Infrared which highlights the presence of vegetation.

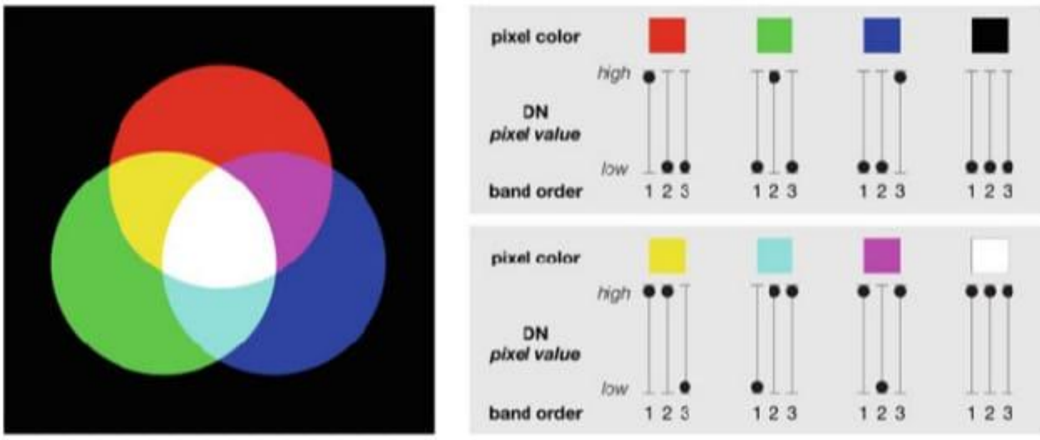
Band combinations are used to highlight the presence of certain materials and/or minimize the representation of other features. By combining bands in different ways and assigning them to different colors, we can create images that highlight specific aspects of the environment, such as vegetation health, land use, or temperature variations.

Color satellite images are composed of multiple, individual channels of data, each corresponding to a specific range of wavelengths. True color and false color composites are two different types of view that are used to gather information in Remote sensing data.



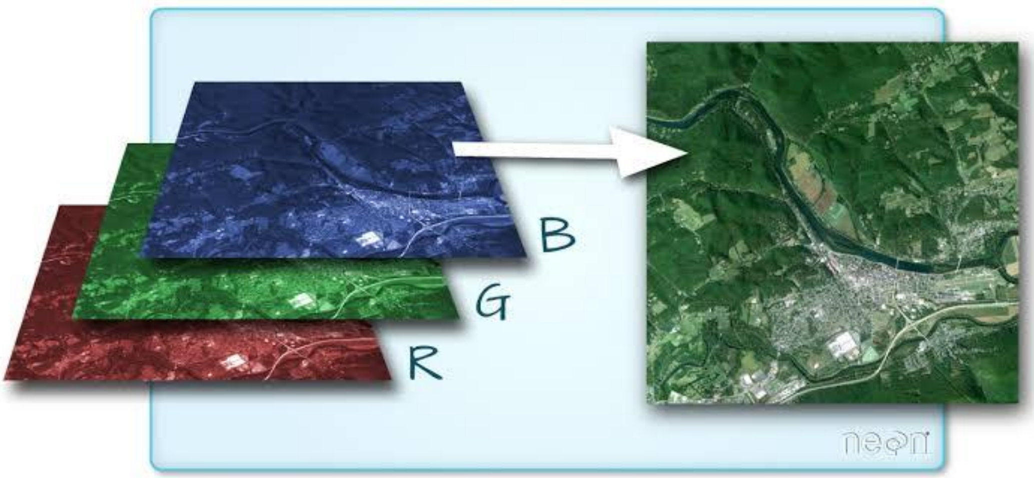
COLOR COMPOSITE

We can use color to compare these visual differences in the pixel values of each band layer all at once as an RGB composite. This method uses the three primary colors (red, green, and blue) to display each pixel's values across three bands. Many colors are formed by combining color primaries in various proportions. The same principles are applied to produce color images taken from airborne cameras or satellite sensors.



TRUE-COLOR COMPOSITE

A natural or true color composite is an image displaying a combination of visible red, green, and blue bands to the corresponding red, green, and blue channels on the computer. In a true color composite, the red, green, and blue channels correspond to the visible light spectrum, similar to what the human eye sees.



This type of composition shows objects on the Earth's surface in their true colors, making it easy to identify familiar features like forests, water bodies, and urban areas. This results in an image that closely resembles a natural photograph, with objects appearing in their true colors.

For example, vegetation appears green, water bodies appear blue, and urban areas appear grey or brown. The red channel is assigned to the band representing red light, the green channel to the band representing green light, and the blue channel to the band representing blue light.

GOOGLE EARTH ENGINE

Google Earth Engine is a cloud-based geospatial analytic platform that allows users to see and analyze satellite imagery of our world. It combines an immense database of satellite images and GIS information with strong computational capabilities, allowing scientists, academics, and developers to analyze and visualize changes to the Earth's surface across time. Numerous applications are supported by Earth Engine, such as studies on climate change, agriculture evaluation, deforestation detection, and environmental monitoring.

STUDY AREA

"If you want to start changes for sustainability you have to start from your city."

In our study, we focus on Surat City to address Goal 15. Surat is a city located in the western part of India in the state of Gujarat. Located on the banks of the river Tapti near its confluence with the Arabian Sea, it used to be a large seaport. "Surat, currently one of the largest cities in western India and the commercial and economic hub of South Gujarat, has witnessed significant infrastructural development in the past 10 years". It has a well-connected transportation system, including a domestic airport, railways, and a network of roads. The city has also witnessed rapid urbanization, leading to the development of modern amenities and residential complexes. Surat has experienced rapid urbanization over the past few decades, transforming from a traditional trading canter to a bustling metropolis. The city has attracted migrants from across India due to its strong economy and employment opportunities, leading to significant population growth. The city registered an annualized GDP growth rate of 11.5% over the seven fiscal years between 2001 and 2008. Surat is one of the cleanest city of India and is also known by several other names like “THE SILK CITY”, “THE DIAMOND CITY”, “THE GREEN CITY”, etc.

Surat city's total area is 461.6 Square kilometres. The planning area is located at 21.1702° N, 72.8311°E. It has an average elevation of 13 meters. Surat is divided into numerous zones, including the North, East, West, Central, South East, South West, and South. Each zone is further subdivided into Wards. There are 134 wards in Surat city.

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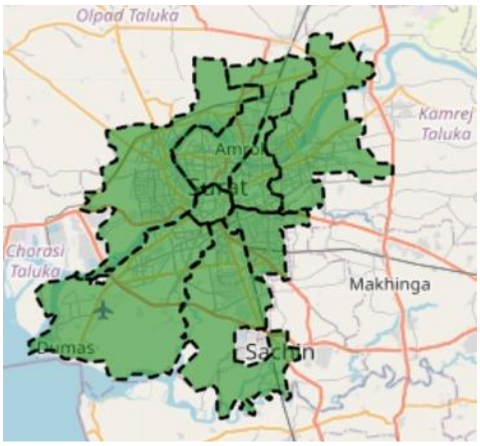


SHAPEFILE

Shapefiles are vector data storage formats for geographic characteristics. It records the location, shape, and attributes of these features. Shapefiles are a popular file format for geographical data. They save data as points, lines, or polygons. sites can indicate addresses, sites of interest, and parcel or ZIP Code centroids. A shapefile consists mostly of a main file, an index file, and a database table. A shapefile is often a collection of files with the same name but various file extensions. Some file types that make up a shapefile include SHP, SHX, DBF, PRJ, XML, SBN, SBX, and CPG.

INDICES

➢ Normalized Difference Vegetation Index :

we utilized the normalized differential vegetation index (NDVI). The Normalised Difference Vegetation Index (NDVI) is a statistic for assessing the health and density of vegetation. The NDVI is based on the idea that good vegetation absorbs the majority of visible light and reflects a significant part of near-infrared radiation. It is calculated from sensor data in two bands: red and near-infrared. NDVI is calculated as the ratio of red (R) to near-infrared (NIR) readings.

NDVI values range from +1.0 to -1.0. High NDVI values indicate healthy vegetation, while low values suggest sparse or stressed vegetation, such as during droughts or in areas affected by deforestation. NDVI is widely used in various fields, including agriculture, forestry, and environmental monitoring, to assess vegetation health, track changes over time, and make informed decisions about land management and conservation efforts.

➢ Enhanced Vegetation Index (EVI) :

The Enhanced Vegetation Index (EVI) is a vegetation index that can be used to measure vegetation greenness. It's generated from the Near-IR, Red, and Blue bands of each scene, and ranges in value from -1.0 to 1.0.

EVI is more sensitive in areas with dense vegetation and corrects for some atmospheric conditions and canopy background noise. It's also more responsive to canopy variations, canopy type and architecture, and plant physiognomy. EVI can be associated with stress and changes related to drought.

you can calculate EVI using the near-infrared (NIR), red, and blue bands available in Sentinel-2 data. The formula for EVI calculation is:

$$EVI = G * \frac{NIR + RED}{NIR + C1 * RED - C2 * Blue + L}$$

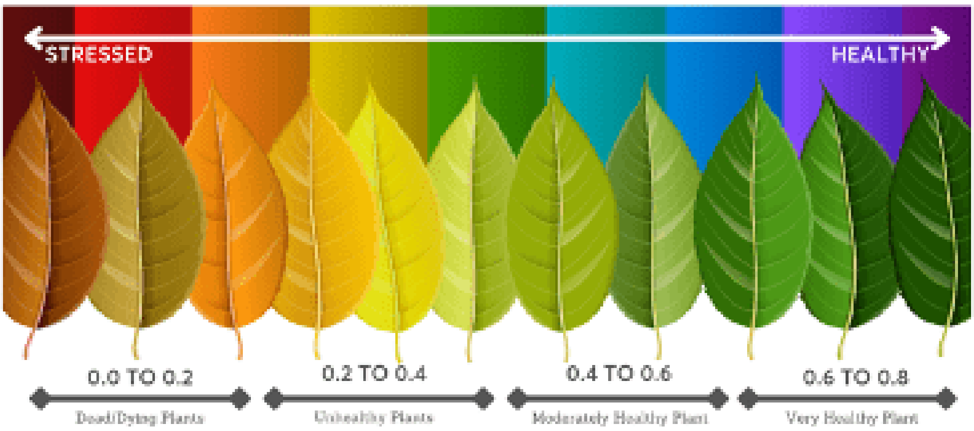
Sentinel 2: $NDVI = 2.5 * \frac{BAND\ 8 - BAND\ 4}{BAND\ 8 + 6 * BAND\ 4 - 7.5 * BAND\ 2 + 1}$

Where:

- NIR is the Near-Infrared band (band 8)
- Red is the Red band (band 4)
- Blue is the Blue band (band 2)
- G is the gain factor (usually set to 2.5)
- C1 is the coefficient of the aerosol resistance term (usually set to 6)
- C2 is the coefficient of the canopy background adjustment term (usually set to 7.5)
- L is the canopy background adjustment factor (usually set to 1)

EVI values typically range from -1 to 1.

- High positive values indicate dense vegetation, with values closer to 1 representing healthier and denser vegetation cover.
- Low or negative values can indicate sparse vegetation, non-vegetated surfaces, or the presence of clouds, shadows, or atmospheric interference.
- Values around 0 might indicate non-vegetated areas or areas with little to no change in vegetation.



➢ Difference between EVI & NDVI :

The Enhanced Vegetation Index (EVI) and the Normalized Difference Vegetation Index (NDVI) are both used to measure vegetation greenness. However, EVI is more sensitive to dense vegetation and corrects for some atmospheric conditions and canopy background noise.

- Spatial resolution: EVI has better spatial resolution than NDVI.
- Atmospheric haze: EVI corrects for atmospheric haze better than NDVI.

- Canopy variations: EVI is more responsive to canopy variations, including leaf area index (LAI), canopy type, plant physiognomy, and canopy architecture.
- Chlorophyll sensitivity: NDVI is chlorophyll sensitive, while EVI is more responsive to canopy structural variations.
- Stress patterns: EVI can show stress patterns in crops that are harder to see in NDVI images.
- Atmospheric conditions: EVI corrects for variations in solar incidence angle, atmospheric conditions, and signals from the ground cover below the vegetation.

For the above reasons, we use EVI instead of NDVI

➢ Normalized Difference Built-Up Index (NDBI) :

we utilized the Normalized Difference Built-Up Index (NDBI). The Normalized Difference Built-Up Index (NDBI) is a spectral index commonly used in remote sensing to identify built-up or urban areas within an image. It is calculated using Near-Infrared (NIR) and Shortwave Infrared (SWIR) bands from satellite imagery, such as those provided by the Sentinel-2 satellite.

The formula for NDBI is:

$$NDBI = \frac{SWIR - NIR}{SWIR + NIR}$$

Sentinel 2: $$NDBI = \frac{BAND\ 11 - BAND\ 8}{BAND\ 11 + BAND\ 8}$$

Where:

SWIR is the reflectance value in the Shortwave Infrared band (band 11)

NIR is the reflectance value in the Near-Infrared band (band 8)

NDBI values range from -1 to +1.

- Positive Values: Areas with positive NDBI values typically represent built-up areas such as urban regions, roads, and infrastructure. The higher the positive value, the higher the density or presence of built-up structures.

- Negative Values: Negative NDBI values often indicate non-built-up areas such as vegetation, water bodies, or bare soil. The more negative the value, the less likely the presence of built-up structures.
- Values Close to Zero: Values close to zero suggest a mix of built-up and non-built-up areas or areas with low urbanization intensity

➢ Normalized Difference Bareness Index (NDBaI) :

Normalized difference bareness index (NDBaI) is a popular index for identifying bare land. It's based on the spectral signature differences between bare soil and backgrounds. NDBaI is often used in LULC and LST-related studies.

The formula for NDBI is:

$$NDBaI = \frac{SWIR-Red}{SWIR+Red}$$

Sentinel 2: $$NDBaI = \frac{BAND\ 11 - BAND\ 4}{BAND\ 11 + BAND\ 4}$$

- In this formula:

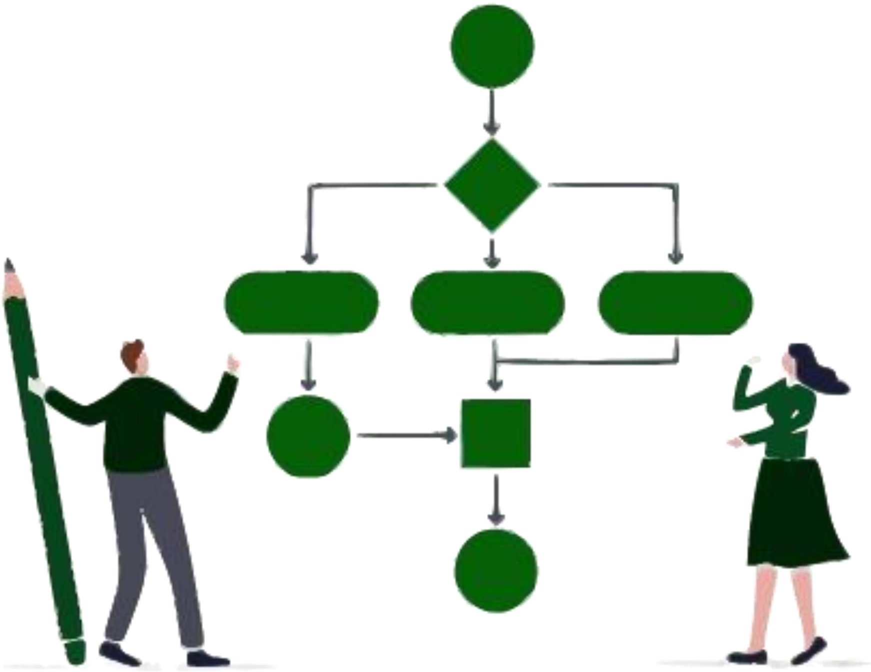
SWIR represents the reflectance in the shortwave infrared band.

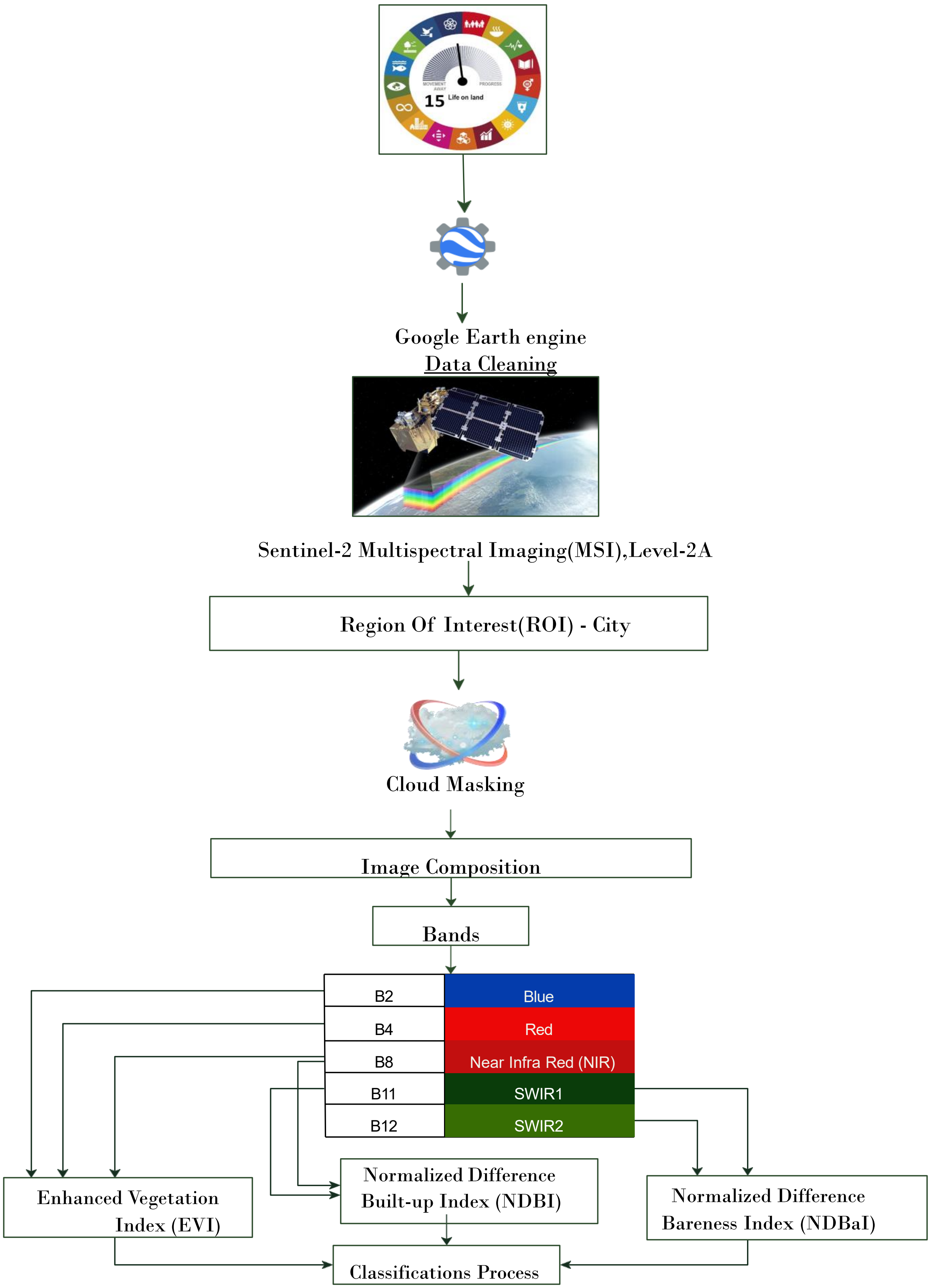
Red represents the reflectance in the red band.

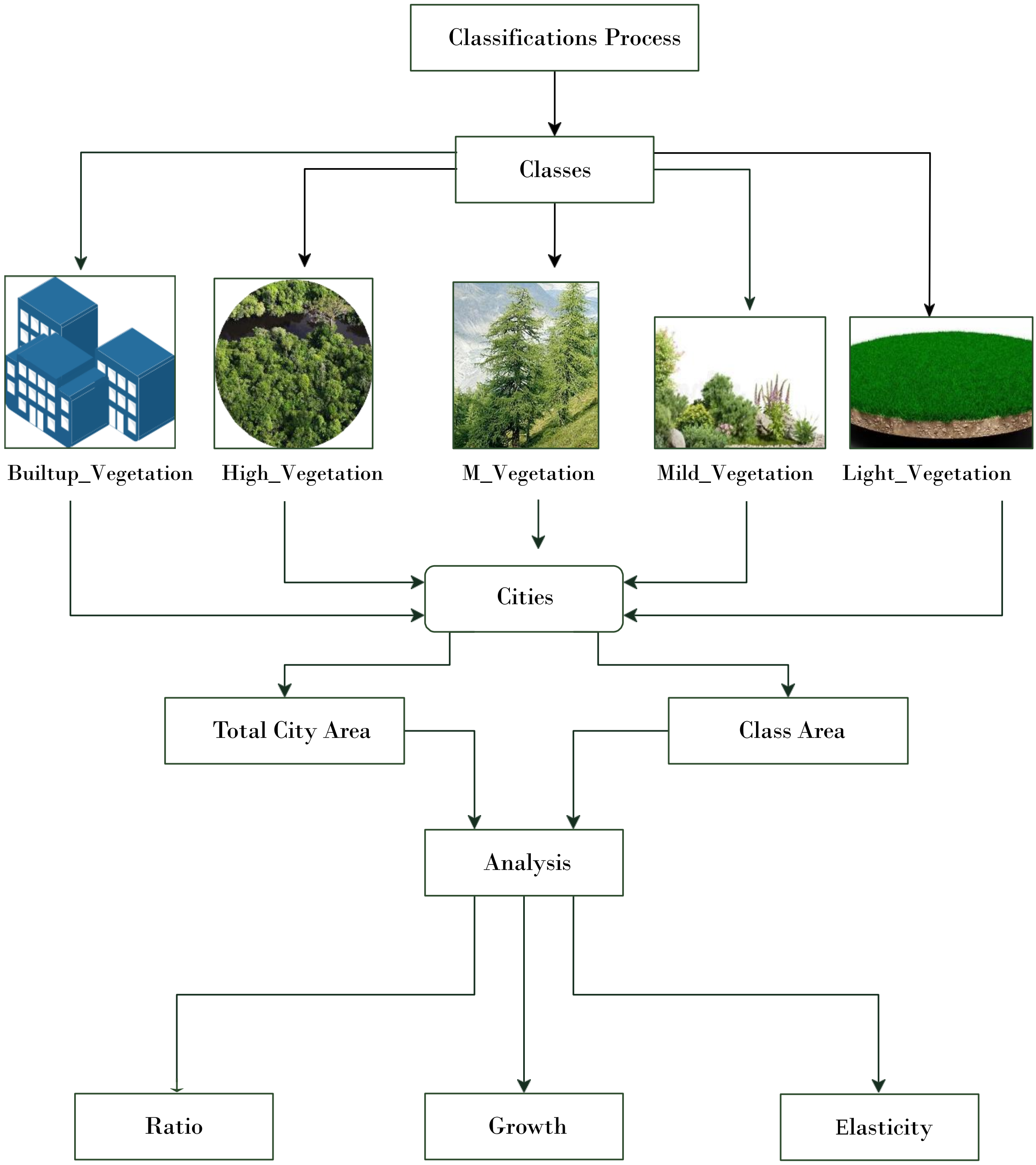
NDBaI values typically range from -1 to 1.

- High positive values indicate areas with bare soil or exposed ground, as these surfaces reflect more shortwave infrared radiation relative to red radiation.
- Low or negative values suggest the presence of vegetation, as vegetation absorbs more shortwave infrared radiation while reflecting more red radiation.
- Values close to zero indicate a mix of vegetation and bare ground or areas with limited vegetation cover.

FLOW CHART




Google Earth engine
Data Cleaning
Sentinel-2 Multispectral Imaging(MSI),Level-2A
Region Of Interest(ROI) - City
Cloud Masking
Image Composition
Bands
B2 Blue
B4 Red
B8 Near Infra Red (NIR)
B11 SWIR1
B12 SWIR2
Enhanced Vegetation Index (EVI)
Normalized Difference Built-up Index (NDBI)
Normalized Difference Bareness Index (NDBaI)
Classifications Process


Classifications Process
Classes
Builtup_Vegetation
High_Vegetation
M_Vegetation
Mild_Vegetation
Light_Vegetation
Cities
Total City Area
Class Area
Analysis
Ratio
Growth
Elasticity

OBJECTIVES

1. Investigate regional variations in vegetation cover and urbanization dynamics among Surat, Vadodara, Mumbai, Bangalore, and Ahmedabad, analyzing their ecological landscapes comprehensively.

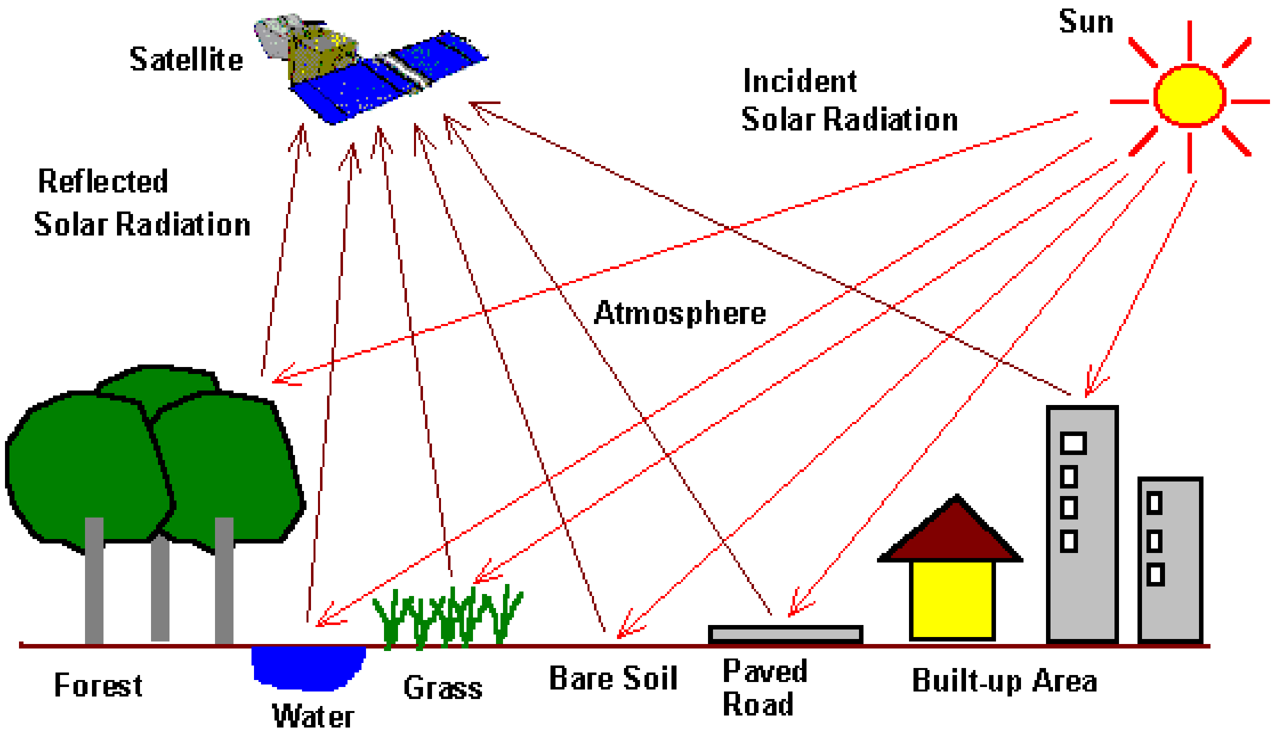
2. Assess the impact of urbanization on vegetation cover in Surat and other cities, evaluating the elasticity of built-up areas and vegetation cover to understand environmental changes and urban-green space balance.

3. Classify cities into Tier-1 and Tier-2 categories based on urbanization levels, comparing vegetation cover, built-up area dynamics, and the ratio of built-up areas to vegetation cover in Surat, Bangalore, Vadodara, Mumbai, and Ahmedabad.

DATA COLLECTION

The study relied primarily on primary data. For the study, we collect and process satellite imagery data from the Copernicus Sentinel-2 mission. utilizes the Google Earth Engine platform to access and analyze satellite data. For extraction of the study area, we use the shapefile of the city. To ensure the quality of the data, we developed a custom cloud masking function. This function filters out cloud cover and atmospheric interference from the satellite imagery, allowing us to obtain clear, cloud-free images for analysis. We composited imagery for each month within the study period, from 2019 to 2023.

We computed indices such as the Enhanced Vegetation Index (EVI), Normalized Difference Built-Up Index (NDBI), and Normalized Difference Bareness Index (NDBaI). Based on the calculated indices, land cover classes such as water, land, built-up, and different types of vegetation such as high vegetation, moderate vegetation, mild vegetation, and light vegetation. The area of each land cover class is computed using pixel-wise area calculation. We collected data for 6 different cities such as Mumbai, Ahmedabad, Bengaluru, Surat, Vadodara, and Chandigarh, and divided them into Tier-1 and Tier-2. Our main focus is on the "Surat" city.



METHODOLOGY

CALCULATION FOR GROWTH

We used simple stats to understand the growth of built-up, high Vegetation, and Moderate Vegetation, Mild Vegetation, Light Vegetation of different cities from 2019 to 2023. We looked at things like the average of different classes(mean), how spread out the data was (variance), and how precise our estimates were (standard error). We also calculated the difference from 2019 to 2023. These stats helped us figure out how much urbanization and vegetation growth in cities.

CALCULATION FOR RATIO

We calculated the ratio between Vegetation and Built-up area of different cities from 2019 to 2023. It indicates a concerning trend of urban expansion at the expense of green spaces. The increasing ratio suggests a shift away from developed and built environments, potentially leading to a more balanced ecological system, increased biodiversity, and improved environmental quality.

CALCULATION FOR ELASTICITY

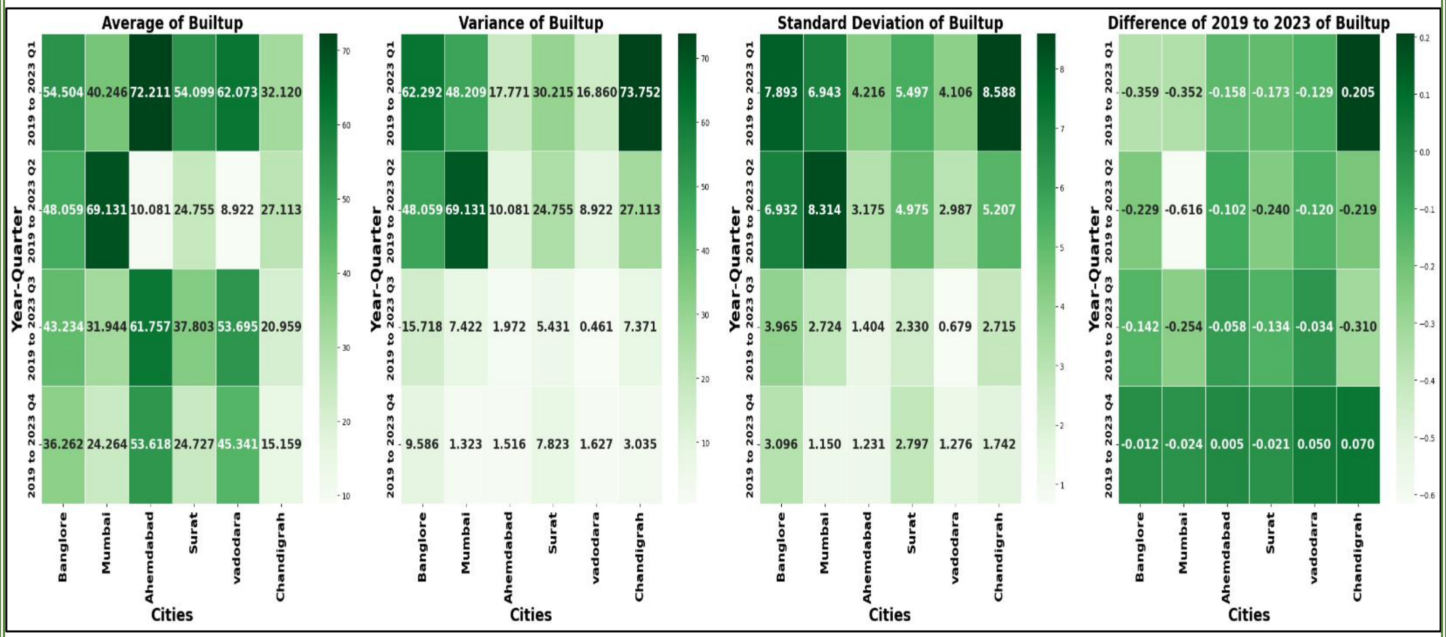
We used simple stats to understand the Elasticity between Built-up areas and different classes of vegetation in different cities from 2019 to 2023. It suggests the degree to which changes in one factor influence the other over the specified time period. A higher elasticity value indicates a stronger relationship between built-up areas and vegetation, meaning that changes in built-up areas are more likely to correspond to proportional changes in vegetation, and vice versa.

STATISTICAL ANALYSIS

"Greener Cities, Brighter Futures": Investigating Urban Vegetation Growth Trends.

Observe the dynamic flow of urban vegetation with our heat map, which illustrates the impressive increase in biodiversity in cities over time.

Built-up Growth Heatmap

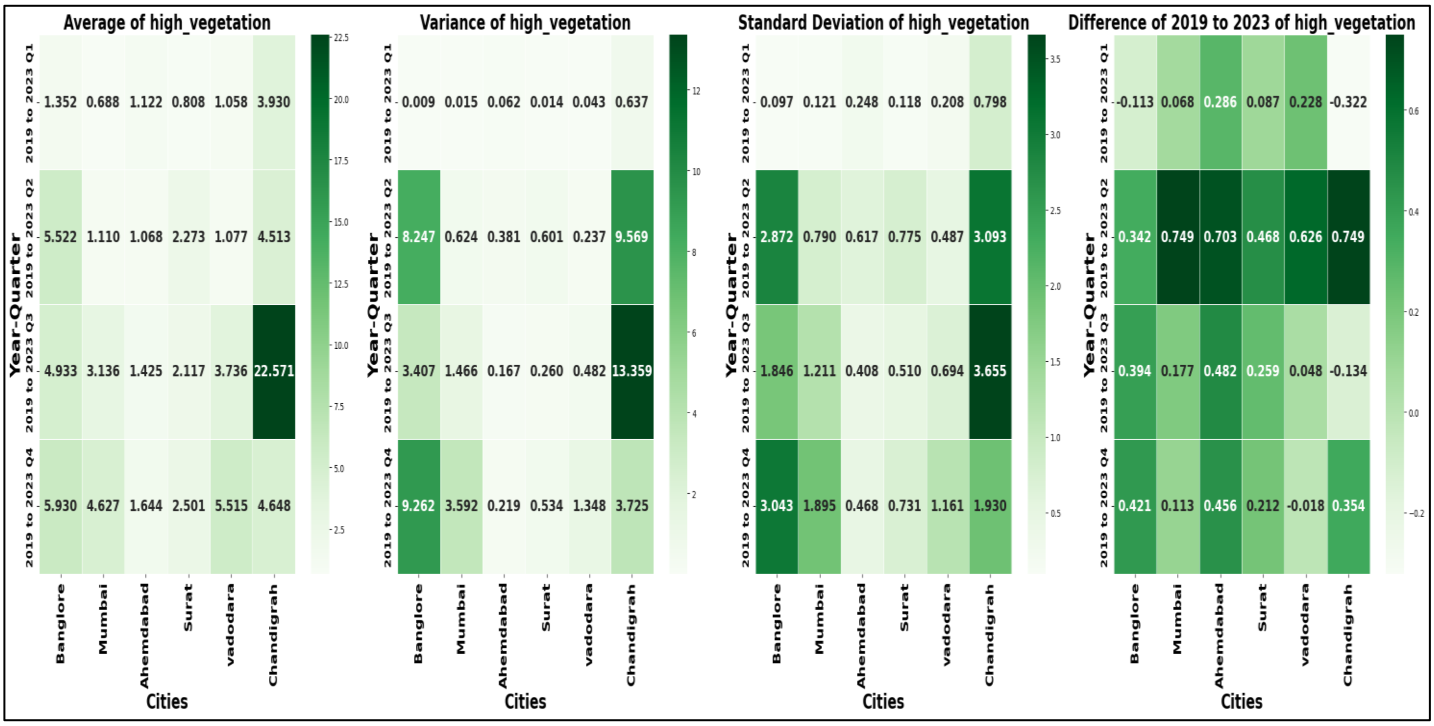


Built-up				
City	**Quar-ter**	**2019**	**2023**	**Diff % 2019 vs 2023**
Chandigarh	Q4	14.18581174	15.25306962	0.070%
Surat	Q3	40.96919189	36.13097894	-0.134%
Ahmedabad	Q4	52.38971345	52.66763544	0.005%
Bangalore	Q4	39.5123757	39.04030641	-0.012%
Mumbai	Q4	24.1262307	23.56495367	-0.024%
Vadodara	Q3	54.84841571	53.04600195	-0.034%

Interpretation:

The data shows minimal built-up area growth across all five Indian cities between 2019 and 2023. Chandigarh has the highest growth rate at 0.07%, followed by Ahmedabad at 0.005%. Surat, Bangalore and Vadodara show negative growth rates, though all very small, ranging from -0.012% to -0.134%.

High-Vegetation Growth Heatmap

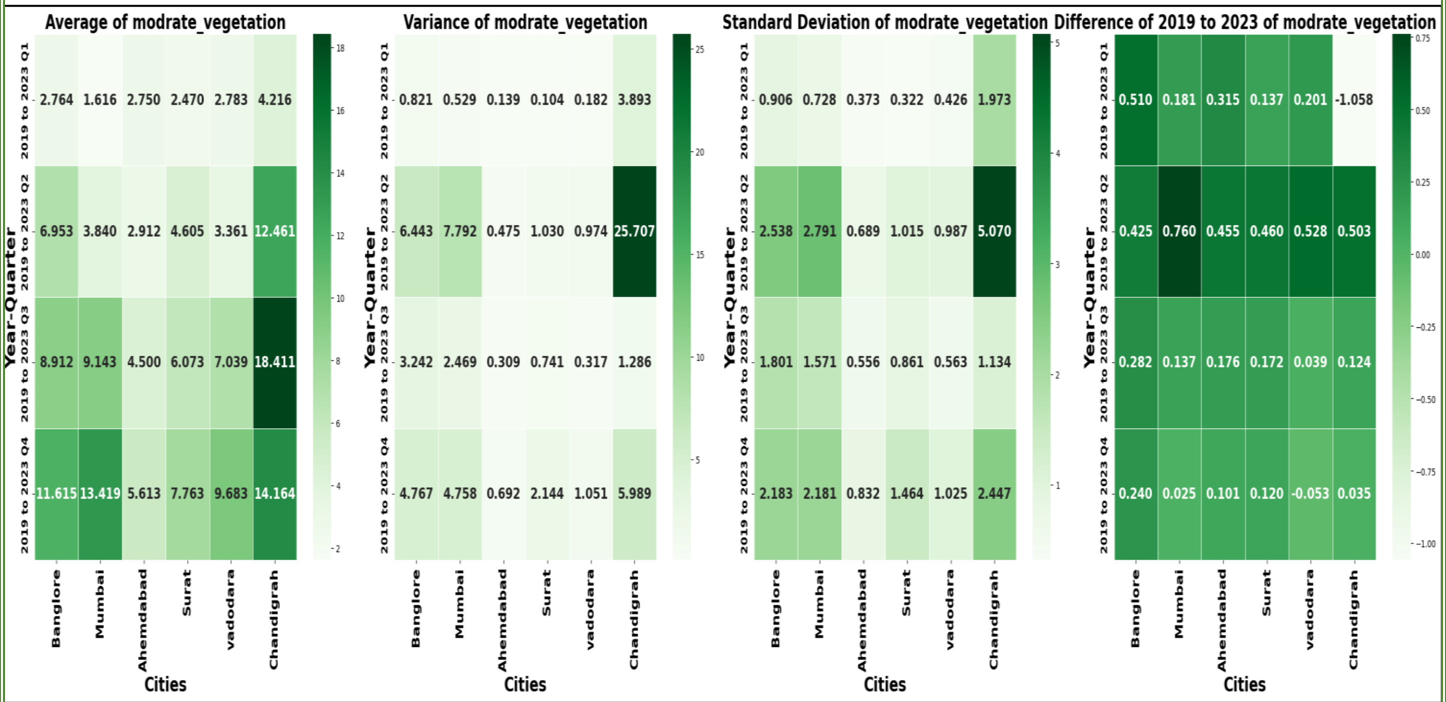


High vegetation				
City	Quarter	2019	2023	Diff % 2019 vs 2023
Chandigarh	Q3	22.58	19.91	12%
Surat	Q4	2.83	3.59	21%
Ahmedabad	Q4	1.25	2.30	46%
Bangalore	Q4	6.28	10.84	42%
Mumbai	Q4	6.20	7.00	11%
Vadodara	Q4	6.57	6.45	-2%

Interpretation:

From the above table, the city with the highest percentage increase in vegetation cover is Ahmedabad, with a 46% increase. Surat and Bengaluru follow with a 21% and 42% increase respectively. Mumbai and Vadodara have a smaller increase in vegetation cover, at 11% and -2% respectively.

Moderate-Vegetation Growth Heatmap

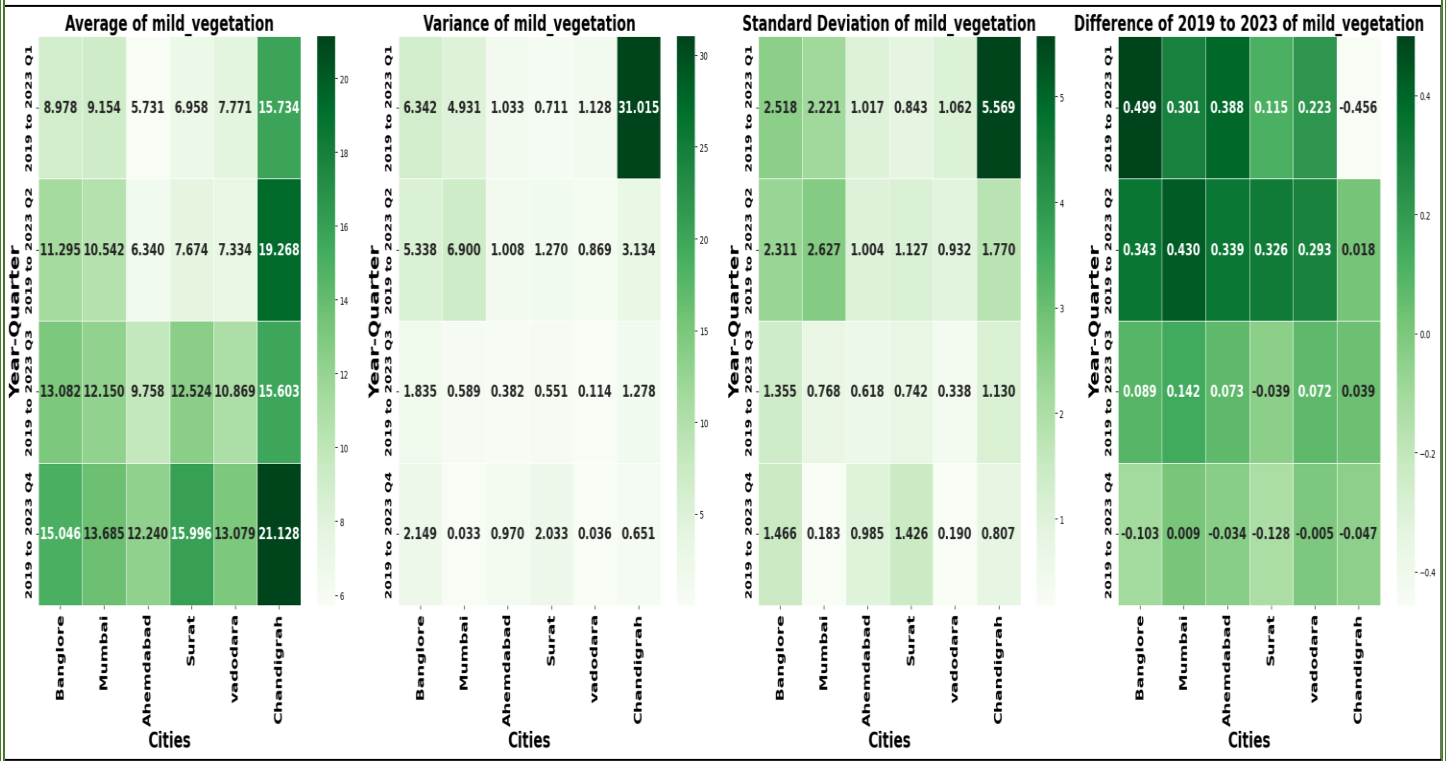


Modrate_vegetation				
City	Quarter	2019	2023	Diff % 2019 vs 2023
Chandigarh	Q3	17.272162	19.714129	12%
Surat	Q4	8.5565416	9.720409	12%
Ahmedabad	Q4	5.989817	6.6631221	10%
Bangalore	Q4	10.600349	13.949405	24%
Mumbai	Q4	15.556401	15.957767	3%
Vadodara	Q4	10.84631	10.301197	-5%

Interpretation:

The data shows moderate vegetation growth, with a 12% increase from 17.27 in 2019 to 19.71 in 2023. Surat has grown, with a 12% increase. Ahmedabad shows moderate vegetation growth, with a 10% increase in 2019 to 6.66 in 2023. Bangalore has the highest vegetation growth among the cities listed, with a 24% increase from 10.60 in 2019 to 13.95 in 2023. Mumbai shows the lowest vegetation growth out of the five cities, with a 3% increase.

Mild-Vegetation Growth Heatmap

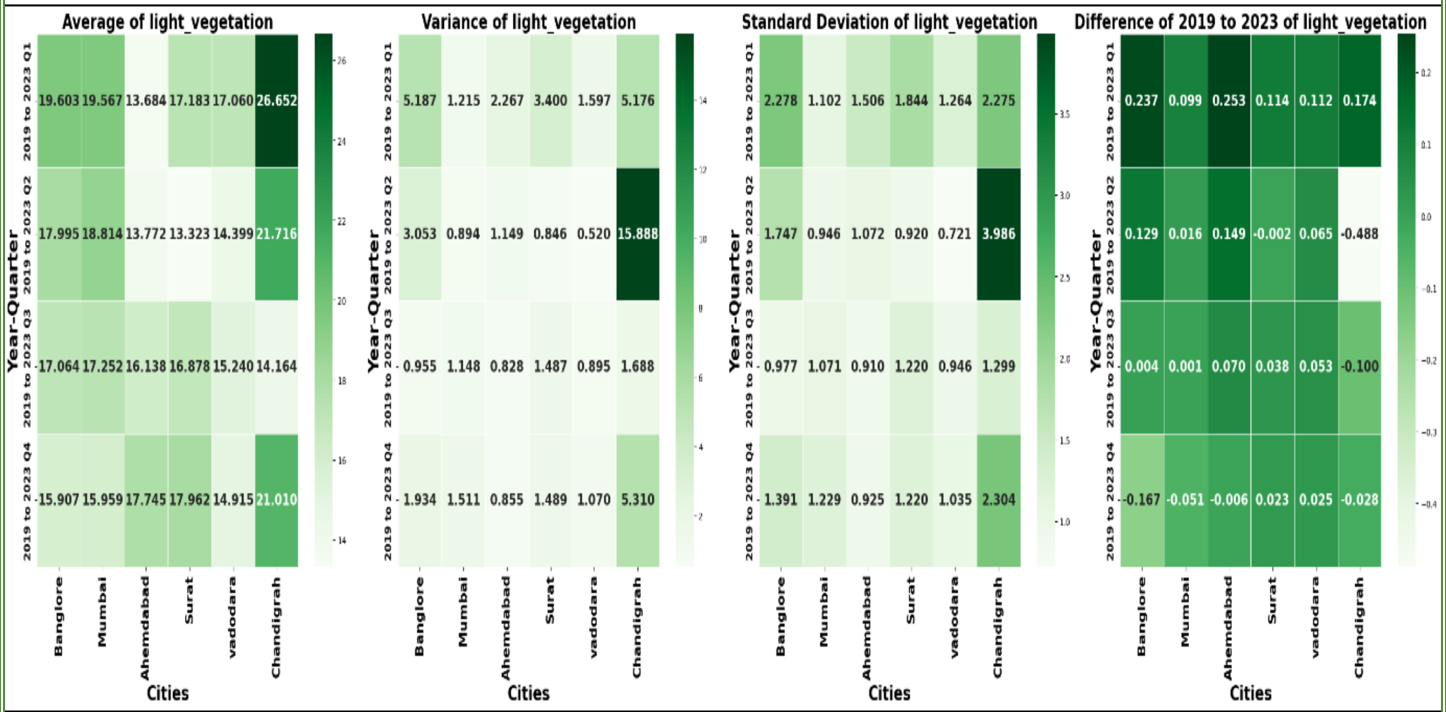


Mild_vegetation				
City	**Quar-ter**	**2019**	**2023**	**Diff % 2019 vs 2023**
Chandigarh	Q4	21.930226	20.940075	-5%
Surat	Q3	17.420692	15.443058	-13%
Ahmedabad	Q4	13.131983	12.706023	-3%
Bangalore	Q4	14.225124	12.898082	-10%
Mumbai	Q4	13.808249	13.926761	1%
Vadodara	Q3	13.153124	13.092912	0%

Interpretation:

Chandigarh has a 5% decrease in vegetation cover, going from 21.93 in 2019 to 20.94 in 2023. Surat has the most significant decrease in vegetation cover, with a 13% difference between 2019 (17.42) and 2023 (15.44). Ahmedabad shows a 3% decrease in vegetation cover. Bangalore has a 10% decrease in vegetation cover, going from 14.23 in 2019 to 12.90 in 2023. Mumbai is the only city that shows a slight increase in vegetation cover, with a 1% difference between 2019 (13.81) and 2023 (13.93).

Light-Vegetation Growth Heatmap



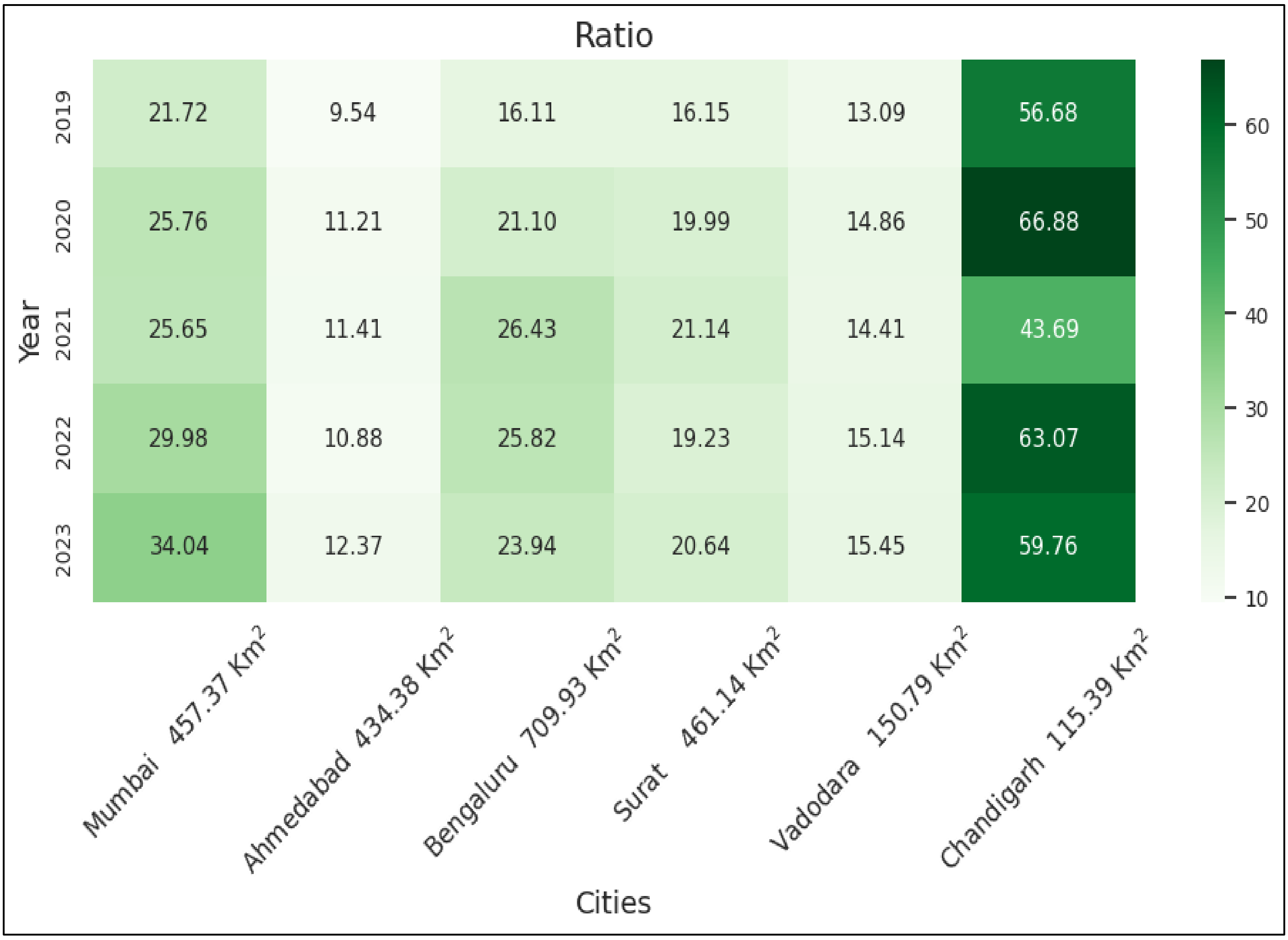
Light_vegetation				
City	**Quar-ter**	**2019**	**2023**	**Diff % 2019 vs 2023**
Chandigarh	Q4	**20.269532**	**19.71439**	-3%
Surat	Q4	**16.474808**	**16.474808**	2%
Ahmedabad	Q4	**17.032002**	**16.937027**	-1%
Bangalore	Q3	**16.150989**	**16.221377**	0%
Mumbai	Q3	**16.159477**	**16.173831**	0%
Vadodara	Q3	**14.007578**	**14.786056**	5%

Interpretation:

Chandigarh has the highest light vegetation growth out of the five cities listed, with a 3% increase. Surat's light vegetation growth is minimal, with a flat growth rate between 2019 (16.47) and 2023 (16.47). Ahmedabad shows minimal light vegetation growth, with a slight decrease of 1%. Bangalore has minimal light vegetation growth, with a 0%. Mumbai also shows minimal light vegetation growth, with a 0% change between 2019 (16.16) and 2023 (16.17).

"Sustainable City Evaluation: Greenery vs. Built Environment Ratio"

Examine how urbanization is changing the terrain and how it affects terrestrial ecosystems. See the striking differences in biodiversity ratios between cities, as clearly depicted by a heatmap visualization that shows how human development has affected life on land throughout time.



INTERPRETATION:

Tier - 1

Over the past five years, Mumbai's built-up-to-vegetated ratio seems to have remained steady. In 2019 and 2023, the figures are 21.72 and 34.04, respectively. This indicates that during the course of the five years, the amount of vegetation cover has increased more than that of built-up areas.

In Ahmedabad, 2019, the values are 9.54 in 2023, they are 12.37. The proportion of built-up areas may have somewhat increased over time, but this trend is not worth it. The percentage of green space in built-up areas in Ahmedabad increased between 2019 and 2023. But it's not as much of an increase as in Mumbai.

Bangalore's built-up-to-vegetative ratio seems to be somewhat rising. The range of values is 16.11 for 2019 and 23.94 for 2023. This implies that during the course of the five years, there may have been a minor increase in built-up areas and a drop in vegetative areas.

Tier - 2

Over time, the ratio has risen significantly, from 16.15 in 2019 to 20.64 in 2023. This suggests that the amount of vegetation has grown in proportion to the built-up area. It implies that rather than increasing its natural space, Surat is adding more built-up areas. This suggests that there might have been initiatives or natural processes leading to an increase in green cover or a decrease in built-up areas.

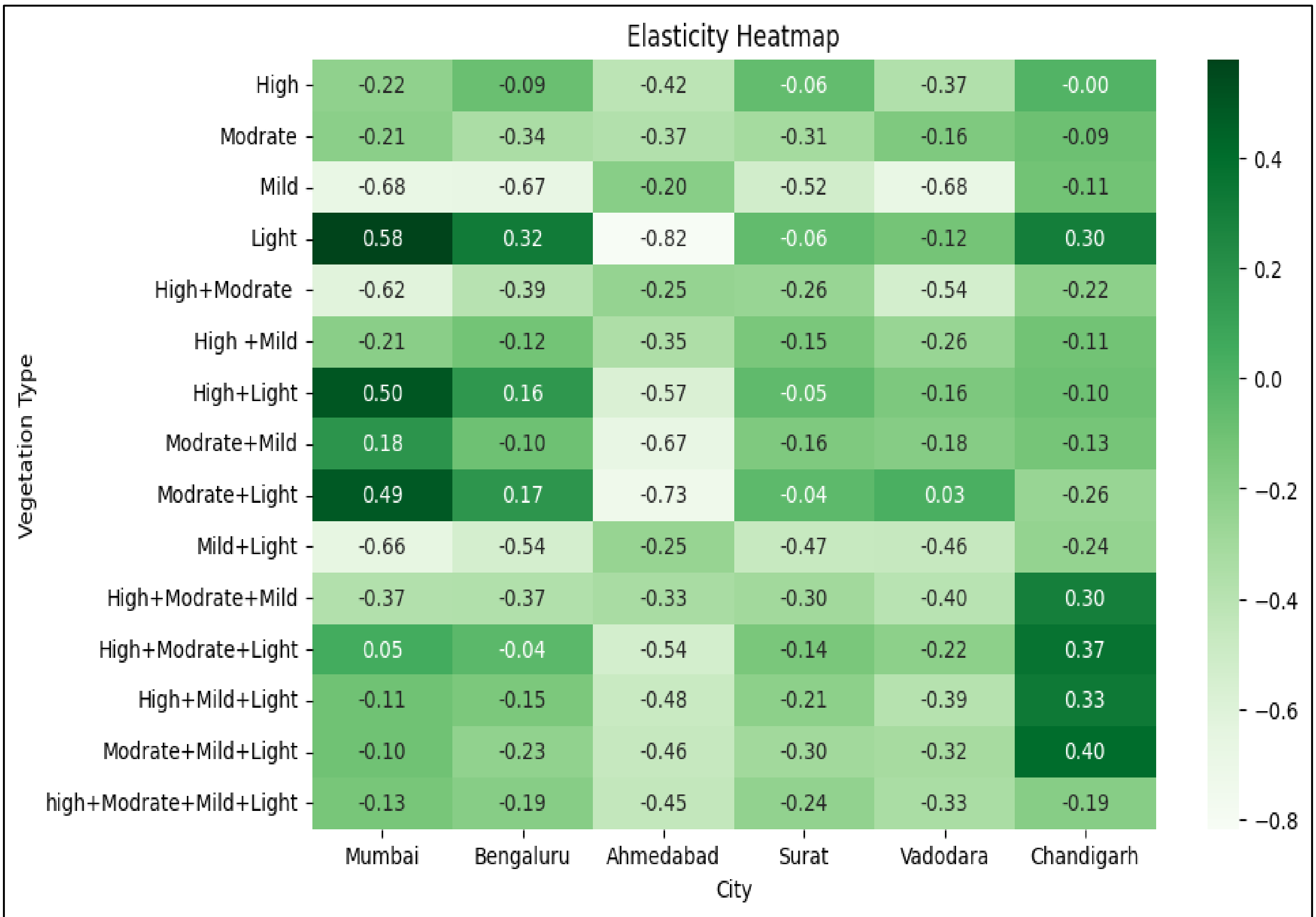
Vadodara's ratio has similarly risen over time, from 13.09 in 2019 to 15.45 in 2023, much like Surat's. Out of all the cities listed over the course of five years, Vadodara has the lowest built-up-to-greenery ratio.

Chandigarh also appears to have a high ratio of vegetation to built-up areas, ranging from 56.68 to 59.76. The dark green color on the heatmap suggests that vegetation cover is dominant in Chandigarh. this overall increase indicates efforts toward maintaining green spaces amidst urbanization pressures, albeit with some variability in the trend.

The analysis draws attention to the different patterns in vegetation-to-built-up ratios between Tier 1 and Tier 2 cities, with certain cities exhibiting increases in greenery and others seeing decreases.

"City Greenery and Built Environment: Insights into Sustainability Elasticity"

Explore our heatmap to see the dynamic patterns of urban ecosystems, characterized by vivid colors that represent the adaptability of terrestrial life.



INTERPRETATION:

The elasticity values give a thorough picture of how urbanization affects the amount of vegetation in cities.

Tier -1

In Mumbai, Urbanization significantly impacts vegetation cover in both high and moderate vegetation areas, with a 1% increase in the built-up area causing a decrease of -0.22 and -0.21 respectively. In areas with both high and moderate vegetation, this increase leads to reduced vegetation by -0.62. Surprisingly, in lightly vegetated areas, there's a slight increase in vegetation cover (0.58) with urban expansion, possibly due to tailored urban planning or environmental policies aimed at conserving green spaces amidst development. Overall, This indicates a substantial impact of urbanization on the city's green spaces, likely resulting in the loss of biodiversity and ecosystem services.

Bengaluru, renowned for its greenery, faces urbanization challenges, evident in vegetation elasticity values. High vegetation areas show a significant decrease (-0.09), reflecting urban development's impact. Moderate vegetation areas also decrease (-0.34), indicating biodiversity loss. Light vegetation areas see a slight increase (0.32), possibly due to conservation efforts. Bengaluru aims to preserve green cover through strategic conservation and green infrastructure development.

In Ahmedabad, there's been a significant decline in green spaces across high, moderate, and light vegetation areas -0.09, -0.34, and 0.32 respectively, reflecting challenges in conserving greenery amid rapid urban growth. These findings underscore the urgent need to incorporate green infrastructure into urban planning to counteract the adverse impacts of urbanization on the environment.

Tier-2

In Surat, High vegetation areas experience a notable decrease (-0.06), indicating a loss of green spaces due to urban expansion. Moderate vegetation areas also witness a decline (-0.31), Even in areas with mild vegetation, there is a significant reduction (-0.52), underscoring the need for sustainable development practices. These findings emphasize the importance of integrating green infrastructure into Surat's urban planning to mitigate the adverse effects of urbanization on the city's environment.

In Vadodara, high vegetation areas see a significant decline (-0.37) in comparison to other cities. In areas with high, moderate, and mild vegetation, a 1% increase in the built-up area results in a 0.40% decrease in vegetation. emphasizing the difficulties in maintaining green areas in the face of accelerating urbanization. In contrast, a 1% increase in built-up area corresponds to a 0.12% decrease in light vegetation in cities.

The elasticity values in Chandigarh, a tier-2 city known for its lush vegetation, show how urbanization has affected the amount of vegetation cover. The loss (-0.09) in moderate vegetation areas also highlights the difficulties in maintaining biodiversity in the face of urbanization. Surprisingly, in lightly vegetated areas, there's a slight increase in vegetation cover (0.30) with urban expansion, possibly due to tailored urban planning or environmental policies aimed at conserving green spaces amidst development.

Overall Insights:

The elasticity values demonstrate the general effect of urbanization on vegetation cover in both tier-1 and tier-2 cities. Tier-2 cities likewise struggle to maintain biodiversity in the face of fast urban growth, even as tier-1 cities see notable drops in greenery. These findings highlight the significance of incorporating green infrastructure into urban planning techniques in order to improve the standard of living for citizens in both tier-1 and tier-2 cities and lessen the negative environmental effects of urbanization.

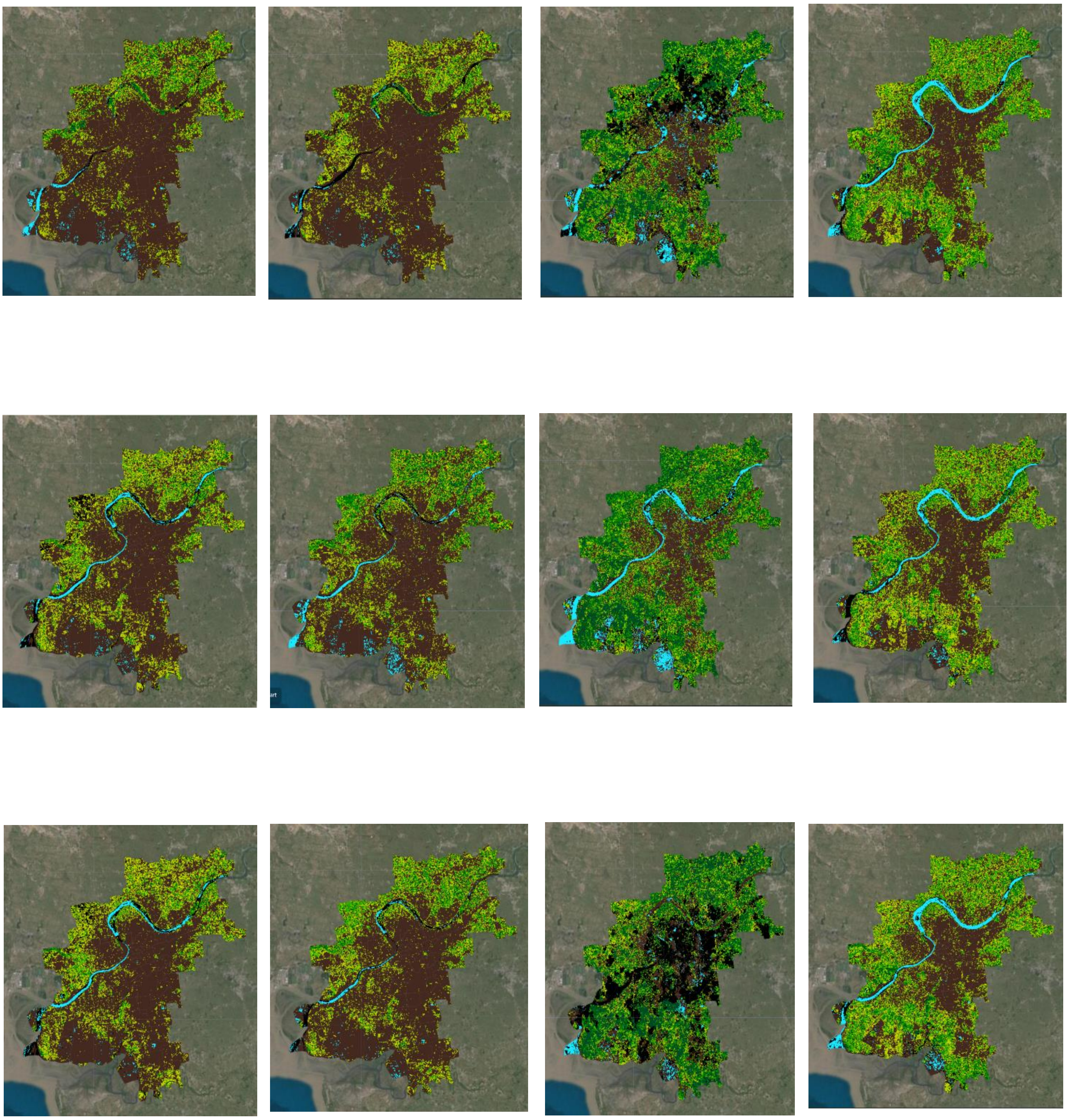
SURAT

(Q1) (Q2) (Q3) (Q4)

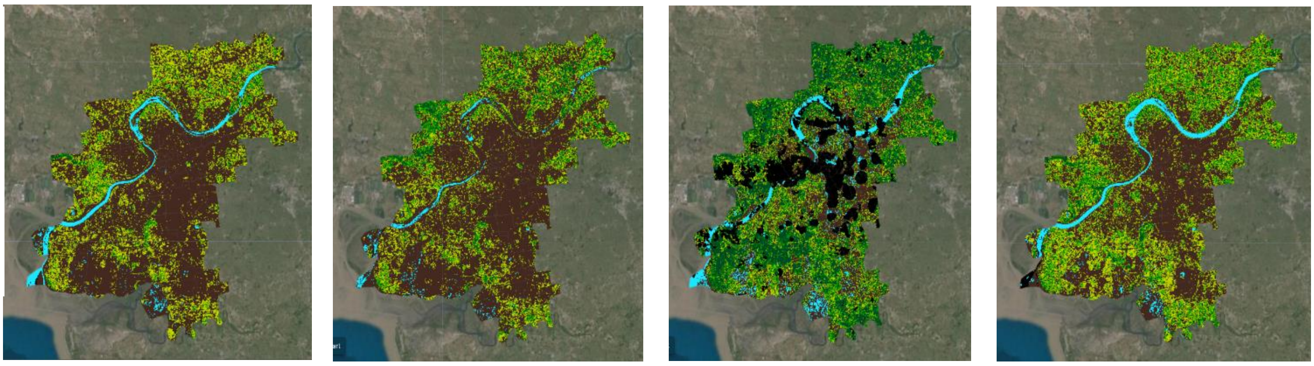
2019

2020

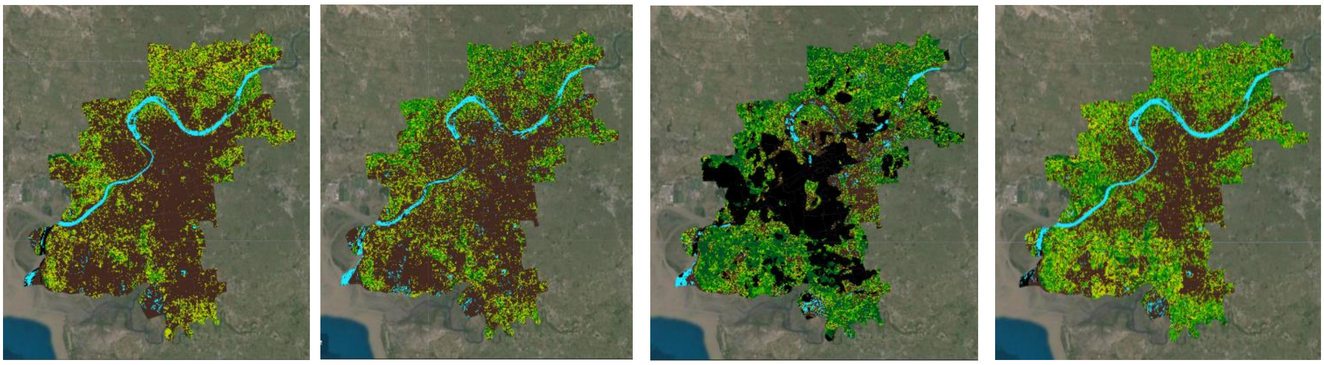
2021



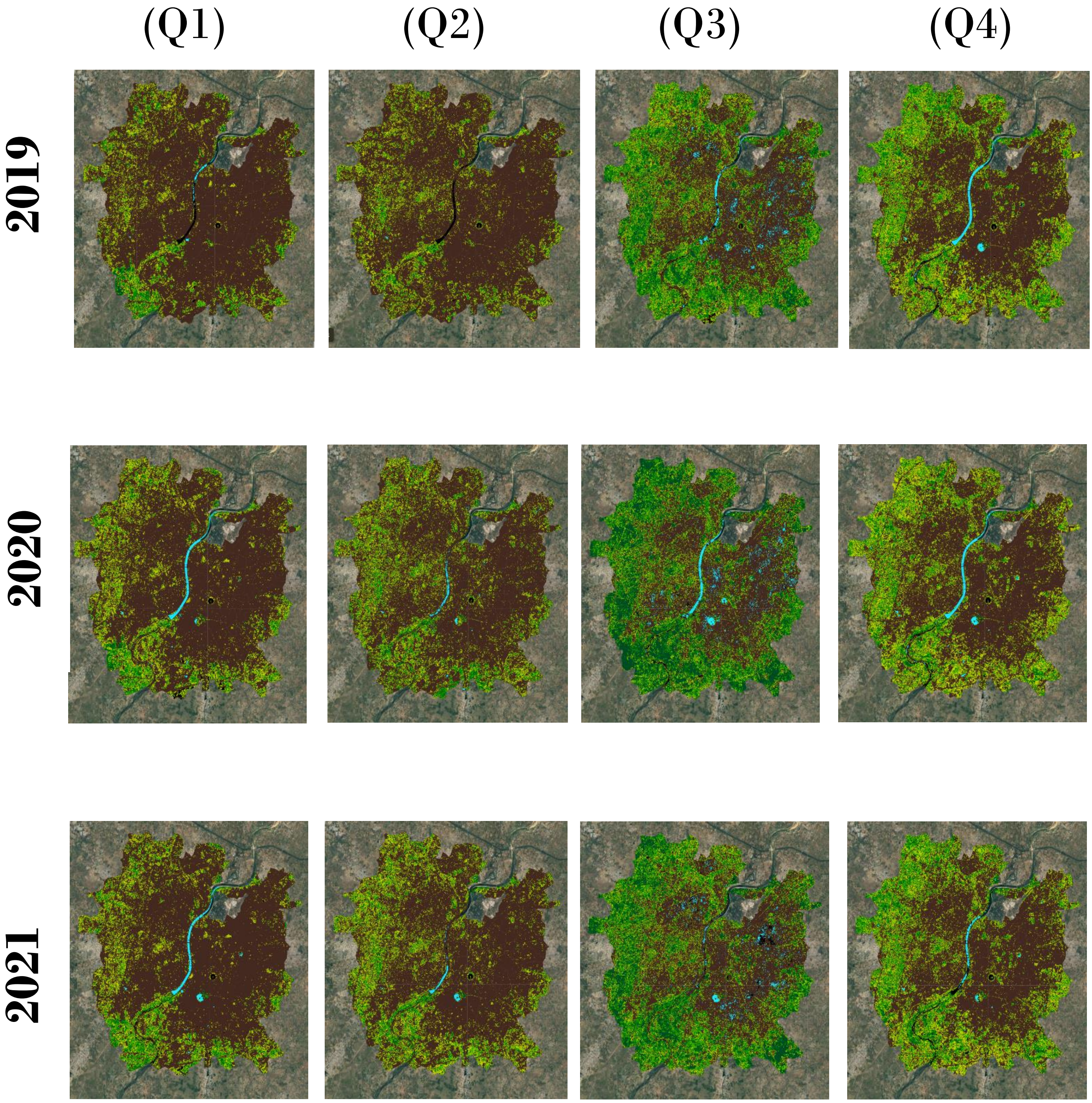
2022



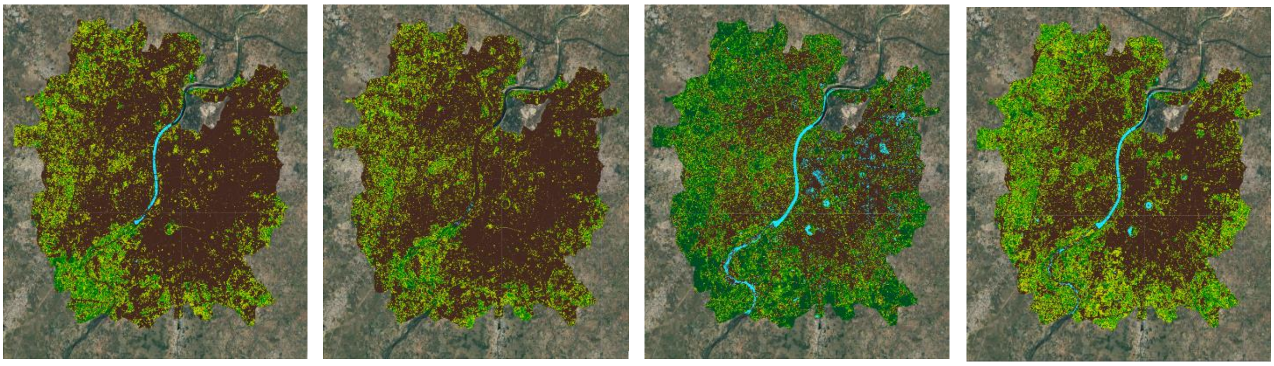
2023



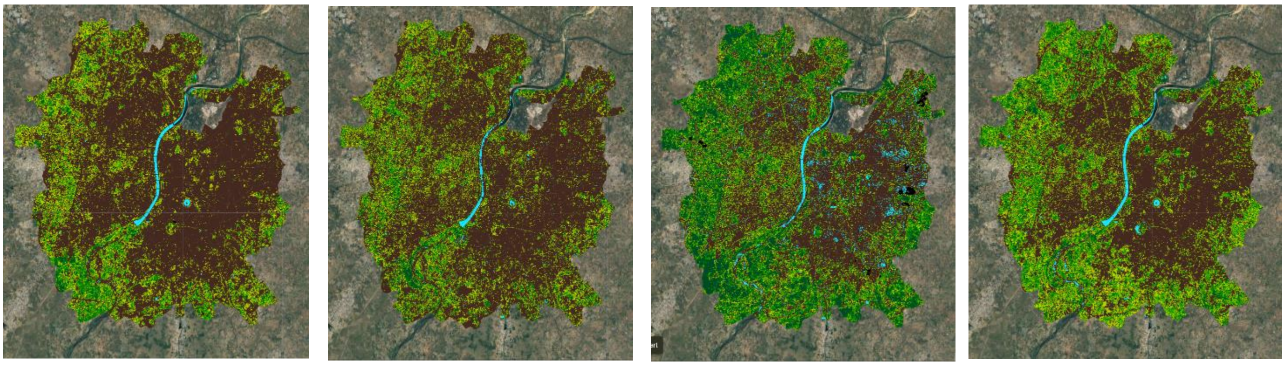
AHMEDABAD



2022



2023



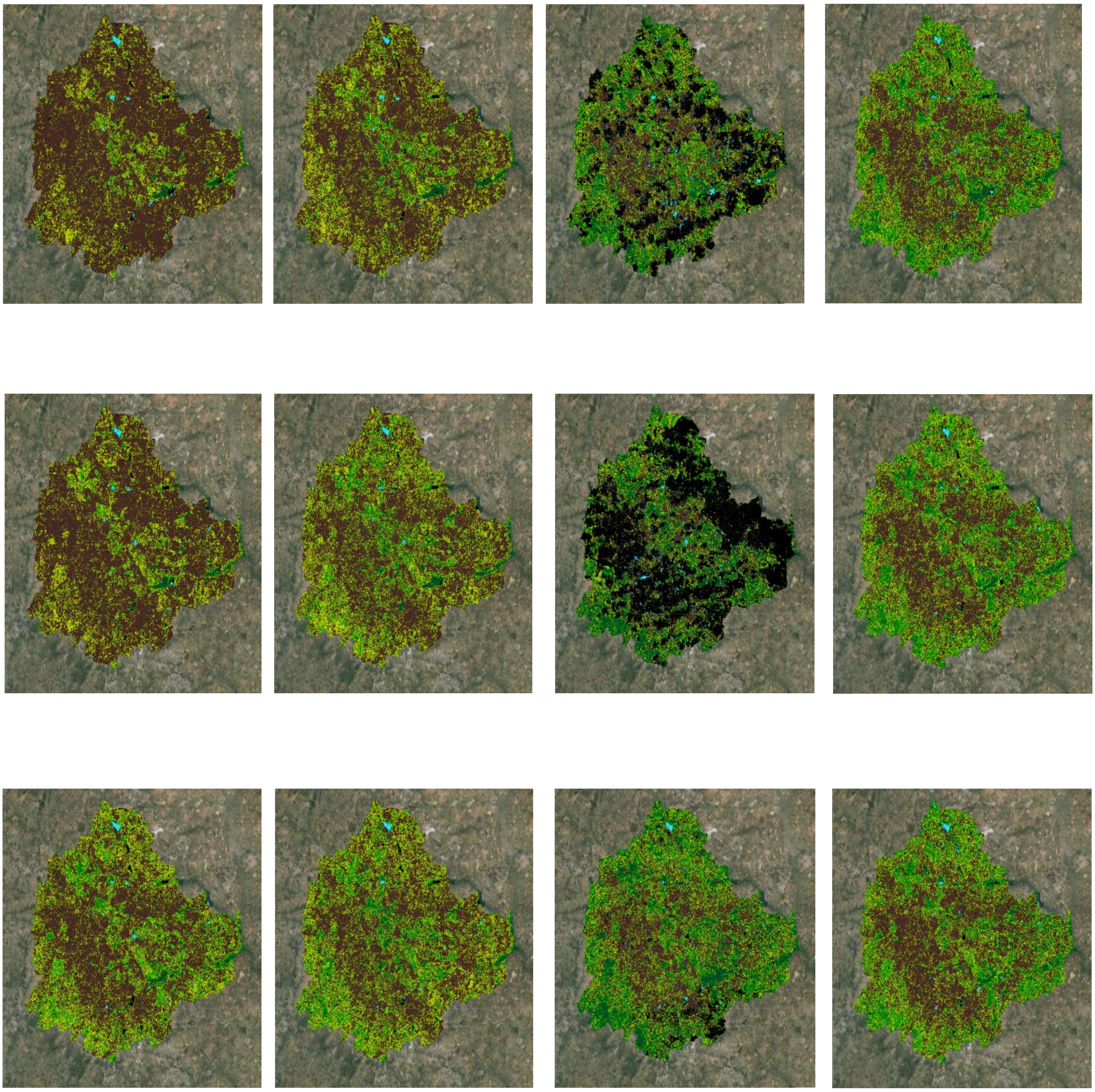
BENGALURU

(Q1) (Q2) (Q3) (Q4)

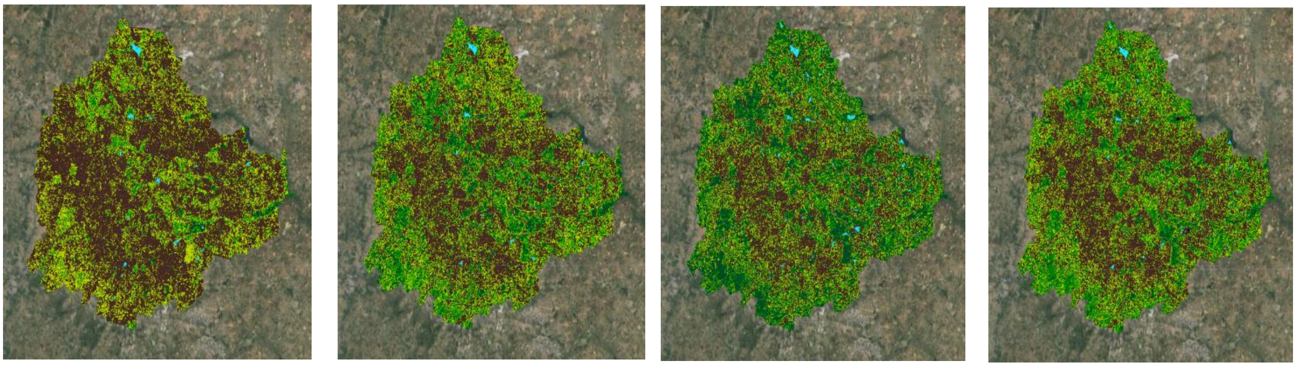
2019

2020

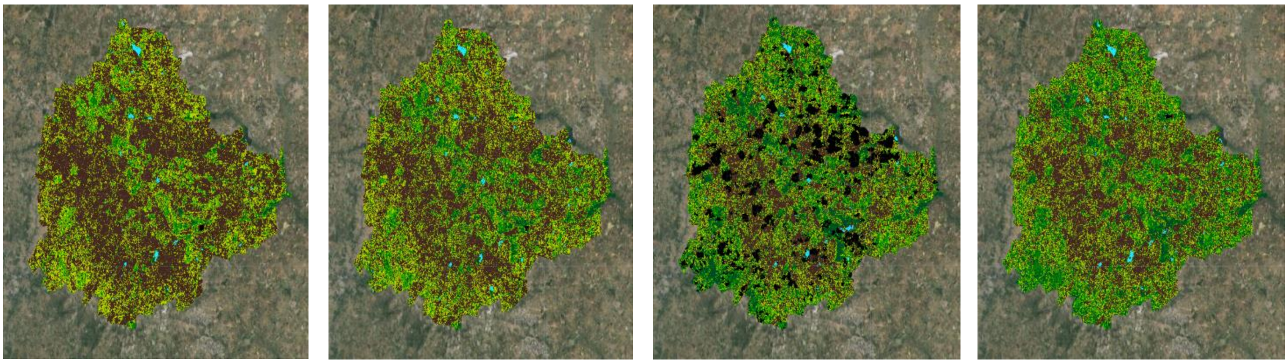
2021



2022



2023



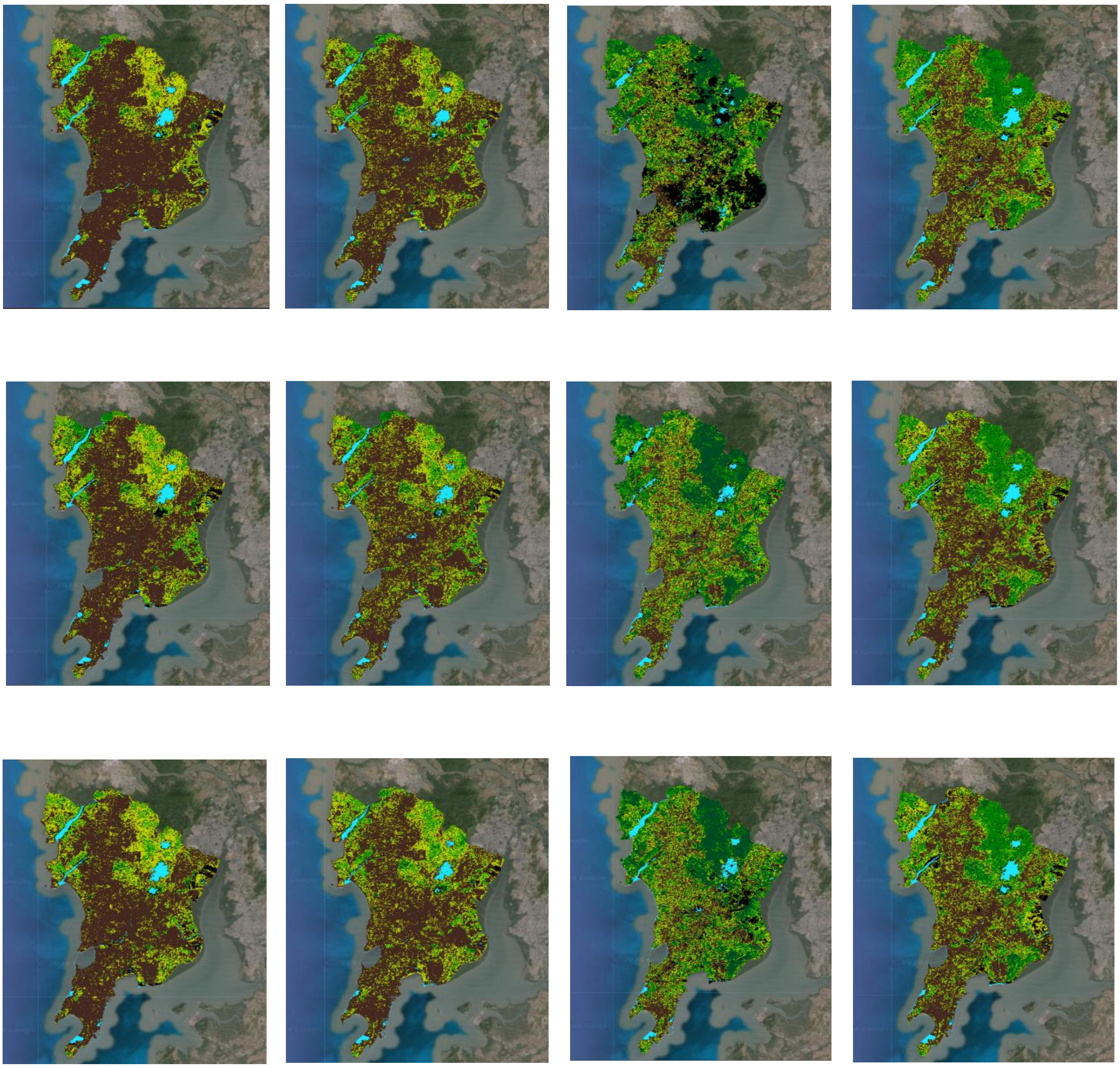
MUMBAI

(Q1) (Q2) (Q3) (Q4)

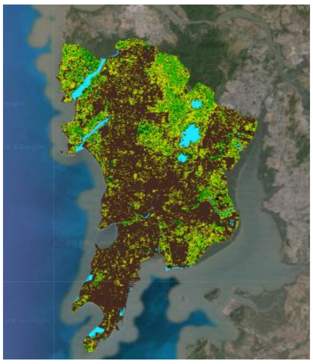
2019

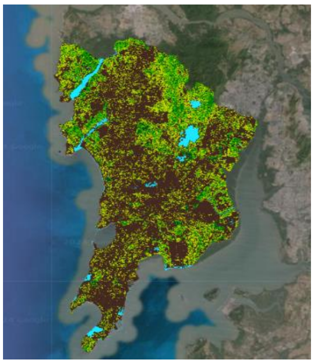
2020

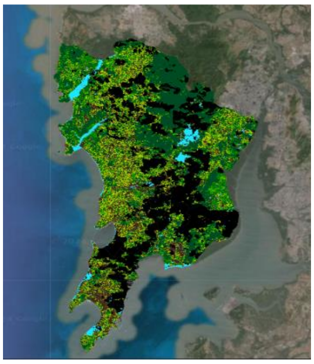
2021

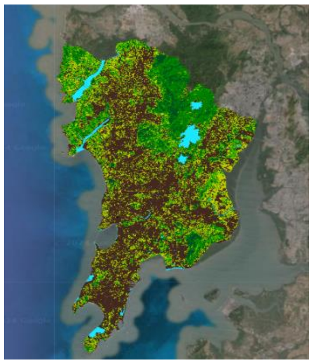


2022

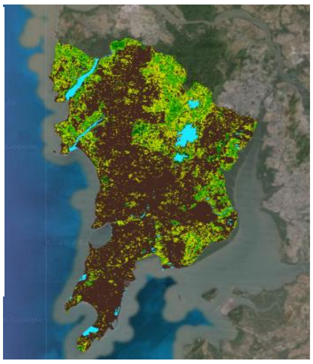


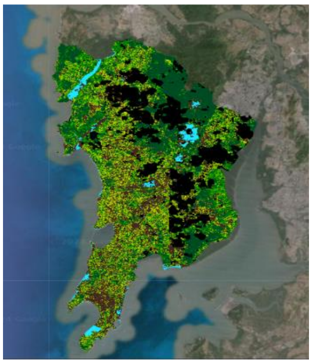


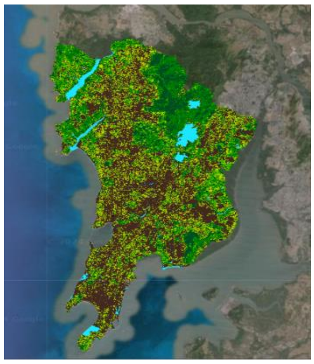




2023







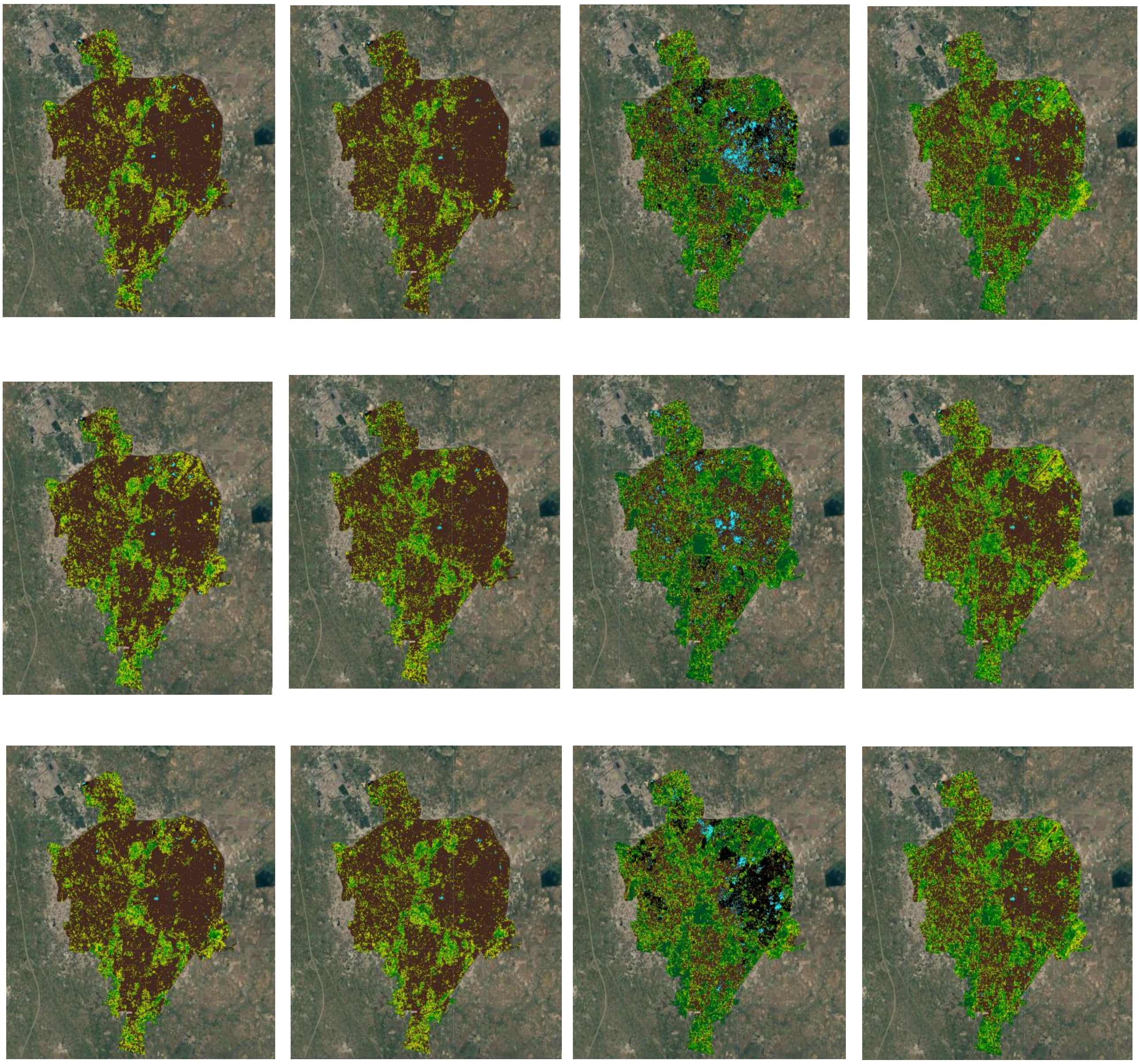
VADODARA

(Q1) (Q2) (Q3) (Q4)

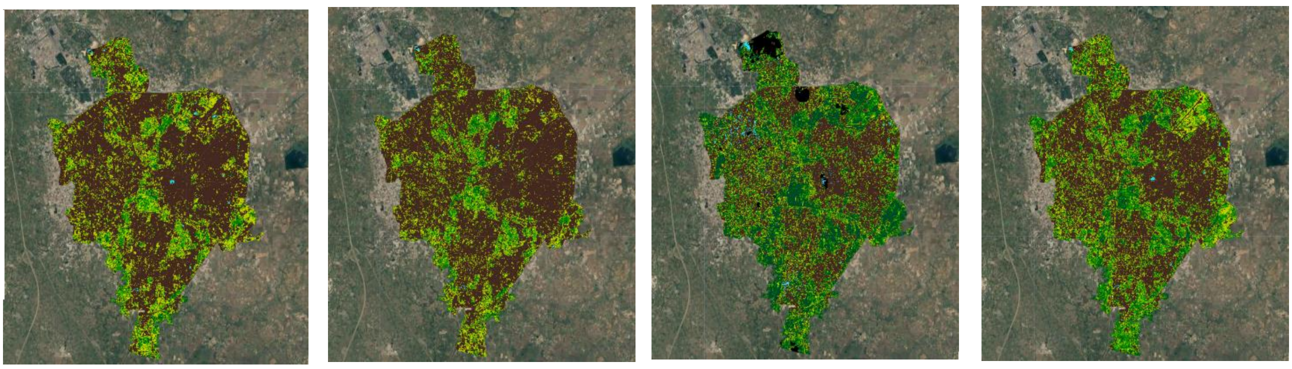
2019

2020

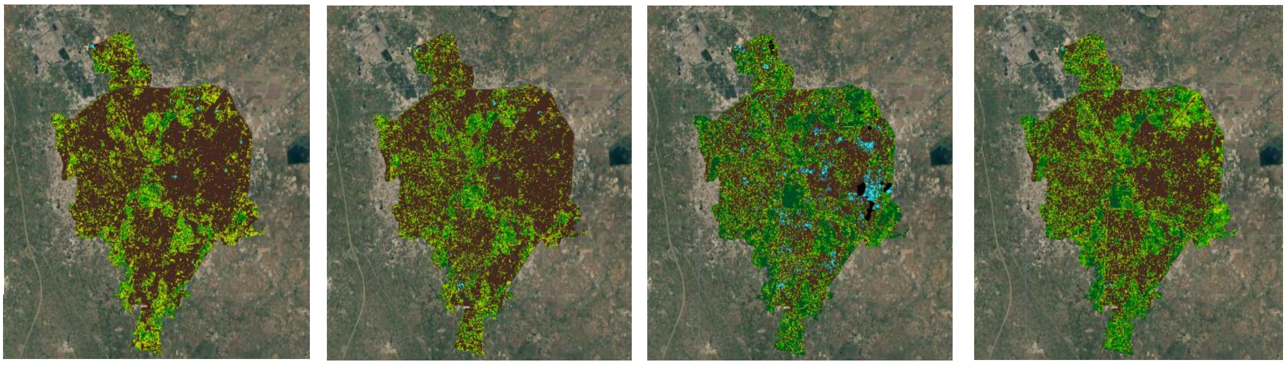
2021



2022



2023



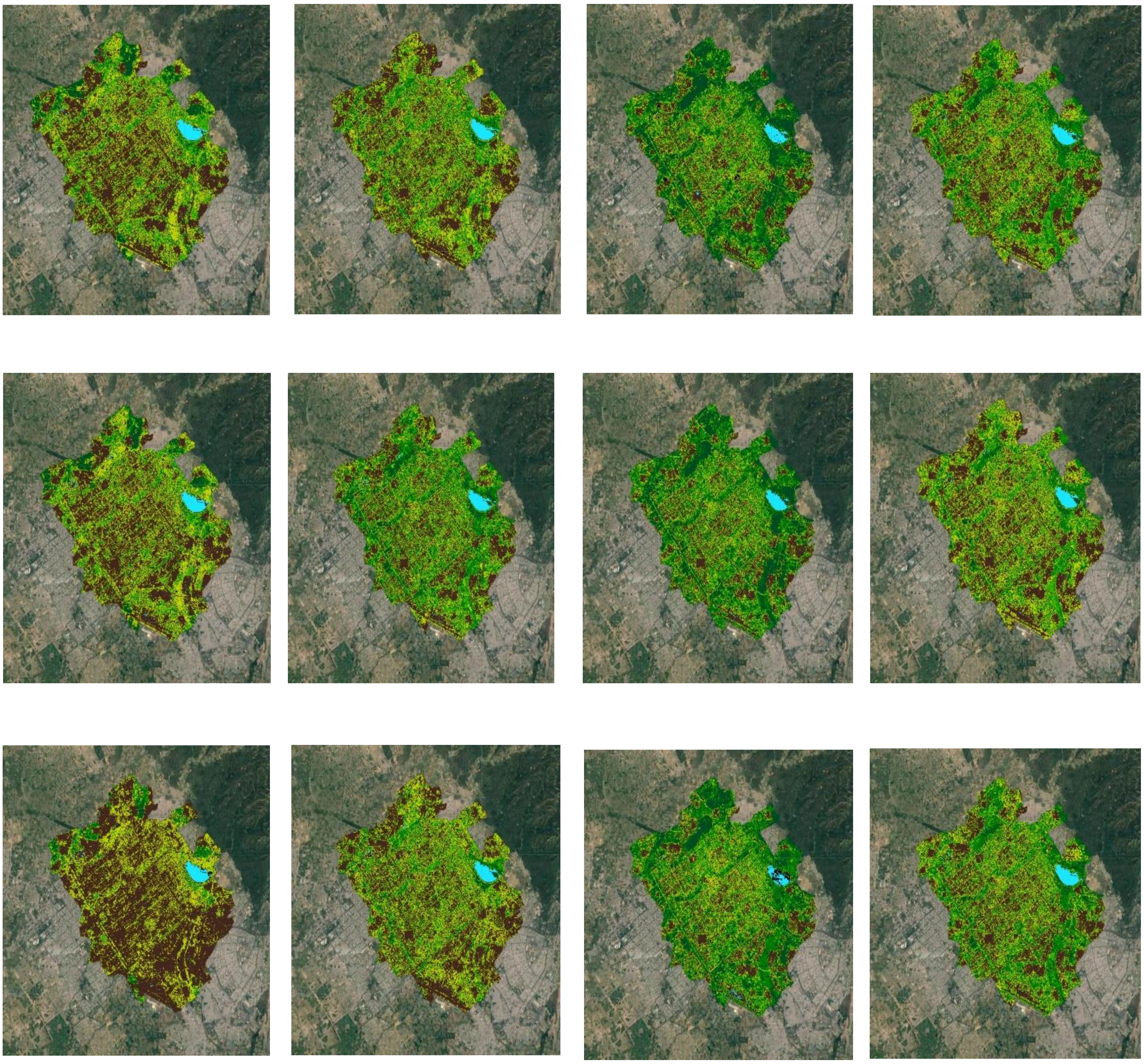
CHANDIGARH

(Q1) (Q2) (Q3) (Q4)

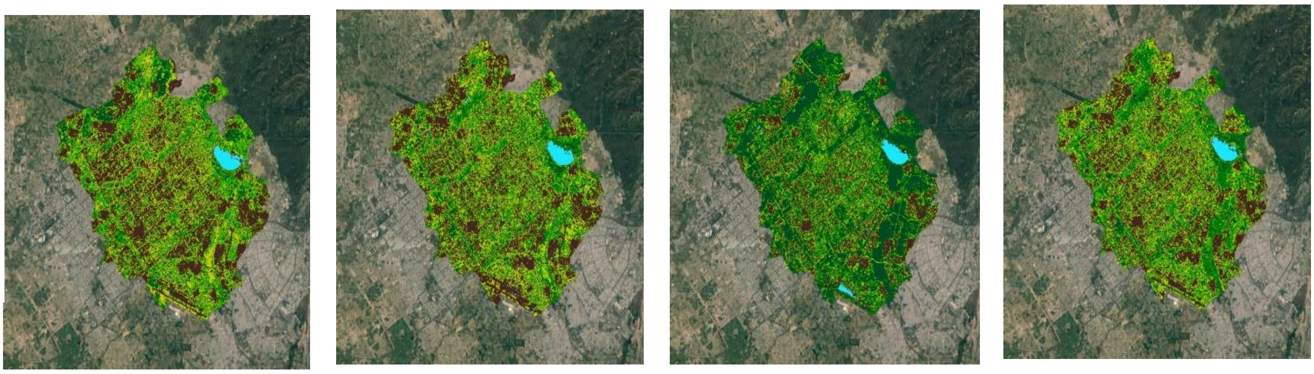
2019

2020

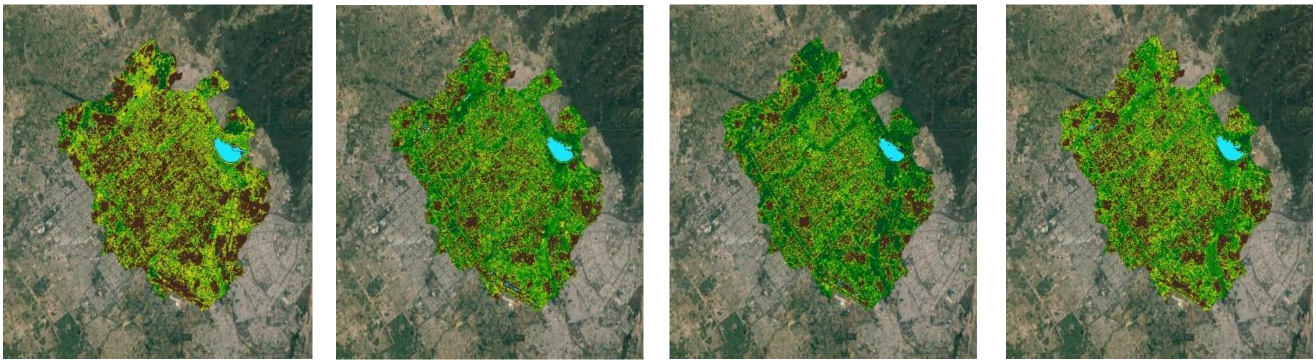
2021



2022

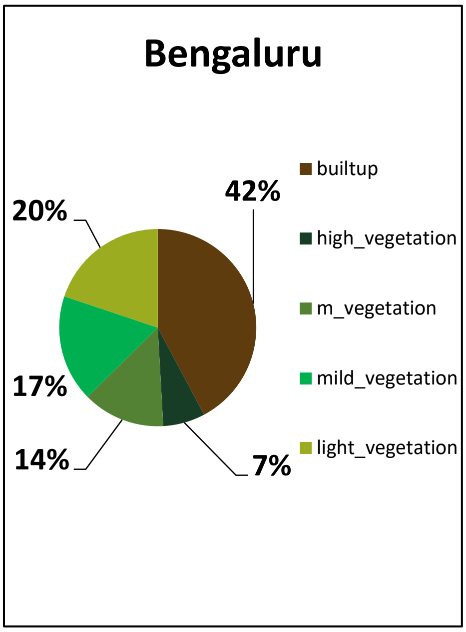


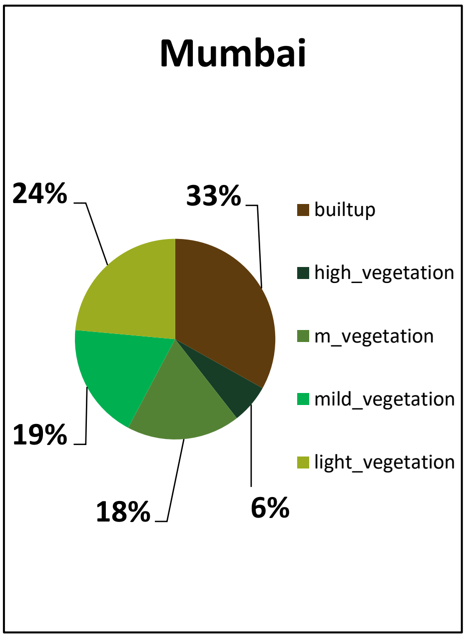
2023

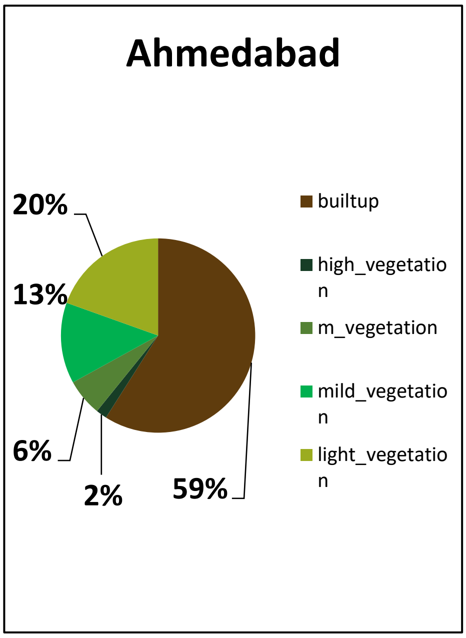


"The Green and Built Spaces of different cities : A 2019 to 2023 Perspective with Seasonal Quarter Insights"

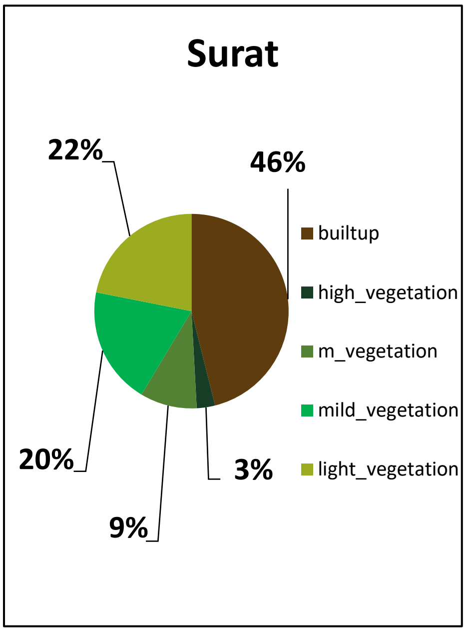
Tier-1 Cities:

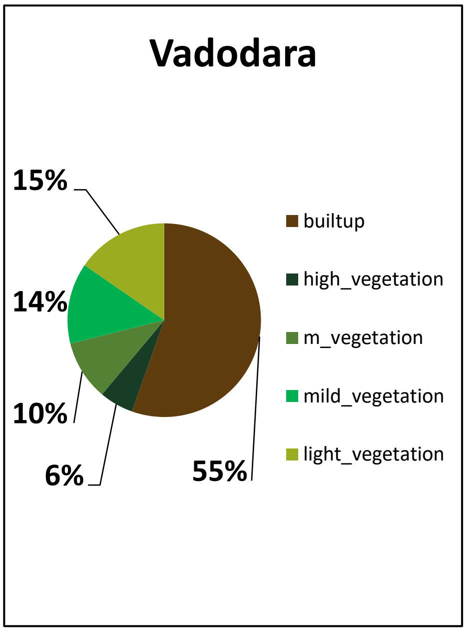


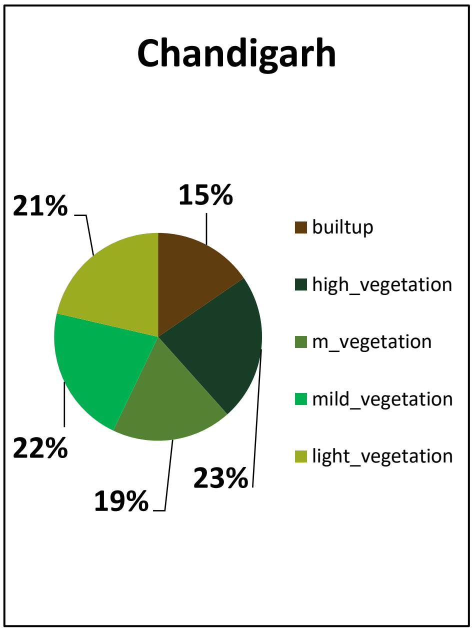




Tier-2 Cities:







FINDINGS

Built-up				
City	Quarter	2019	2023	Diff % 2019 vs 2023
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Mumbai	Q4	24.1262307	23.56495367	-0.024%
Vadodara	Q3	54.84841571	53.04600195	-0.034%

Surat has a negative growth rate of 13% between 2019 and 2023. This could be due to a number of reasons, such as everyday villages included in SMC's limit, So the area of Surat is increasing due to which the built-up area of Surat is showing less, people do gardening on their rooftops.

Ahmedabad shows a very small positive growth rate of 5% between 2019 (52.39 km^2) and 2023 (52.67 km^2). This suggests that the built-up area in Ahmedabad has remained relatively stable over the four-year period.

Chandigarh also has a very small positive growth rate of 70% between 2019 (14.19 km^2) and 2023 (15.25 km^2). This indicates that the built-up area in Chandigarh has grown slightly over the four years, but at a slow pace because maybe changes in government regulations.

High vegetation						
City	**Quarter**	**2019**	**2023**	**Diff % 2019 vs 2023**	**Elasticity**	**Interpretation**
Chandigarh	Q3	22.58	19.91	12%	0	The city loses the High - vegetation volume but is not impacted by High-vegetation
Surat	Q4	2.83	3.59	21%	-0.06	Low negative effect
Ahmedabad	Q4	1.25	2.30	46%	-0.09	Low negative effect
Bengaluru	Q4	6.28	10.84	42%	-0.09	Low negative effect
Mumbai	Q4	6.20	7.00	11%	-0.22	Medium negative effect
Vadodara	Q4	6.57	6.45	-2%	-0.37	High negative effect

Chandigarh has a small positive growth rate in the built-up area (7%) and a 0% elasticity value. While the built-up area increased slightly, vegetation cover remained stable. Because Chandigarh has land for urbanization, vegetation stays stable.

Ahmedabad shows a very small positive growth rate in the built-up area (5%) and a 21% increase in high vegetation cover but if 1% increase in built-up then 9% decrease in high vegetation.

Surat has a positive growth rate of 21% in high vegetation. From the elasticity, it can be shown that if 1% built-up increases then 6% high vegetation decreases. This suggests that Surat doesn't have land for building up so for the urbanization they cut high vegetation.

Modrate_vegetation						
City	**Quarter**	**2019**	**2023**	**Diff % 2019 vs 2023**	**Elas-ticity**	**Interpretation**
Chandigarh	Q3	17.27	19.71	12%	-0.09	Low negative effect
Surat	Q4	8.55	9.72	12%	-0.31	High negative effect
Ahmedabad	Q4	5.98	6.66	10%	-0.34	High negative effect
Bengaluru	Q4	10.60	13.94	24%	-0.34	High negative effect
Mumbai	Q4	15.55	15.95	3%	-0.21	Medium negative effect
Vadodara	Q4	10.84	10.30	-5%	-0.16	Medium negative effect

Chandigarh has a very small positive growth rate in the built-up area (7%). Similar to Surat and Ahmedabad, the small change in built-up area is unlikely to be the main driver behind the decrease in vegetation cover. The elasticity value for Chandigarh is -0.9, which is significantly lower than Surat and Ahmedabad. This suggests that a 1% increase in the built-up area has a much smaller negative impact on vegetation cover in Chandigarh compared to the other two cities.

Ahmedabad shows a very small positive growth rate in the built-up area (5%) and a 3% decrease in vegetation cover. The elasticity value is -0.34. Even though the change in built-up area is minimal, the negative elasticity value suggests a similar pattern to Surat - that a 1% increase in built-up area might be linked to a 34% decrease in vegetation cover.

Surat has a positive growth rate of -12% in moderate vegetation areas. The elasticity value is -31%. This suggests that a 1% increase in built-up area in Surat might be associated with a 31% decrease in vegetation cover. Compared to high vegetation, moderate vegetation has a high negative effect.

Mild_vegetation						
City	**Quarter**	**2019**	**2023**	**Diff % 2019 vs 2023**	**Elas-ticity**	**Interpretation**
Chandigarh	Q4	21.93	20.94	-5%	-0.11	Low negative effect
Surat	Q3	17.42	15.44	-13%	-0.52	High negative effect
Ahmedabad	Q4	13.13	12.70	-3%	-0.67	High negative effect
Bengaluru	Q4	14.22	12.89	-10%	-0.67	High negative effect
Mumbai	Q4	13.80	13.92	1%	-0.68	High negative effect
Vadodara	Q3	13.15	13.09	0%	-0.68	High negative effect

Chandigarh has a very small positive growth rate in the built-up area (7%) and a -5% decrease in vegetation cover. The elasticity value is -11%. A 1% increase in the built-up area might be associated with a 0.11% decrease in vegetation cover.

Ahmedabad shows a very small positive growth rate in the built-up area (5%) and a -3% decrease in vegetation cover. The elasticity value is -0.67. Even though the change in built-up area is minimal, the negative elasticity value suggests a similar pattern to Surat. That is, a 1% increase in the built-up area might be linked to a 67% decrease in vegetation cover.

Surat has a negative growth rate of 13% decrease in vegetation cover. The elasticity value is -0.52. This suggests that a 1% increase in built-up area in Surat might be associated with a 52% decrease in vegetation cover. However, the decrease in vegetation cover is much larger than the change in built-up area, so other factors are likely at play.

We find mild vegetation mainly in fields and farms and because of the development of urban areas, this mild vegetation is being cut. This is one of the main reasons for decreasing mild vegetation.

Light_vegetation						
City	**Quarter**	**2019**	**2023**	**Diff % 2019 vs 2023**	**Elas-ticity**	**Interpretation**
Chandigarh	Q4	**20.26**	**19.71**	-3%	0.3	High positive effect
Surat	Q4	**16.47**	**16.47**	2%	-0.06	Low negative effect
Ahmedabad	Q4	**17.03**	**16.93**	-1%	0.32	High positive effect
Bengaluru	Q3	**16.15**	**16.22**	0%	0.32	High positive effect
Mumbai	Q3	**16.15**	**16.17**	0%	0.58	High positive effect
Vadodara	Q3	**14.007**	**14.78**	5%	-0.12	Medium negative effect

Surat has a negative growth rate of -0.134% in built-up areas and a 2% increase in vegetation cover. The elasticity value is 0.6. This suggests that a 1% increase in a built-up area in Surat might be associated with a 6% decrease in vegetation cover,

Ahmedabad shows a very small positive growth rate in the built-up area (5%) and a 1% decrease in vegetation cover. The elasticity value is 0.32. if a 1% increase in the built-up area might be linked to a 32% decrease in vegetation cover.

Chandigarh has a very small positive growth rate in the built-up area (7%) and a 3% decrease in vegetation cover. The elasticity value is 0.3. A 1% increase in the built-up area might be associated with a 3% decrease in vegetation cover.

Here we have seen that the light vegetation has been increasing. This is because most of the two-way roads are being separated by planting light vegetation in the divider. In the recent scenario, gardening is becoming a font of many people and they build gardens around their households. This is also one reason behind increasing of light vegetation.

VISUALIZTION

"Temporal Evolution of Land Cover: Surat"

LIMITATION

- **Satellite Resolution Limitation:** The satellite imagery from Sentinel-2 may have limitations in resolution, which could affect the accuracy of distinguishing between different classes of vegetation and built-up areas, especially in densely populated urban areas with complex land use patterns.

- **Seasonal Variability:** The data collected through satellite imagery may vary seasonally due to changes in vegetation cover and weather conditions, which could impact the accuracy and reliability of the analysis, particularly in regions with distinct wet and dry seasons.

- **Data Processing Challenges:** The process of collecting and analysing data from the Google Earth Engine platform may encounter technical challenges such as data gaps, processing errors, or inconsistencies, which could affect the accuracy and completeness of the results.

- **Classification Accuracy:** The classification of land cover into built-up and vegetation classes, as well as the further subdivision of vegetation into high, moderate, mild, and light categories, may be subject to classification errors, especially in areas with mixed land use or spectral confusion.

- **Limited Ground Truth Data: The** analysis may lack sufficient ground truth data for validation and calibration, which could introduce uncertainties in the interpretation of results and the generalization of findings to other areas beyond the study cities.

SCOPE

- **Supercharge Urban Planning with Advanced Data:** High-quality ground truth data becomes the foundation, capturing details like vegetation and infrastructure.

- **Constant satellite:** Constant satellite monitoring multiple cities at one time and includes other parameters like weather atmospheric events city town policy

- **Deep learning (DL) and Machine learning (ML):** Advanced algorithms like deep learning and machine learning step in to analyze this vast data stream. They automatically classify and detect features like buildings, roads, trees, and even solar panels, saving time and resources for planners.

- **Image enhancement can give us cleaner and High-resolution images:** Image enhancement techniques can significantly improve the quality of satellite data, removing noise and sharpening details. This allows for a clearer understanding of urban dynamics and the identification of subtle changes that might otherwise go unnoticed.

SUGGESTION

- Advocate for government enforcement of new policies on urbanization to ensure that green spaces are preserved and not diminished.

- Promote green policies aimed at controlling rapid urbanization and fostering sustainable cities.

- Implement strict penalties for violations of green policies and deforestation practices

- Launch campaigns to raise awareness about environmental preservation and the need to regulate high levels of urban development.

- Enhance data integrity and accessibility by encouraging cities to maintain updated shapefiles, and recommend that they make these files available on their municipal corporation websites or on platforms like Google for wider use and analysis

USEFULNESS

- **Better Township Planning:** We can create denser, walkable communities with integrated green infrastructure like parks, green corridors, and rooftop gardens. This reduces urban sprawl and promotes a healthy living environment.

- **Data-Driven Policymaking:** Municipal corporations can leverage data analytics to monitor land use patterns, detect unusual activity like illegal deforestation, and optimize resource management. This facilitates informed policy decisions that promote green spaces.

- **Collaborative Research and Scholarship:** By fostering collaboration between urban planners, environmental scientists, and policymakers, research can be directly translated into actionable strategies for sustainable

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