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PRELIMINARY OBSERVATION OF NDVI-BASED VEGETATION DYNAMICS AND ITS RELATION TO ENVIRONMENTAL VARIABLES IN MAJOR CITIES OF SAURASHTRA REGION, INDIA

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ABSTRACT:

Climatic variables have a significant role in the vegetation index of a region, however not much studies have been conducted around them. The aim of this study is to observe the relationship between vegetation index (Normalised Difference Vegetation Index) and weather parameters. Saurashtra region has seen a general decline in natural vegetation over the last 30 years, especially in urban and coastal areas. This research uses Normalised Difference Vegetation Index on QGIS using Landsat 5 and 8 images to examine the spatiotemporal changes in the greenery and vegetation of Rajkot (Urban), Junagadh (forested), and Porbandar (coastal) cities between 1991 and 2021. The study reveals a significant decrease in the amount of vegetation, especially along Rajkot's urban growth corridors. However, there are only a few small-scale forestry and greening initiatives visible. The vegetation in Junagadh has significantly declined showing rapid urban conversions, with a few high NDVI pockets still existing in the city. There are apparent restoration initiatives, especially in riparian zones, but their reach and influence are constrained. Porbandar's vegetation is declining, especially in peri-urban areas, and it is being extensively replaced by built-up areas. Over time, there appears to have been some beneficial effects near water bodies on account of modest riparian restoration and small-scale greening. This study also discusses policy recommendations that encourage academics and urban planners to prioritise native and climate-resilient vegetation and incorporate green infrastructure into urban development. Involving the community in urban greening initiatives will encourage environmental stewardship and public participation. Lastly, resistance to shifting urban and climatic conditions will be ensured by adaptive management and frequent policy reviews.

KEYWORDS: *Normalised Difference Vegetation Index (NDVI), Weather Parameters, Urbanization, Remote Sensing, Quantum GIS (QGIS), Saurashtra region.*

INTRODUCTION:

The Saurashtra region includes Rajkot, Junagadh, Bhavnagar, Porbandar, Jamnagar, Amreli, Surendranagar, and parts of Ahmedabad district in Gujarat's southwest. Saurashtra is a peninsula comprising a rocky tableland, coastal lowlands, and an undulating plain with hills and rivers flowing in different directions. The eastern border of Saurashtra is a low-lying area that served as the former maritime connection between the Gulf of Kutch and Khambhat. Saurashtra's major water divide is an elevated piece of ground connecting the highlands of Rajkot and Girnar. The climate in the region is semi-arid with monsoons. Rainfall patterns in Gujarat's Saurashtra region are highly variable, affecting the local ecosystem, agriculture, and water resources. Saurashtra's diverse weather systems and geographical location lead to highly varied and unpredictable rainfall patterns (Sodha et al. 2023). Rainfall plays a crucial role in changing the environment and sustaining life. Understanding rainfall variability is critical for managing agricultural and water resources in regions such as Saurashtra region, where the monsoon is the dominant weather system discovered that remote sensing-based data performed similarly to point estimations from field research in reliably measuring ET0, making it a very helpful tool in the semi-arid regions. Hence, for investigating the relationship between weather parameters and NDVI, technologies like remote sensing and GIS are used.

As cities grow in population and scale, they often cause environmental deterioration and lasting changes to the urban ecosystem. It causes an increase in pollutants, soil degradation, land use/land cover change, and unsustainable development, among other things. LULC change has traditionally been a significant challenge in the global environmental crisis. Unprecedented change in the LULC has contributed to deforestation, landscape fragmentation, habitat loss, global warming, desertification, ecosystem service loss, biodiversity, carbon loss due to soil rarefraction and natural extremes, among other things.

Carbon store and sequestration: Urban areas in the world account for over threefourths of Carbon emissions and a significant source of pollution. Expanding developmental activities such as industries, constructions, transports, vehicles and power plants in cities are causing serious pollution. As a result, the quality of air has become a matter of concern for human health. In a few other cities, tree cover dominates over the concrete jungle but situation is reverse in majority of the cities. The concrete jungles with negligible tree cover have a high level of pollution. People in such cities have poor quality of life due to the presence of harmful gases and dust particles, and very high temperature during summers. To reduce net emission of Carbon gases, forest or tree covers in the urban area are considered a main source of Carbon sequestration.

Temperature moderation: Concrete structures absorb heat, increase temperature of the structures and radiate heat, which increases air temperature during the summer. The vegetation absorbs heat and uses light in photosynthesis, subsequently reducing the availability of sunlight that would heat up the atmosphere and land surfaces.

Trees are an important, coeffective solution for reducing pollution and improving air quality. Leaf stomata, the pores on the leaf surface, take in polluting gases which are then absorbed by water inside the leaf. Some species of trees are more susceptible to the uptake of pollution, which can negatively affect plant growth. Ideally, trees should be selected that take in higher quantities of polluting gases and are resistant to the negative effects they can cause.

Vegetation distribution is affected by climate conditions and human activity patterns over time. Weather parameters such as temperature, precipitation, and light affect the overall pattern of vegetation, including its grade, distribution, and zonal fluctuation. Environmental changes have a substantial impact on the dynamics and evolution of vegetation.

Remote sensing technology has enabled researchers to observe landcover change dynamics from space. NDVI measures biophysical aspects of vegetation, including growth status and dynamics. It is commonly used in the study of global or regional vegetation classification and cover changes.

The aim of this study is to analyze the spatio-temporal changes in vegetation cover (using NDVI) of major cities of Saurashtra over a defined period of time and to correlate NDVI with various weather parameters such as temperature, rainfall, humidity etc. which will help us understand the impact of urbanisation on surrounding vegetation health.

Remote sensing is the use of electromagnetic waves emitted, reflected, or diffracted by sensed objects to detect the earth's surface from space with the goal of improving natural resource management and environmental protection. The satellite imagery obtained contains spectral and spatial information about the earth's surface features with a finite radiometric resolution. The fundamental idea underlying remote sensing is the unique interaction of electromagnetic waves with objects. Electromagnetic light is reflected by a target at a specific wavelength.

The Normalized Difference Vegetation Index (NDVI) measures plant life by comparing near-infrared light (reflected by plants) to purple light (refelcted by flowers). NDVI is a measure of plant photosynthetic activity. It is computed by dividing the difference between near-infrared and visible reflectance by their sum. The NDVI constantly varies between -1 and +1.

Here is a table showing spectral characteristics of Landsat data used for assessing Land Use Land Cover changes and Normalized Difference Vegetation Index:

Landsat Sensor	Band Number	Wavelength Range (µm)	Spatial Resolution (m)	Application in LULC & NDVI
Landsat 4-5 (TM)	Band 1 (Blue)	0.45 - 0.52	30	Helps to analyse Water body mapping, soil characteristics
	Band 2 (Green)	0.52 - 0.60	30	Helps to analyse Vegetation health, urban areas
	Band 3 (Red)	0.63 - 0.69	30	Helps to analyse Vegetation discrimination, NDVI (with Band 4)
	Band 4 (NIR)	0.76 - 0.90	30	Helps to analyse Vegetation, NDVI calculation
	Band 5 (SWIR-1)	1.55 - 1.75	30	Helps to analyse Soil moisture, vegetation stress

Landsat Sensor	Band Number	Wavelength Range (µm)	Spatial Resolution (m)	Application in LULC & NDVI
	Band 6 (Thermal)	10.40 - 12.50	120 (resampled to 30)	Helps to analyse Surface temperature analysis
	Band 7 (SWIR-2)	2.08 - 2.35	30	Helps to analyse Soil and rock differentiation
Landsat 7 (ETM+)	Band 1 - Band 7	Same as Landsat 5 TM	Same as Landsat 5 TM	Helps to analyse Similar applications
	Band 8 (Panchromatic)	0.52 - 0.90	15	Helps to analyse High-resolution land cover mapping
Landsat 8 (OLI/TIRS)	Band 1 (Coastal/Aerosol)	0.43 - 0.45	30	Helps to analyse Coastal and atmospheric correction
	Band 2 (Blue)	0.45 - 0.51	30	Helps to analyse Water and vegetation analysis
	Band 3 (Green)	0.53 - 0.59	30	Helps to analyse Vegetation and urban studies
	Band 4 (Red)	0.64 - 0.67	30	Helps to analyse NDVI (with Band 5)
	Band 5 (NIR)	0.85 - 0.88	30	Helps to analyse NDVI, vegetation health
	Band 6 (SWIR-1)	1.57 - 1.65	30	Helps to analyse Soil moisture
	Band 7 (SWIR-2)	2.11 - 2.29	30	Helps to analyse Geological studies

Landsat Sensor	Band Number	Wavelength Range (µm)	Spatial Resolution (m)	Application in LULC & NDVI
	Band 8 (Panchromatic)	0.50 - 0.68	15	Helps to analyse High-resolution LULC mapping
	Band 9 (Cirrus)	1.36 - 1.38	30	Helps to analyse Cloud detection
Landsat 8 (TIRS)	Band 10 (Thermal-1)	10.6 - 11.19	100 (resampled to 30)	Helps to analyse Surface temperature mapping
	Band 11 (Thermal-2)	11.5 - 12.51	100 (resampled to 30)	Helps to analyse Surface temperature mapping
Landsat 9 (OLI-2/TIRS-2)	Band 1 - Band 11	Similar to Landsat 8	Similar to Landsat 8	Helps to analyse Improved land cover and NDVI accuracy

STUDY AREA:

Rajkot is located in Gujarat State's central plains, at the centre of the Saurashtra peninsula. Rajkot's elevation is 138 meters above mean sea level. The climate in Rajkot is hot and dry. Over the past 40 years, the average maximum temperature has been 43.5 °C, while the average lowest temperature has been 24.2 °C. Rajkot receives an average annual rainfall of 500 mm. Rainfall has been below normal over the last 20 years. Rajkot city covers 104.86 km^2 and has a population density of 12,735 people/km^2 with a total literacy rate of 82.20%. Junagadh city is situated between latitudes 21° 31'N and 70° 49' E. The settlement serves as a gateway to the Gir Forest, home to the world's last wild Asiatic Lion population. In addition to Gir, the Girnar Ranges, Barda Hills, and Vidis plains host diverse species, particularly avifauna. Junagadh experiences a tropical wet and dry environment with three distinct seasons: mild winter (November-February), hot summer (March-June), and monsoon (July-October).Summer temperatures in Junagadh range from 28°C to 38°C, making for challenging weather conditions. During the winter, temperatures range from 10°C to 25°C. Junagadh's weather is influenced by various variables, including its proximity to the sea. The latent winds from the sea impact the meteorological conditions in the region. Porbandar District, located in the southwest of the Saurashtra Peninsula, is a key district in Gujarat State. Porbandar district has an area of approximately 2316 square kilometres (2011 Census). It is located between latitudes 20°45" and 22°05" North and longitudes 69°20" and 70°10" East. The area has a semi-arid climate, with an average annual rainfall of 70 cm. Surface water temperatures in the field range from 22°-24°C, with pH levels between 7 and 7.5. The topography of the area is flat near the coast and undulating inland. The drainage pattern in this area is 'radial' to subdendretic.

METHODOLOGY:

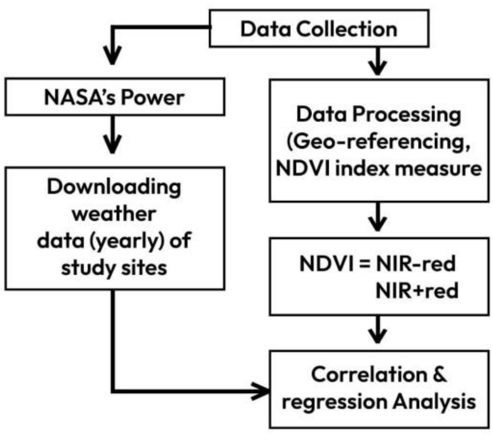


Fig.: Methodology flowchart of the study

Using Landsat satellite imagery, Normalised Difference Vegetation Index (NDVI) maps were created in order to examine vegetation dynamics during the previous 30 years. The study used Landsat 5 Thematic Mapper (TM) and Landsat 8/9 Operational Land Imager (OLI) datasets that were downloaded from the Earth Explorer portal of the United States Geological Survey (USGS). Since they are suitable for NDVI computation and have consistent temporal coverage, the Landsat 5 data (1984–2013) and Landsat 8/9 data (2013–present) were chosen. Using QGIS, an open-source geographic information system popular for remote sensing applications, the approach was divided into three main steps: preprocessing, NDVI computation, and spatial analysis (Zhang et al., 2019; Chen et al., 2021).

Each dataset was given raster layers in QGIS that corresponded to the red and near-infrared (NIR) bands. Landsat 5 loaded Band 3 (Red, 0.63-0.69 µm) and Band 4 (NIR, 0.76-0.90 µm), while Landsat 8/9 used Band 4 (Red, 0.64-0.67 µm) and Band 5 (NIR, 0.85-0.88 µm) (Roy et al., 2014; Jiang et al., 2022). The utilization of appropriate spectral bands is critical for accurately evaluating vegetation health and density, as NDVI is sensitive to variations in chlorophyll content and canopy structure.

A shapefile containing the research area's administrative boundary was included as a vector layer to focus the analysis on the defined geographic extent. The raster datasets were then clipped with the vector layer to guarantee that NDVI calculations were limited to the research region, minimizing processing time and computing load (Gao et al., 2020). The clipping technique ensures spatial consistency over several time periods, allowing for accurate temporal comparisons of vegetation patterns.

After preprocessing, the NDVI was determined using the conventional formula:

$$(NDVI = (NIR-R) / (NIR+R)$$

Where, NIR: Near-infrared light R:

Visible red light

This method efficiently normalizes disparities in vegetation reflectance by contrasting healthy vegetation's high NIR reflectance with its low red spectrum reflectance (Pettorelli et al., 2005; Tucker, 1979). NDVI values typically range from -1 to +1, with values closer to +1 indicating dense, healthy vegetation and negative values representing water bodies or non-vegetated areas. The NDVI was calculated using the raster calculator tool in QGIS, which is a popular technique in vegetation monitoring research (Huete et al., 2002; Kandasamy et al., 2020).

The generated NDVI maps were visually evaluated to determine spatial patterns of vegetation dynamics. To ensure consistency and accuracy, the Semi-Automatic Classification Plugin (SCP) in QGIS was used to correct the satellite imagery, reducing atmospheric interference and standardizing reflectance values over time (Chander et al., 2009; Vermote et al., 2016). The NDVI results derived from the analysis are a useful tool for assessing long-term changes in vegetation health, land use changes, and potential environmental implications in the study area.

By using this methodological approach, a strong dataset of NDVI maps was created, allowing for a full spatiotemporal assessment of vegetation dynamics over the last three decades. The findings of this study contribute to ongoing global research on vegetation monitoring and environmental sustainability, and are consistent with previous studies that have successfully used NDVI for land cover change detection and ecological assessment (de Jong et al., 2011; Kennedy et al., 2018).

Correlating Environmental variables:

We need to measure the weather in order to predict it. It's critical to know what the weather was like today and yesterday if you want to know what the weather will be like tomorrow. It's also useful to know the average weather on a specific day of the year. Collecting data on a daily basis can reveal patterns and trends, as well as aid in understanding how our environment operates. Any facts or numbers about the status of the atmosphere, such as temperature, wind speed, rain or snow, humidity, and pressure, are included in weather data.

Climate refers to a region's long-term weather trend, which is usually averaged over 30 years. NASA's POWER (Prediction of Worldwide Energy Resource) data, with a grid resolution of one-half arc degree longitude by one-half arc degree latitude, is freely available for download via a web interface. The data, funded by the NASA EarthScience Directorate Applied Science Program, provides daily global coverage for all weather parameters from 1983 to the present, with a several month delay from January 1997 to the present. This data is widely used in agricultural modelling for crop yield simulation and other crop simulation exercises, as well as plant disease modelling (Sparks, 2018).

Thus, area specific weather data of each city was downloaded from POWER data and was compared with our NDVI data to understand the statistical correlation between them.

RESULTS AND DISCUSSION:

Normalised Difference Vegetation Index of Rajkot:

The transition from higher NDVI zones to moderate or lower NDVI in the city periphery strongly shows that urban sprawl and industrial/residential growth are the primary factors. The drop in maximum NDVI values from ~0.50 to ~0.45 suggests a potential loss in dense vegetation regions. While this drop may appear insignificant numerically, it might signify major environmental and agricultural changes. Instead of broad, contiguous stretches of agriculture or forest, 2021 will most likely include more fragmented, smaller areas of greenery spread throughout and around the built-up grid. The reservoir or lake in the east remains stable throughout time, however some minor NDVI shifts along the borders of waterbody may indicate ecological changes, encroachment, or water-level fluctuations.

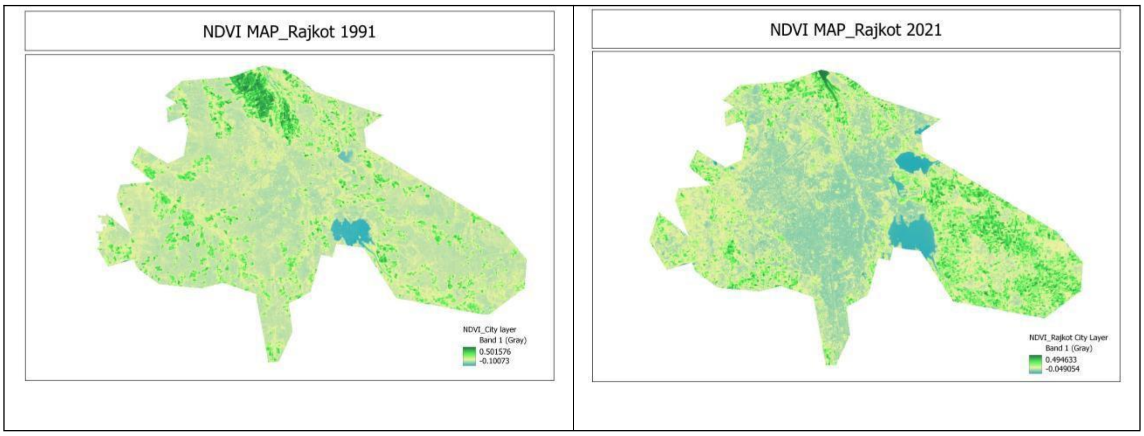
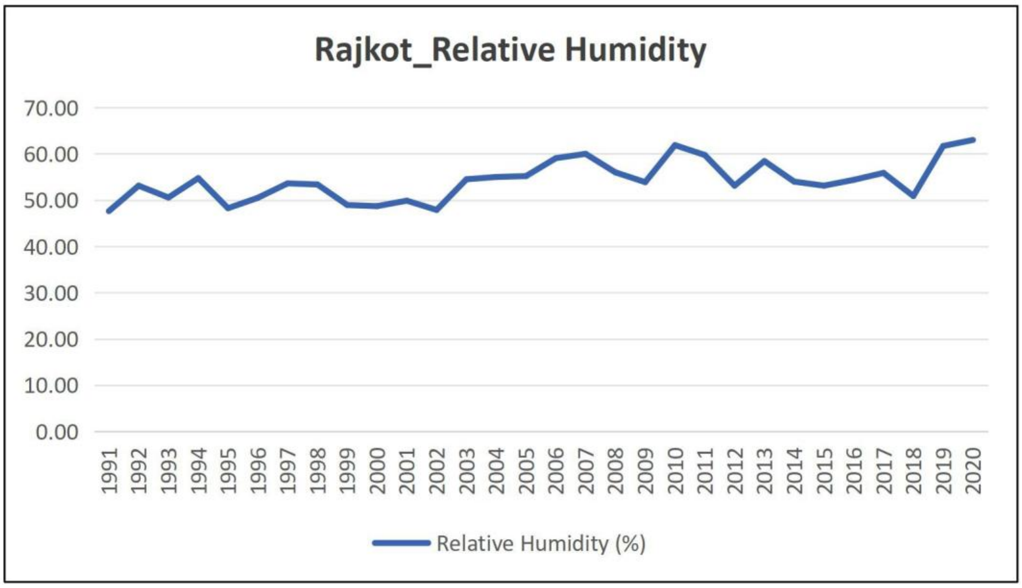
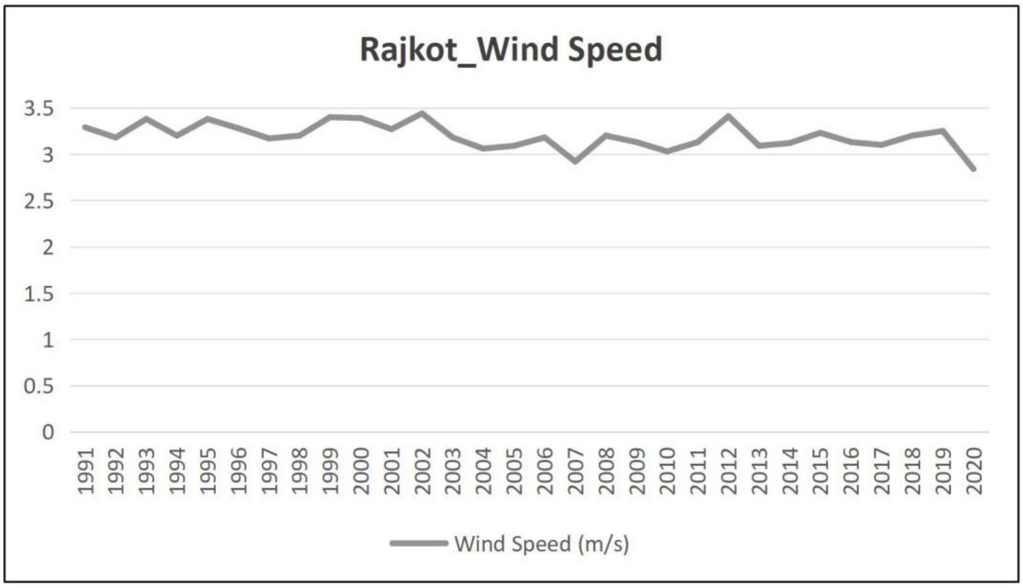
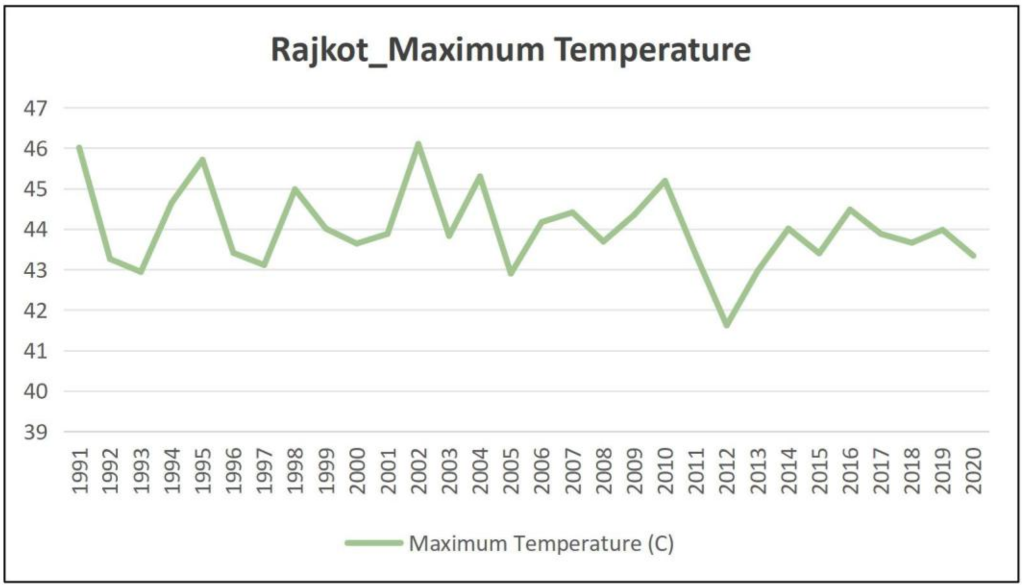


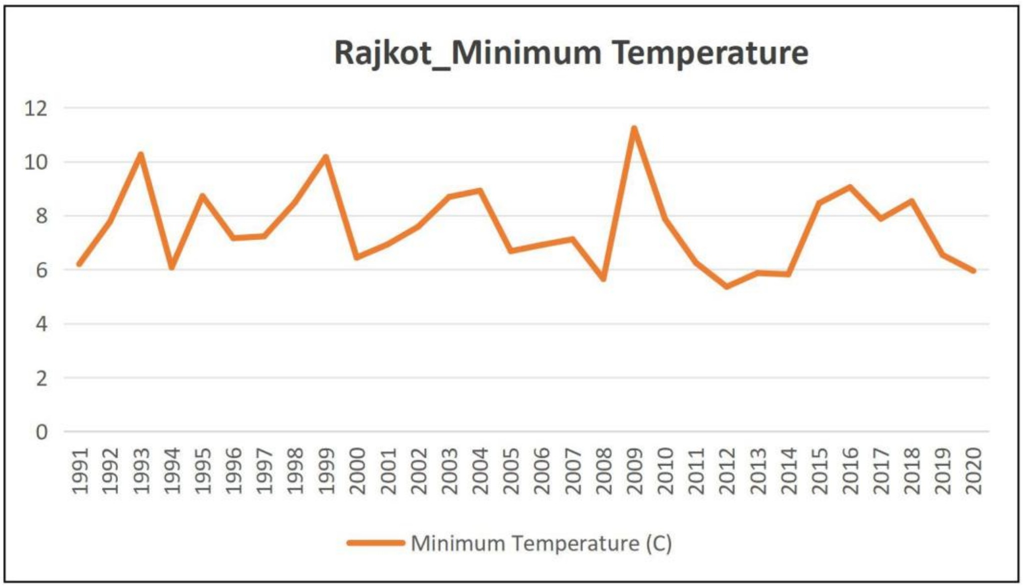
Fig: NDVI Map of Rajkot

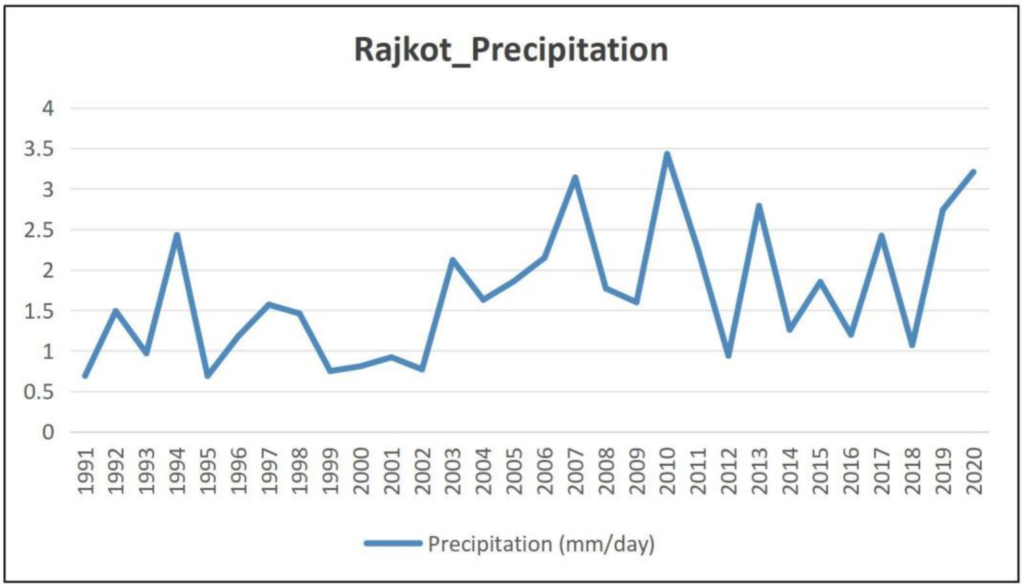
Correlation of NDVI of with weather parameters of Rajkot:




Rajkot_Wind Speed
3.5
3
2.5
2
1.5
1
0.5
0
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
Wind Speed (m/s)


Rajkot_Maximum Temperature
47
46
45
44
43
42
41
40
39
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
Maximum Temperature (C)


Rajkot_Minimum Temperature
12
10
8
6
4
2
0
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
Minimum Temperature (C)



Decreased maximum temperature and increased humidity may cause a regional climatic shift or a change in monsoon patterns, resulting in more frequent or intense rainfall events and higher moisture content in the air. Despite this seemingly favorable climate for vegetation, the urban footprint has grown dramatically, limiting the possibilities for huge, continuous vegetative patches. Lower wind speeds may be a direct result of urban growth (buildings act as barriers). This may preserve humidity, but it does not necessarily improve NDVI if the area is covered with impermeable surfaces. In principle, more rain can help plants develop. However, the 2021 NDVI image shows a shift in vegetation distribution rather than an increase in total vegetation because large areas of former farmland are expected to be covered by houses, highways, and industrial complexes, preventing the creation of high NDVI zones.

Normalised Difference Vegetation Index of Junagadh:

There seems to have slight decrease in the high NDVI of Junagadh which possibly indicates loss of very dense vegetation or seasonal variation. The expansion of NDVI in 2021 is the result of urban growth or larger waterbodies. Major areas of the city remain in moderate NDVI giving us a hint that agriculture and open land still persist despite of urban pressure.

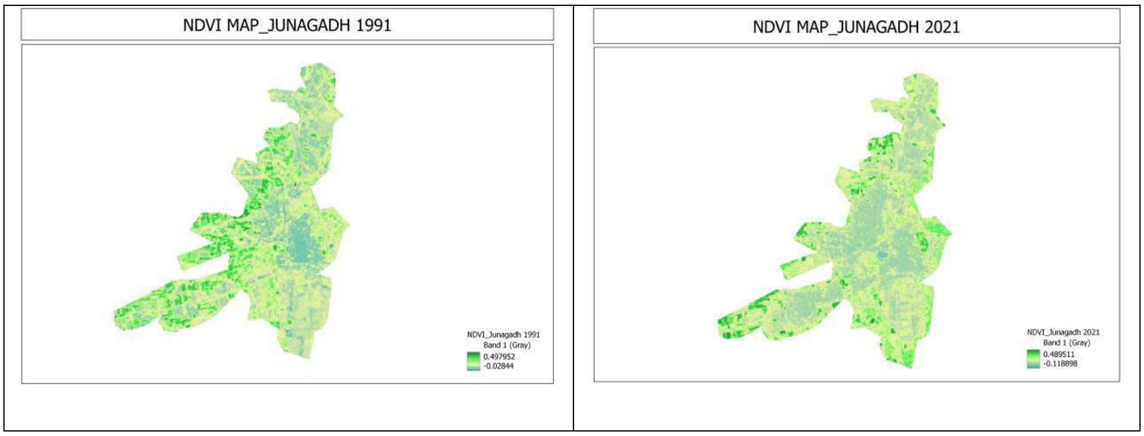
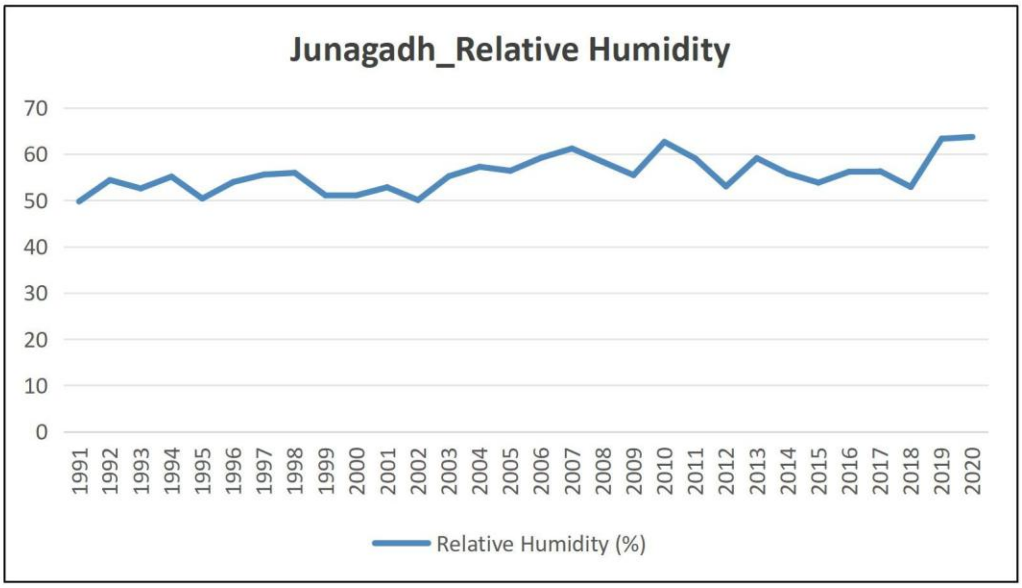
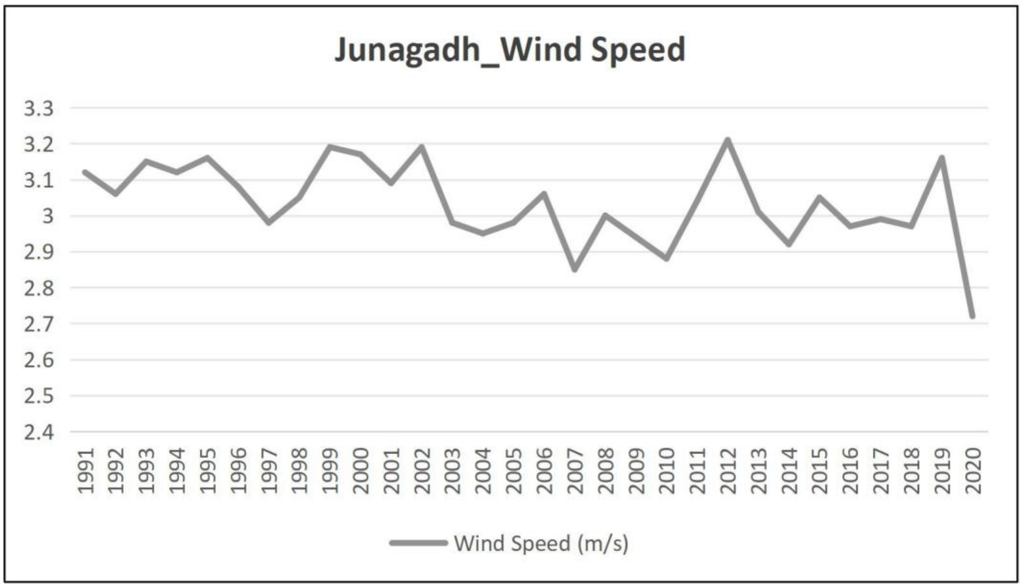
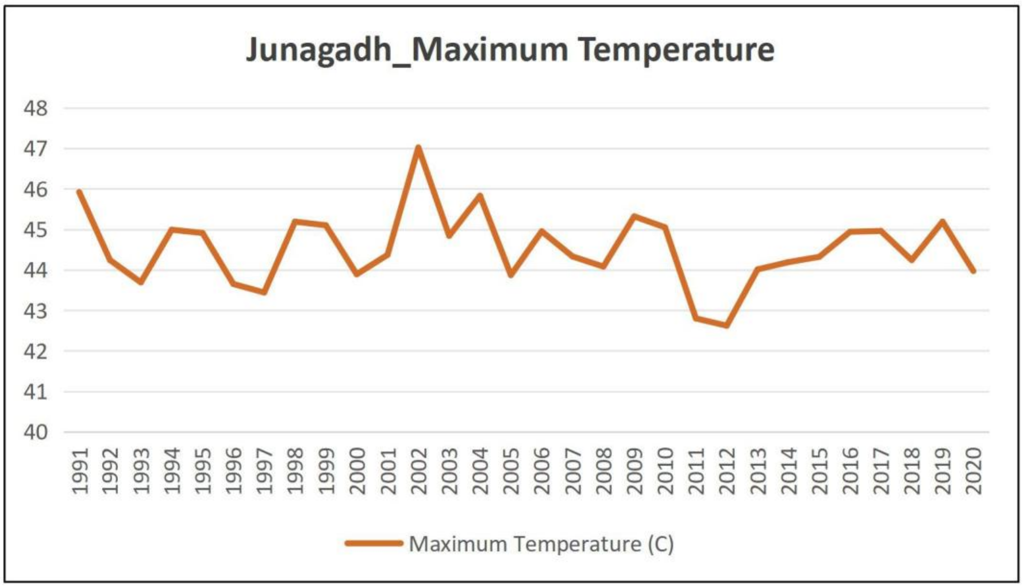


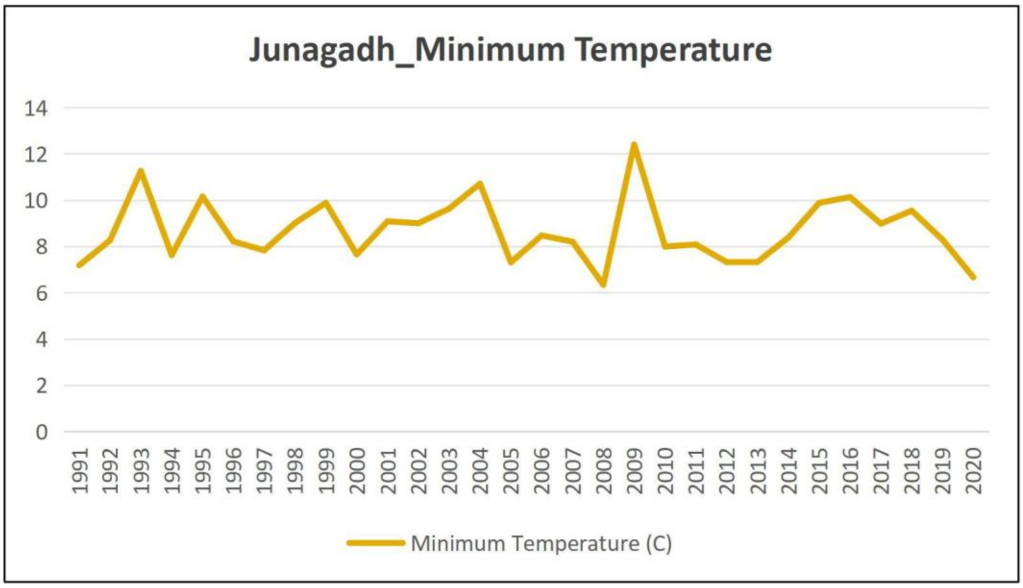
Fig: NDVI Map of Junagadh

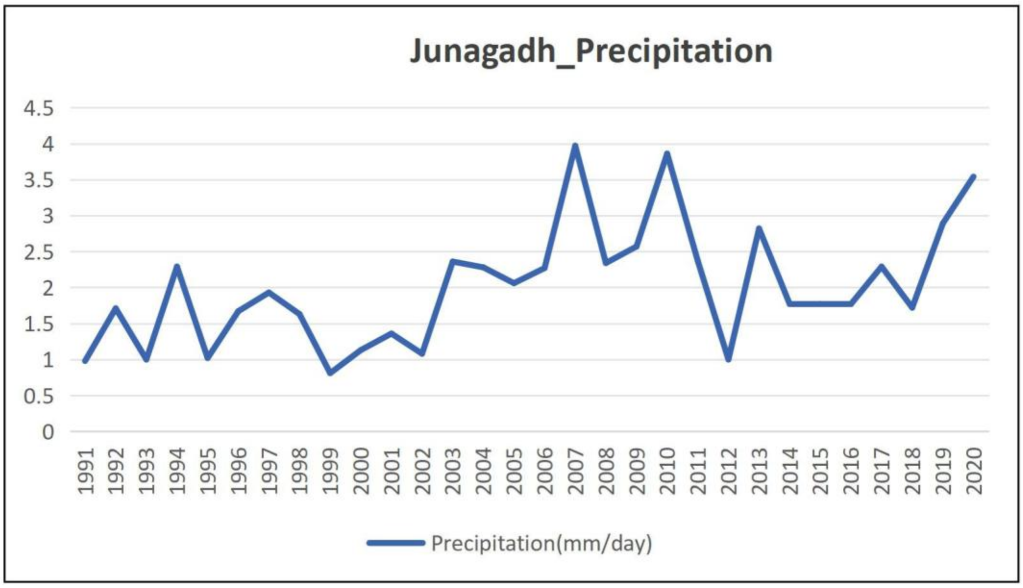
Correlation of NDVI of with weather parameters of Junagadh:






Junagadh_Maximum Temperature
Maximum Temperature (C)


Junagadh_Minimum Temperature
Minimum Temperature (C)


Junagadh_Precipitation
Precipitation(mm/day)

As precipitation is increased by 3.5 fold, it in turn improves soil moisture leading to greener patches in agricultural zones. Despite increase in precipitation maximum NDVI in 2021 is slightly lower due to development of urban areas. Lower maximum temperature and lower wind speed can be the positive factor to maintain high humidity and helping vegetation strongly. This climate data is more conductive to robust vegetation than 1991. However, as Junagadh has expanded substantially where built-up surfaces replace farmlands or natural vegetation leading NDVI near zero or negative. This dynamic explains why Junagadh could not show overall rise in NDVI despite favourable weather conditions for vegetation.

Normalised Difference Vegetation Index of Porbandar:

In some areas of porbandar 2021, there is a notable increase in maximum NDVI pointing to healthier vegetation and better management. However there persist negative NDVI zones likely corresponding to urban centers, waterbodies or newly built-up areas. Moreover, it is expected to see more low patches of NDVI if the city footprint expands. Overall NDVI can still increase if farmlands and newly irrigated zones become more productive.

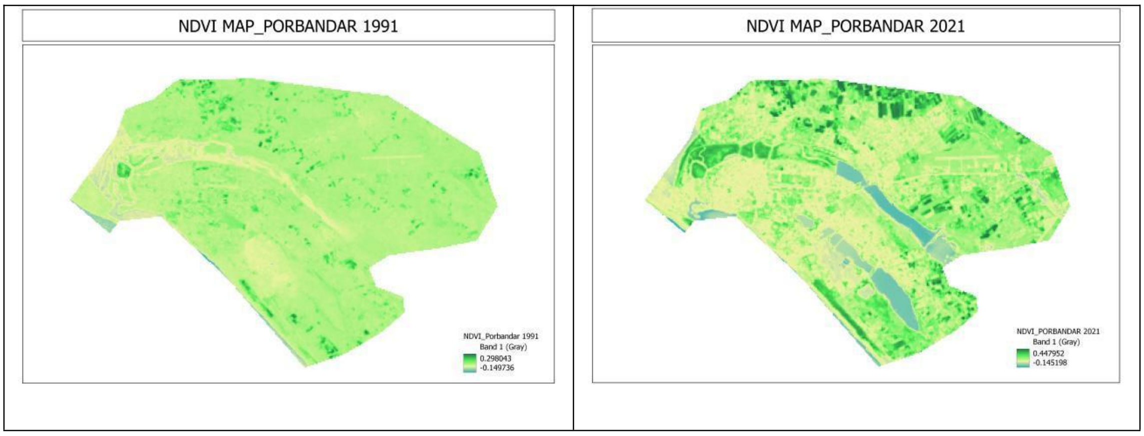
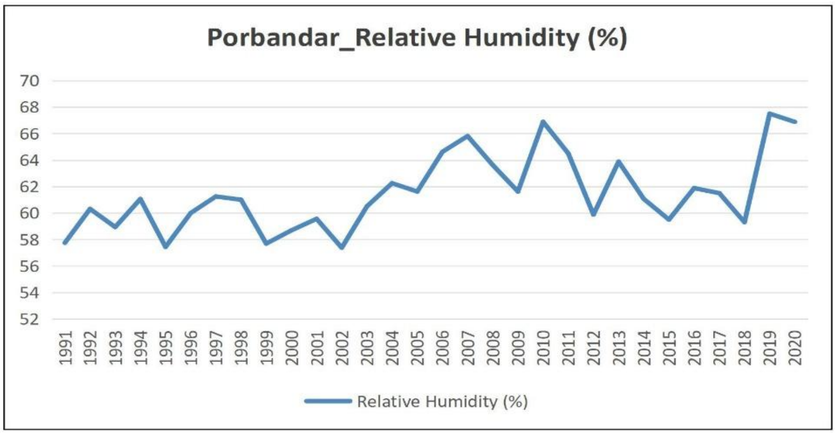
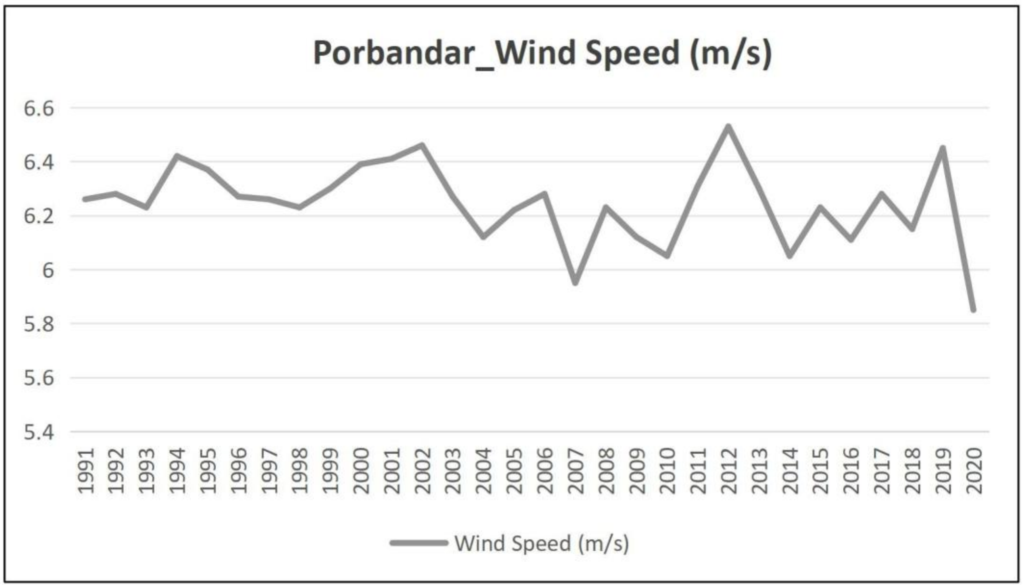
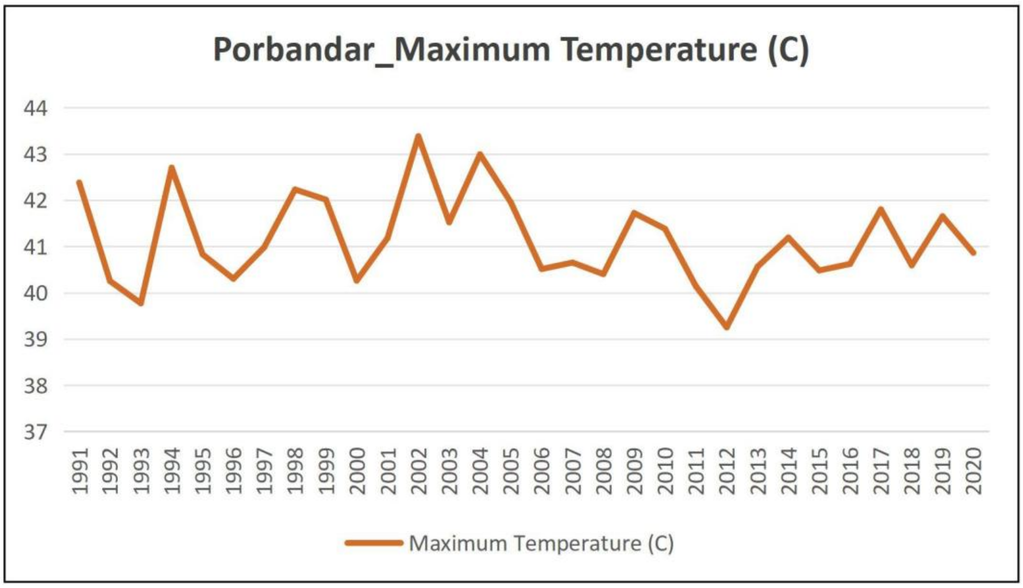


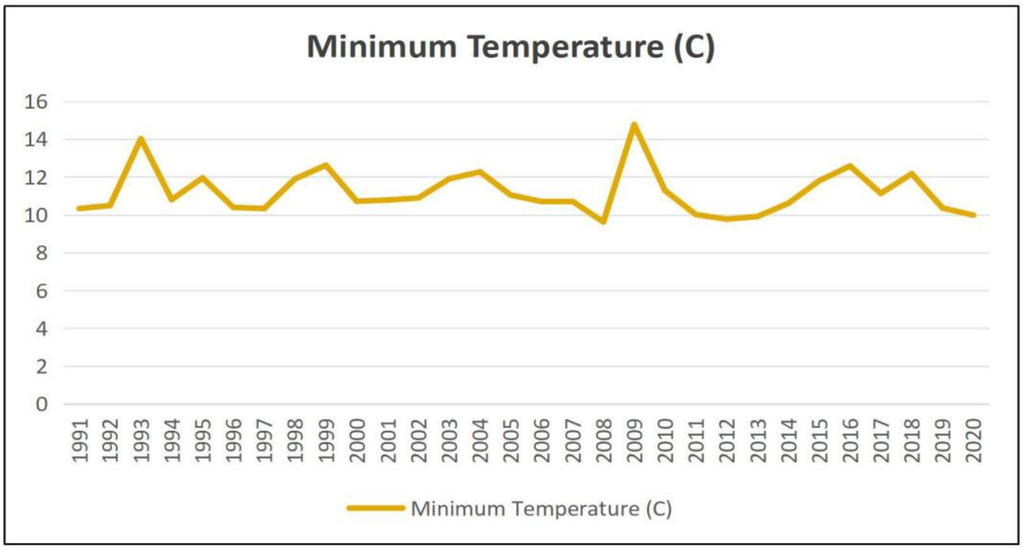
Fig: NDVI Map of Porbandar

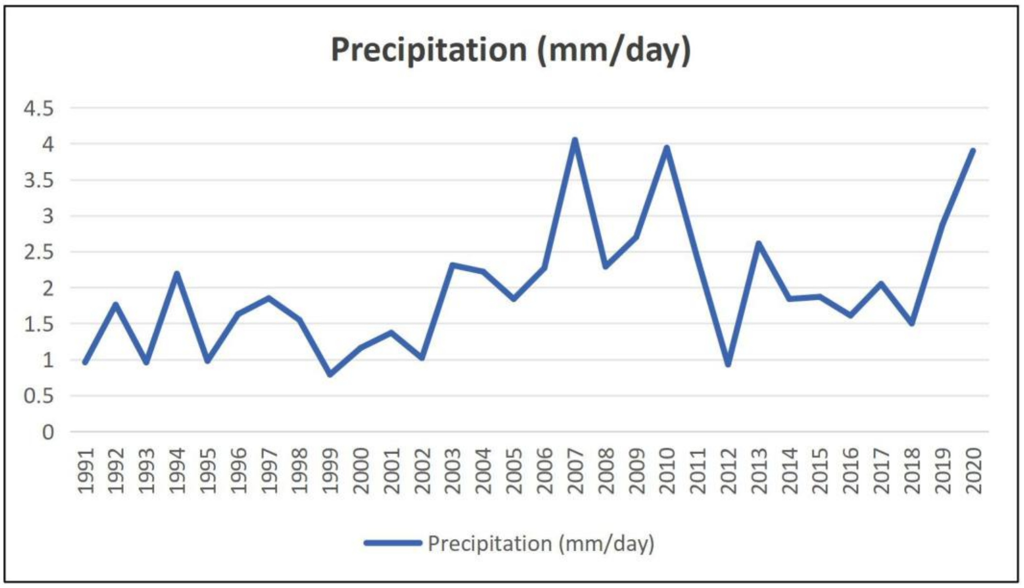
Correlation of NDVI of with weather parameters of Porbandar:




Porbandar_Wind Speed (m/s)
6.6
6.4
6.2
6
5.8
5.6
5.4
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
Wind Speed (m/s)


Porbandar_Maximum Temperature (C)
44
43
42
41
40
39
38
37
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
Maximum Temperature (C)


Minimum Temperature (C)
16
14
12
10
8
6
4
2
0
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
Minimum Temperature (C)



When we correlate NDVI maps with weather parameters, it can be clearly observed that higher precipitation, high humidity and low maximum temperature can lead to healthy green vegetation. Upper NDVI in 2021, certainly shows that some regions of the study area have taken advantage of the better climate conditions and have developed well irrigated agricultural fields or newly planted green belts. Despite favourable weather conditions, if Porbandar continuously expands urban areas, we fear to witness low NDVI in near future. Also, as Porbandar is located on the coast, its microclimate is influenced by sea breeze, humidity and potential shift in shoreline land use. Thus, NDVI patches near water-bodies or developed waterfronts remain consistent since years.

CONCLUSION:

Correlations between the seasonal variations in the NDVI and climatic variables (Humidity, Windspeed, Tmax, Tmin and Precipitation), were analyzed. It was observed that in Saurashtra region (Rajkot, Junagadh, Porbandar cities) precipitation has a significant effect on its vegetation. Vegetation growth in Saurashtra region was not limited primarily by temperature. A comparison of NDVI trends and the NDVI– climate relationship indicated that NDVI trends were controlled by precipitation in the Saurashtra region. These results give us possible vegetation–climate relationships and future change in the terrestrial carbon cycle. Correlation study between NDVI and Climatic variables showed a strong significant correlation. The presence of vegetation and water bodies shows strong relationship with climatic variables.

The article results on correlating NDVI with climatic variables to understand the impact on health of urban vegetation over the period of 30 years. It was observed that all the three cities viz. Rajkot, Junagadh and Porbandar showed a dominant influence of urbanization which transformed high NDVI and densely vegetated areas into more moderated or negative NDVI zones. This transformation lead to constant reduction or fragmentation of continuous green spaces, indicating that growth in urbanization has encroached upon areas that were once characterized by robust agriculture or natural vegetation. It was noted that despite favourable conditions of climate like increased rainfall, hightened humidity and moderate temperatures which are suppose to promote vegetation growth, the potential for enhanced vegetation health got largely subdued on account of the mitigating effects of urban development.

Though the overarching narrative of urbanization is common, the nuances refer among all the cities of the study area. In Rajkot, it is observed that there is decline in maximum NDVI values and the emergence of fragmented vegetation patches indicating aggressive urban expansion that has gradually reduced the extent of dense vegetation cover. Junagadh on the other hand, points on stabilized or slight decrease in maximum NDVI values coupled with increase in negative NDVI zones. This pattern means that despite improved weather conditions, urban growth and alteration in waterbodies are constraining the potential benefits of favourable weather trends. In contrast, Porbandar has a more complex scenario locating increase in maximum NDVI and suggesting that targeted greening initiatives with water management may mitigate some adverse effects of urbanization.

This integrated evaluation stresses on the necessity for strategic and sustainable urban management that leverages climatic benefits while mitigating the impacts of urban sprawl. The findings of the study advocate for incorporating green infrastructure such as urban agriculture, enhanced green belts plus effective water management systems into urban planning. Lastly, while urban expansion emerges as the driving force across all the cities, specific manifestation of vegetative change differs significantly. These differences at micro level stand for the need of localized, context-specific approaches in both research and policy making to foster sustainable urban environments in the face of growing climatic and developmental pressures.

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