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Spatiotemporal Analysis of Urban Growth, Sprawl and Structure of Rajkot, Vadodara and Surat (Gujarat-India) based on Geographic Information Systems, in Relation to the Sustainability Pentagon Analysis

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Abstract

Irregular and exponential growth of urban/suburban commercial and residential zones has resulted in improper and irreversible land transformation and use. The lack of data regarding the driving forces to sprawl and densification of suburban areas, identification of the pressures created by unplanned sprawl over time and inadequate information to measure, monitor and understand the sprawl and structure of a demography has resulted in an imbalanced sustainable development leading to numerous adverse impacts on a demography's natural, human, physical, social and financial capital. In the present study, patterns of spatiotemporal growth, sprawl and structure of three cities, namely, Rajkot, Surat and Vadodara (Gujarat-India) were studied over the past decade with the help of Remote Sensing and Geographic Information Systems. Ground surveys regarding the inferences from the processed GIS images were performed in order to understand the impacts of climate change on health and economy, due to non monitored urban sprawl over the past decade. The driving forces to the sprawl have been accounted and related to the financial development of the cities over time of study. The temporal pressures hence created have been related to resultant impacts of climate change due to improper environmental planning and management. The study also compares the growth rate and sprawl patterns of the three cities on the basis of Sustainability Pentagon Analysis, by distributing relatively equal weights to the driving forces of the change in urban structure and their resultant effects. It ultimately suggests the ways in which the sprawl of urban and suburban centers of the cities could be planned and moderated for achieving sustainable development.

Keywords: Climate Change Impact, Driving Forces, Pressures, Sustainability Pentagon, Urban Heat Island Impacts, Urban/Suburban Sprawl and Structure

1. Introduction

We have been a witness to the exponential increase in urbanization over the past 5 decades. With the growing number of megacities around the world, over the past three decades[1], the productive effects of spatial environmental planning with respect to the projection of driving forces that would catalyze the sprawl of demography are evident. India is one of the fastest growing economies in the world today and probably the second most populous country too. The rate of migration from rural to urban areas has been increasing ever since the advent of privatization and globalization policies in India in 1991. The driving forces to migration from rural areas, such as, better job opportunities, better education, better lifestyle, etc. have resulted in creating several pressures on the urban demography like power deficit, inadequate and improper water supply and poor indoor living conditions due to encroachment in market areas. The steadily increasing natural population pressure has triggered the rates of

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slum dwelling and below poverty line populations in rapidly growing economies. Hence, when we monitor the driving forces to sprawl in any demography, we would be able to precisely study the pressures they would create and the state they would result to. This, would form the basis for planning a demography in a manner that the natural, human, physical (infrastructure), social and financial capitals are balanced and the issues related to each of these are properly addressed, in order to attain sustainable development. This study focuses on studying the spatiotemporal growth of urban structure of three major cities of Gujarat, namely, Rajkot, Vadodara and Surat, over the past decade by remote sensing and geographic information system techniques. These have proven to be very useful in studying various changes in urban land use and their effects over time[2–4].

2. Methodology

The method to study the objective was classified into three basic parts, namely, studying the remotely sensed images, relating the increase in land use to climate change and relating the inferences from the above two to sustainable development objectives[5]. The data from LANDSAT-5 TM was processed by layer stacking methods and Land Surface Temperature and other parameters like Normalized Difference Vegetation Index (NDVI) and Land Use Land Cover were processed to study the effects of the spatiotemporal urban sprawl on the resident population of all the three cities.

In order to derive the land surface temperature from LANDSAT 5 TM images there are only three parameters - emissivity, transmittance and effective mean atmospheric temperature which are required by mono window algorithm. Studying the surface temperature would turn to be the key to determine the effects of land use and increase in built up area on the city's climate. The reflectance measurements in the red and near infrared portion of the spectrum were calculated in order to derive the NDVI from LANDSAT-5 TM. For calculating the LST values, the DN values of the imageries had been converted to radiance values. As we had the GeoTIFF format data we directly converted it into radiance data using ENVI 4.3 software. Further atmospheric correction was performed on the data by using the local values for meteorological parameters. NASA has a webpage that provides values for Transmittance, Upwelling Radiance and Downwelling Radiance, for Landsat data. (http://atmcorr.gsfc.nasa.gov/).

$$CV_{R2} = (CV_{R1} - L\uparrow / \varepsilon \tau) - (1 - \varepsilon / \varepsilon) L\downarrow \quad (1)$$

Where, CVR2 = atmospherically corrected cell value as radiance, CVR1 = Cell value as radiance, L↓ = Downwelling Radiance, L↑ = Upwelling Radiance, τ = Transmittance , ε = Emissivity (typically 0.95)[5]. The datasets from LANDSAT-5 TM were then separately studied under different classes of Built up, Non Built up, Water Body and Vegetation, in order to relate the effects of the driving forces to urban sprawl with the natural, physical (infrastructure), human, social and financial capitals, which constitute the basis to evaluate sustainable development of any demography.

3. Study Area: Demography and Driving Forces to Change

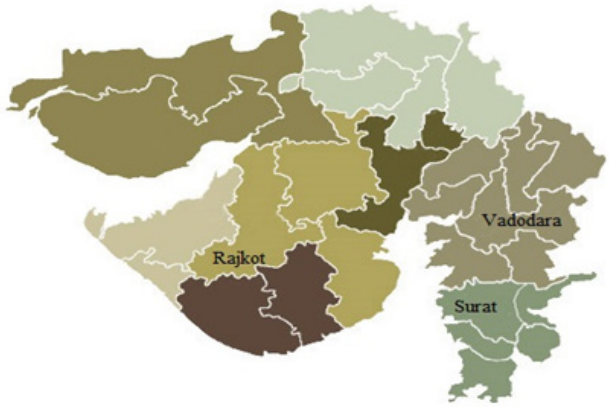

Figure 1. Gujarat State Map. Locations of Rajkot, Vadodara and Surat in Gujarat.

Rajkot is situated in Western Gujarat, popularly known as 'Saurashtra', while Vadodara and Surat are situated in the Southern parts of the state (Figure 1). Rajkot, Vadodara and Surat are the fourth, third and second largest cities of Gujarat, respectively. The average population in each city ranges around three million in all the three cities. During the previous decade, Rajkot has experienced a rapid industrial growth complemented by real estate development, mostly towards the city boundaries. While

Surat is growing with its native business of diamonds, textiles and medium scale industries. Vadodara, on the other hand has been benefited by the arrival of several refineries, oil and gas exploration companies, corporate, etc. Thus, the driving forces to change in the structure and sprawl of all the three cities principally depend on the actions which produced them. While Rajkot and Surat's urban and suburban sprawl has been governed without a prior environmental planning and quantification of the effects over other capitals which constitute the demography, Vadodara on the other hand has spread as per appropriate planning and hence it experiences comparatively lower pressures on its demographic capitals in comparison to Rajkot and Surat.

4. Results and Discussion

In the case where we deal with the relation of demography's growth with the principles of sustainable development, the key issue to address is the accuracy of assessment of the parameters chosen. Hence, change in vegetative cover, built up area and surface temperatures were separately studied for the years 2000 and 2010 for all the three cities. For relating the change in temperature over the decade, the images from both, summer and winter seasons were studied and the ones showing significant difference have been used.

4.1 Rajkot

Being the largest city in Saurashtra (a part of Gujarat), Rajkot has attracted the attention of many investors from the state and even outside it. Hence, a steady decrease in the open land area has been observed over the past decade. With reference to the Figure 2, we infer that the built up area has increased with the increasing population. On the other hand, the vegetation has also increased as a result of good irrigation schemes in Saurashtra (which is mostly devoid of good rains).

Higher normalized difference vegetation index values of about 0.4 to 1 were observed in the Northern and Western part of Rajkot. While the South eastern areas, with dense urban areas and water bodies, were observed to have very low normalized difference vegetation index values.

An increase in vegetation in the Northern part and conversion of sparse vegetation into dense vegetation in the North eastern with the increase in number of water bodies is evident in the Southern and South eastern part. Hence, the vegetation has been growing at a good rate to cater the continuously increasing population pressures and even balance the agricultural market against others[6].

Temporally, the mean surface temperature was observed to increase by about 3.7°C, from about 41.935°C in 2000, to 45.65°C in 2010 indicating hotter winter months. Thus, its climatic cycles were found to be in an inappropriate balance.

The Western areas of the city had been observed to be the most affected by Urban Heat Island effect, followed by the South western parts. Thus, the resident population is vulnerable to several diseases resulting due acute change in climatic conditions[7] and ambient air quality.

4.2 Vadodara

Spatially, an increasing urban growth has been observed principally in the Southern part and secondarily South western parts of the city. Vegetation has been decreasing in the Western part and can be significantly noticed. The sprawl of urban and suburban areas has been driven by the development of special economic and commercial zones in the city.

The Figure 3 shows higher normalized difference vegetation index values over time of about 0.4 to 1 for

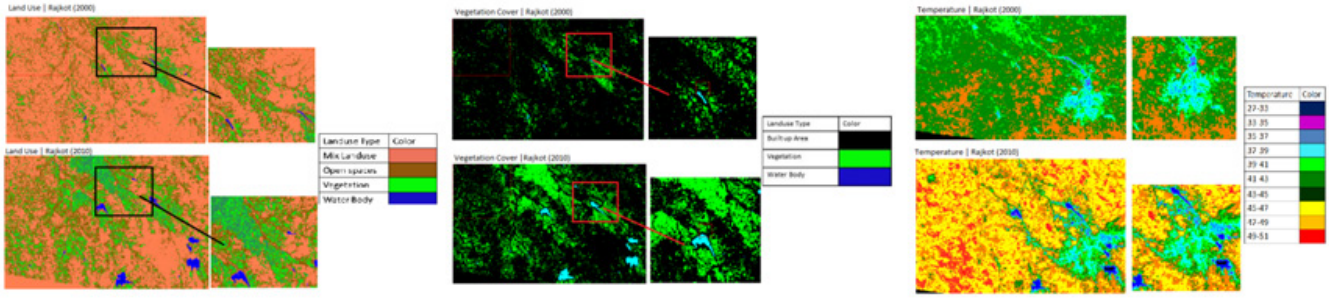

Figure 2. Spatiotemporal changes in land use, vegetation and temperature in Rajkot city.

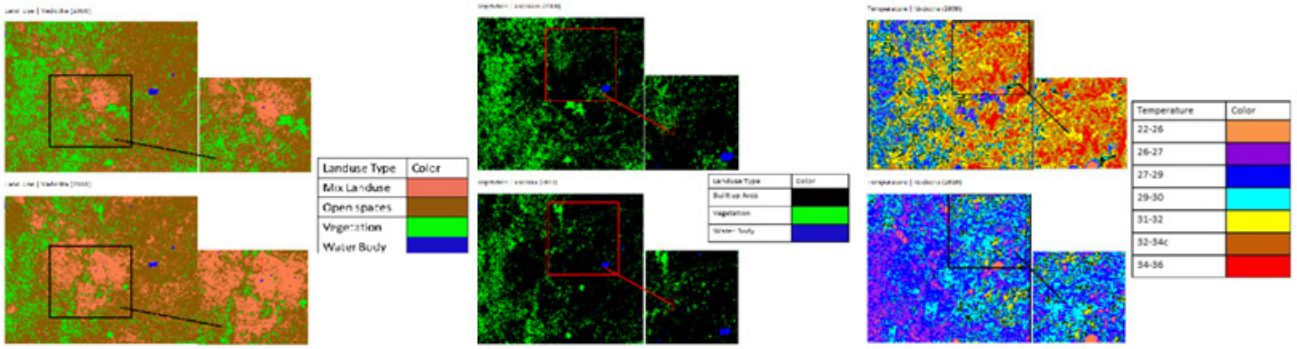

Figure 3. Spatiotemporal changes in land use, vegetation and temperature in Vadodara city.

Vadodara west. The central areas of the city, which have dense urban residential and commercial activities, were observed to have significantly lower normalized difference vegetation index values.

With respect to the change in the land use and built up area in the Southern and South western parts, conversion of sparse vegetation into dense vegetation with the increase in number of small water bodies is evident in the Eastern part.

The steady increase in the number of small water bodies has complemented the spread of green cover in the city. Comparatively lower encroachment in the city and steady spread of green cover have proven to be beneficial to aid the natural capital against the pressures created by increasing infrastructure, transportation and population over the past decade.

Moreover, the pre planning of the transportation facilities from the old city to the newly sanctioned economic zones and industrial belts have helped the urban local bodies, monitor the sprawl of urban and suburban areas. Temporally, the mean surface temperature was observed to decrease by about 3.5°C, from about 35.68°C in 2000, to 31.7°C in 2010 indicating colder winter months.

The Eastern areas of the city had been observed to be the most affected by Urban Heat Island effect, followed by the South and South western parts. Increase in number of small water bodies being the reason in former case, while large proportions of open land converted to built form being the reason in latter. Thus, the residents of the city would experience colder winters and hotter summers if the trend persists.

4.3 Surat

Spatially, an increasing urban growth has been observed principally in the South western part and secondarily Southern parts of the city. Vegetation has been increasing in the North western part and can be significantly noticed in Figure 4. Spatially observing higher normalized difference vegetation index values of about 0.4 to 1 were observed in the Western and North western part of Surat. While the Southern and South eastern areas, with dense urban areas and water bodies, were observed to have very

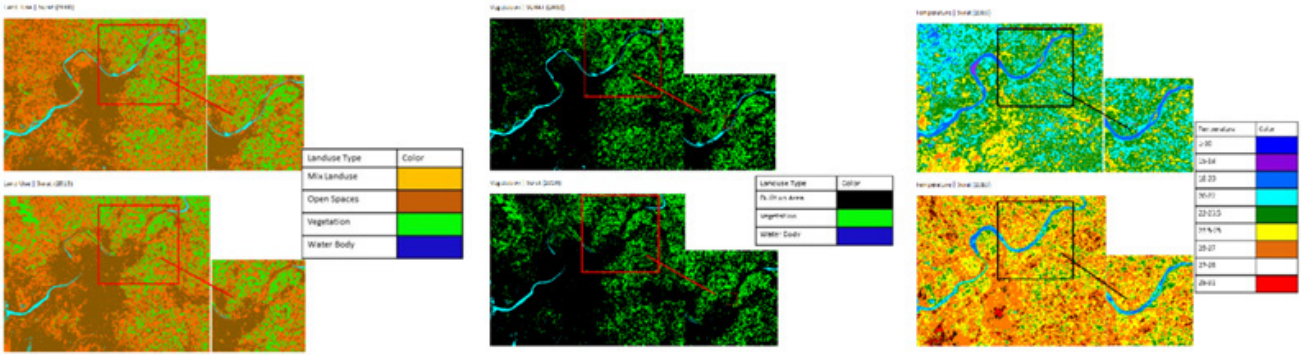

Figure 4. Spatiotemporal changes in land use, vegetation and temperature in Surat city.

low normalized difference vegetation index values. The significant decrease in the flow of water in the River Tapi is due to the pressures created by increasing population, rapid commercial and industrial growth and non monitored urban sprawl and infrastructure development.

The driving forces which have led to creating this pressure on the city's natural capital are, increasing and non monitored use of river water for industrial and commercial purposes, use of sand from river beds for construction activities, etc. which disturb the river bed and also reduce the water flow. An increase in vegetation is observed in the North western part. Conversion of sparse vegetation into dense vegetation is observed in the Northern part. The growth of vegetation has been found to be occurring more or less at the same rate as compared to 2000.

Temporally, the mean surface temperature was observed to increase by about 3.9°C, from about 24.2°C in 2000, to 28.1°C in 2010 indicating hotter winter months. This indicates a persistent imbalance in the seasonal cycles, resultant from the pressures by various driving forces mentioned above. The North western areas of the city had been observed to be the most affected by Urban Heat Island effect, followed by the South western parts. Decrease in amount of River Tapi being the reason, while large proportions of vegetation converted to built form being the reason in later.

4.4 Comparison of Effects of Spatiotemporal Urban Sprawl on Sustainable Development

A persistent improvement in the vegetative cover in the Northern and gradual densification of green cover in the North eastern parts, in Rajkot is a positive thematic indicator with regard to the sprawl against the pressures generated by the demographic and environmental data variables like growth in slum population, population density, industrial share in energy demand, per capita municipal solid waste generation and monitoring water supply and treatments. A continuous increase in the supply of water and creation of water bodies in Rajkot has aided the natural capital to sustain the growing industrialization[8].

While the annual monitoring and inclusion of inferential statistical results denote the state of the primary indicators have helped the stakeholders in Vadodara to balance the work participation ratio, percentage green area in the city and share of renewable energy[9].

These measures have aided the creation of small water bodies across the city, conversion of sparse vegetation to dense vegetation in the Southern and South western parts and judicial supply of residential and industrial water demand[9], aiding Vadodara's natural capital to sustain the increasing urbanization. The significant positive results of the decrease in temperature during the winter months and reduction in emissions from energy generation, advocate Vadodara's positive approach towards sustainable development. Whereas in Surat the non monitored urban sprawl and biased growth of physical capital have created significant negative pressures on the natural capital[10] and have produced noticeable rise in temperature, water demand-supply deficit, geometrically progressive emissions from the industrial and residential solid waste generation, making its natural capital weaker in comparison to the other two. Though the indices such as work participation ratio, average annual per capita income and promotion of mixed land use in Surat have shown significant positive results over the past decades, the state of environment reported in the demography does not advocate its sustainable development. The analysis of sustainable development of all the three cities clearly indicates that the adaptation of annual monitoring of the state of environment[11] in Vadodara has aided the stakeholders to decide about the extent of use of natural resources. Hence, the procurement of such data by governing authorities would form the first step towards sustainable development for all the three cities[12].

5. Conclusion

With the inferences of the impacts of spatiotemporal urban sprawl on sustainable development of the demography due to rapid and persistently increasing resource demands, the importance of actions by the Urban Local Bodies in accurate and applicable policy formations in order to mitigate the pressures created by the changing climate is evident[13].

Thus, in the current scenario the most effective way to procure the data regarding the temporal change in the pro and anti environment variables which play a major role to sustain the rapid urban development activities would be to prepare annual Environmental Status Reports as a part of State of Environment Reporting[14]. This would provide holistic yet detailed information about the concerns related to sustaining the natural capital (resource), the causative factors to its depletion while synchronizing the

stakeholder actions that forms the root of driving forces to any spatiotemporal change. This application would generate enough and accurate information to catalyse policy formation, engage stakeholders to implement it and constantly monitoring the status quo of the implemented actions.

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