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GIS and Space Data for Time Series Analysis

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Abstract

Geographic Information System (GIS) is a unique tool that enables intelligent use of space data and other geospatial information for wide varieties of analysis. GIS is platform that seamlessly allows vector and raster data to be integrated and used for advanced analysis and inferences. The GIS platform with its unique property of handling attribute information with necessary linkages with underlying Database system allows required references to various database elements for analysis. The interactive properties of GIS with its query system helps in many visual information extractions and building up of multiple mathematical scenarios, particularly useful for the time series analysis. Space data, in the form of satellite images of multiple timeframes, could be easily ingested into such a GIS system after necessary pre-processing and multi-image registration. Geospatial analysis of data is ably supported on a GIS platform that helps in analyzing satellite image data and at the same time generation of interactive maps for analysis. Considering time series analysis as the focus, with the help of satellite data, an open source GIS platform is used with both raster and vector data analysis to highlight changes that are occurring with regard to land and water. The work clearly highlights the impacts and transitions derived as part of the outcome of a GIS based analysis of such data.

Keywords: Geographic Information System, raster data, vector data, Quantum GIS, Natural Color Composite Image, Digitalization, Normalized Difference Vegetation Index, transition analysis, impact analysis

I. INTRODUCTION

Multiple events occur in nature, that could prove to be significant at different points of time, which could be tracked and monitored using geospatial technologies. Considering this, it is necessary to plan for systematic data collection at different points of time, so that specific objectives could be monitored over a period of time and also corrective measures could be put in place, based on outcomes. For example, change in urbanization indirectly indicates growth in population and spread in urban dwellings, increased activities of humans in a given-areas etc. Such a phenomenon is also known as urban sprawl monitoring. Similarly, changes in land use over a period of time indicates the shift in land use practices by the local people in a given area, which could be based on economics or demand-supply outcomes. In the present global scenario, it is more essential to track changes and also to analyze historical data to establish transitions in weather and climatic factors to understand factors influencing changes in global weather or climatic conditions. Such studies can only be carried out over a robust GIS platform using Time Series analysis, supported with historical data and evidences. Time series analysis deals with analysis of time-stamped data sets while also ensuring data collection at similar conditions for cross-comparison of data sets and for reliable results.

In the proposed problem, it is planned to use multiple time data sets to enable time series analysis of land and water related changes with time. This essentially means that historical occurrences of events are captured as data sets and used for analysis and inferences. Satellite data sets play a major role in providing the most crucial inputs on historical and current status of any land and water related parameters. Earth observation satellites have been providing data over different parts of the earth for many decades. Space Data from Indian Remote

Sensing (IRS) Satellites, Landsat, Copernicus and others are accessible for download and use, particularly with reference to time series. This helps in using such data for varieties of objectives related to natural resources management.

While satellite data provides historical data sets for analysis, there is a need for data processing platform. The platform should support geospatial data analysis. In the present study, Quantum GIS (QGIS) platform is chosen to carry out necessary analysis of multi-time satellite data and corresponding analysis. QGIS is an open GIS platform that allows varieties of geospatial data inputs and analysis capabilities. Multi-time satellite data needs to be systematically integrated in to the QGIS platform for analysis and inference. QGIS supports both raster layers and vector layers; vector data is stored as either point, line, or polygon features, and multiple formats of raster images are supported. This software also supports the shapefile format as well as other formats; the shapefile format is defined as a geospatial vector data format which describes vector features i.e. points, lines, and polygons. These vector features can represent rivers, lakes, islands, water wells etc., and each item usually has attributes that describe these features, such as ID, name, temperature and so forth.

Hence, the choice of research problem addresses many important factors, namely, need for time series analysis, use of historical satellite data sets, use of QGIS platform for problem solving. A combination of these are planned to be used to establish a time series data analysis platform to study changes and transitions that occur in nature and also to arrive at specific inferences based on the time series analysis.

Objectives

The main aim here is to utilize GIS technology in order to carry out Time Series Analysis or Change Analysis on multitemporal satellite data. The objectives to achieve this include the following i.e.

- Choose an Area of Interest (AOI) for analytical purposes. For this study, we will consider a portion of Bengaluru, India as our Area of Interest (AOI).
- Download multi-time satellite image data sets for Time series analysis.

Here, satellite data for 2008, 2011, 2014, 2016 and 2017) for the November month is downloaded from the “Bhuvan geoportal” of ISRO. Indian Remote Sensing (IRS) is chosen for analysis in the proposed study.

- Co-register each satellite image data set and then ingest them into the QGIS platform. Create Vector and Raster layers for analysis.
- Create Natural Color Composite (NCC) Images for multi-time image products, that is from the year 2008 to 2016.
- Perform the digitalization of waterbodies on the Natural Color Composite (NCC) images of each multi-time data set, that is from the year 2008 to 2016.
- Compute Normalized Difference Vegetation Index (NDVI) Image for each data set for analysis.
- Time-series analysis of these multi-temporal images with a focus on vegetation and water in the Area of Interest (AOI). Two types of analysis, i.e. transition analysis and impact analysis are done.
- Derive qualitative and quantitative outputs for further analysis and to derive inferences on changes that have occurred in the study area.

II. PROPOSED METHODOLOGY DESCRIPTION

This proposed methodology will be divided into five parts.

1. Satellite Data Download

Indian Remote Sensing (IRS) Satellite data is downloaded from the Bhuvan Geoportal of ISRO and are systematically organized for use under the current study. Considering objective of the proposed study, it is necessary to demonstrate the changes occurring to our natural resources by referring to historical data and the recent data sets to establish the direction of changes and their impacts. Hence, multi-date images from IRS are downloaded.

2. Generation of Natural Color Composite (NCC)

A natural color composite, also known as true color composite, is defined as an image that displays a combination of the visible and infrared bands data that correspond with the red, green and blue filters on the computer. The natural color composites are produced for each of the multi-time images, that is 2008 to 2017for visual analysis of data for the selected AOI. It is noticed that 2017 data is cloud infested and hence eliminated for further analysis. The NCC products for each satellite image data set (2008-2016) are highlighted below.

Figure 1: Nov 2008 NCC Image.

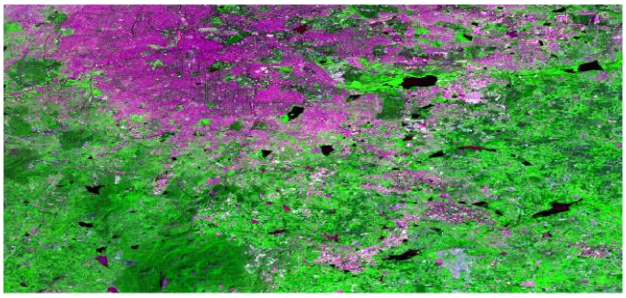

Figure 2: Nov 2011 NCC Image.

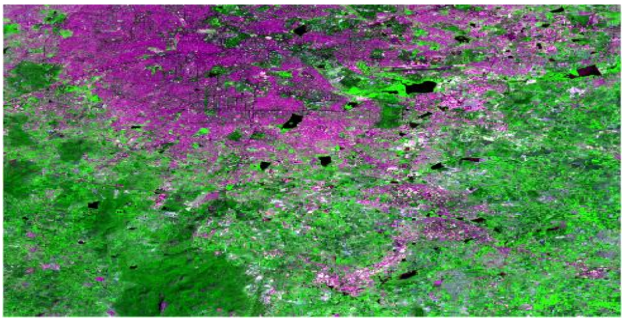

Figure 3: Nov 2014 NCC Image.

Figure 4: Nov 2016 NCC Image.

Note: GREEN - Vegetation, BLACK - Deep waterbodies, PINK/ORANGE – Urban or Open Field
The visual inspection of NCC images clearly highlight that there are many changes that have occurred with respect to vegetation, waterbodies, urbanization etc., some of which will be demonstrated as part of the analysis in this study.

The images clearly highlight the changes in vegetation in many of the areas with the emergence of new urban areas and also the dynamic changes occurring to waterbodies, including the quality of water. The changes that are taking place around Belandur tank is quite significant, as there is a significant urban pressure. A string of tanks that feed one another is also clearly seen, but with the increased urbanization the streams are losing out to urbanization and hence one could see increased pollution in most of these lakes.

1. Digitalization of Waterbodies

With the availability of co-registered satellite images, one of the important data to be extracted is the digitalization of multi-date waterbodies and the creation of vector database on water. Through this process, vector data on water bodies is created using the NCC data in the background. The vector features as polygons, representing water bodies, is created with necessary attributes about the water bodies (Figure 5).

Figure 5: Digitized / Vectorized water bodies

Note: The digitized waterbodies in the above image is represented in a light blue color.

- Creation of Normalized Difference Vegetation Index (NDVI) Images

As mentioned earlier, satellite data is available in multiple bands, ranging in visible and Infrared bands of the electromagnetic spectrum. Taking advantage of the behavior of reflected light in Red and Near-InfraRed (NIR) spectrum, it is well established that vegetated areas could be distinctly highlighted. Hence, Normalized Difference Vegetation Index (NDVI) is generated. Normalized Difference Vegetation Index, abbreviated as NDVI, is defined as a simple graphical indicator that is used to assess whether or not the observed target contains live green vegetation. It is often used in spatial platform to analyze remote sensing measurements. NDVI is the traditional vegetation index used by researchers for extracting vegetation abundance from remotely sensed data. [8]

Normalized Difference Vegetation Index (NDVI) quantifies vegetation by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs). [6]

The NDVI is calculated from these individual measurements in Red and NIR for each pixel reflectance value. That is, each data record of Red and NIR is passed through the following equation to estimate NDVI, which is written in the output scene for every pixel. This is done for the entire image of each date ranging from 2008 to 2016 with exactly similar processing and look-up-table for display. The NDVI is calculated from these individual measurements as follows:

$$NDVI = (NIR - RED) / (NIR + RED) \ [6]$$

where RED and NIR stand for the spectral reflectance measurements acquired in the red (visible) and near-infrared regions, respectively.

NDVI always ranges from -1 to +1. [6] Negative values of NDVI (values approaching -1) correspond to water. Values close to zero (-0.1 to 0.1) generally correspond to barren areas of rock, sand, or snow. Lastly, low, positive values represent shrub and grassland (approximately 0.2 to 0.4), while high values indicate forests or thick tree-clad areas (values approaching 1).

Under this project, we have four sets of NDVI images generated (2008 to 2016). The following illustrations displayed below highlight the NDVI images generated from this concept (Figure 7, Figure 8, Figure 9 and Figure 10).

Normalized Difference Vegetation Index (NDVI) Images

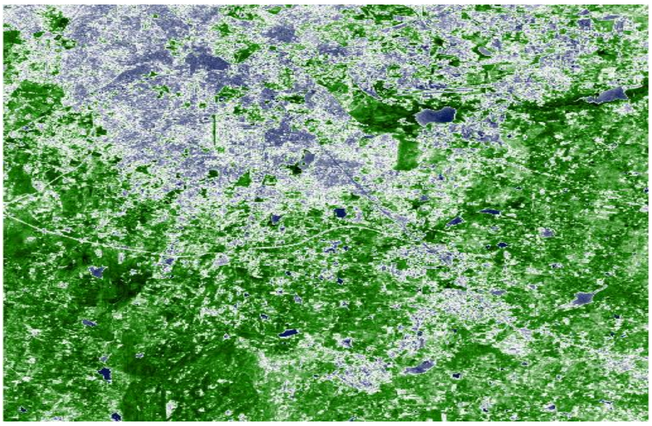

Figure 7: NDVI Image of November 2008 Satellite Data

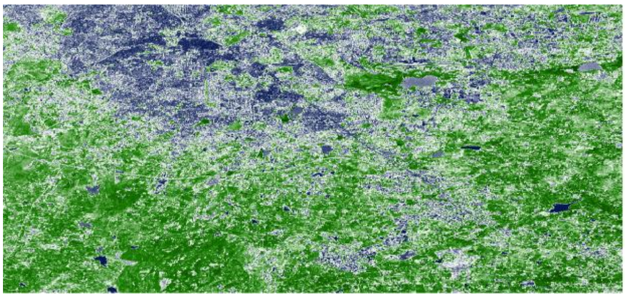

Figure 8: NDVI Image of November 2011 Satellite Data

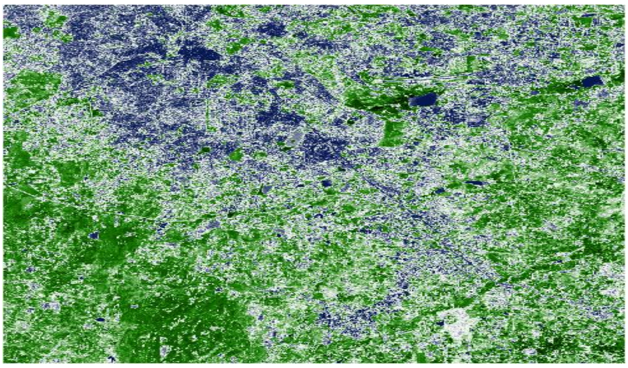

Figure 9: NDVI Image of November 2014 Satellite Data

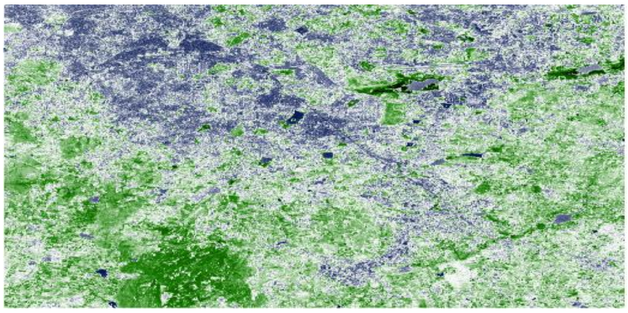

Figure 10: NDVI Image of November 2016 Satellite Data

- Time Series Analysis

The next important task is to carry out a Time-series analysis of these multi-temporal data sets (NDVI) that highlight the vegetation in the Area of Interest (AOI). This section addresses the analysis of data for multi-time vegetation to establish changes in vegetation status. The NDVI images of multi-dates is considered for this part of the study. Two types of analysis are planned as part of this section to ensure the impact of change in times with vegetation and water. First is Transition analysis that establishes step-wise changes and also the trends and the Second is the impact analysis for the entire time range.

- Transition Analysis

Transition Analysis helps in addressing the progressive changes taking place in the given AOI

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from time to time. That is, the changes taking place from T1 data set to T2 data set gets highlighted first, wherein two nearest data sets are used for analysis. Further analysis of a similar kind is done between the T2 data set and T3 data set in order to further establish changes in the next two nearest data sets. This process is continued until the last date image is considered for analysis.

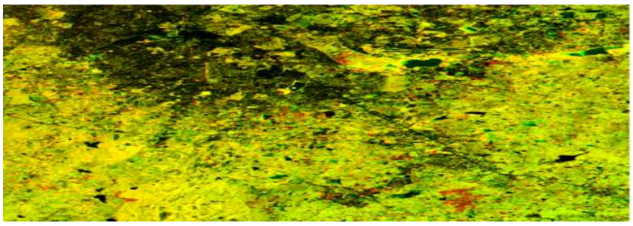
- Impact Analysis

Impact Analysis deals with the overall changes that have taken place over a definite period of time, which also amounts to highlighting the cumulative changes that have taken place in the Area of Interest (AOI). This amounts to using two dates NDVI images, one from the first time 'T1' and the other being the last 'Tn'. In current study 2008 NDVI image is used for T1 and 2016 for Tn. With this impact due to changes occurring in the entire Area of Interest (AOI) during the entire timeframe is derived as the outcome. These two images are considered for analysis to carry out pixel to pixel change analysis in order to highlight the amount of changes occurring in the AOI.

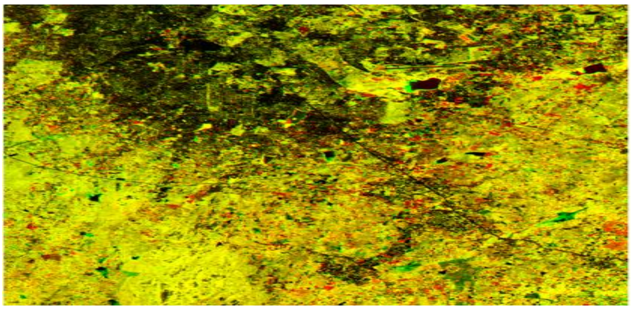
III. RESULTS & DISCUSSION

Transition analysis highlights many interesting details with regards to time series changes. It helps in quantifying the changes occurring in each time transition and it also helps in establishing which time transition had maximum change and vice-versa. This could also be correlated to factors contributing to such changes, such as, urbanization etc. The resulting output from this analysis also helps in the study of the trend of transition which also helps in establishing the pattern of changes. Based on these results it is also possible to re-adjust the time lags, if needed, for transition analysis, which could impact the pattern of changes with respect to vegetation versus urbanization.

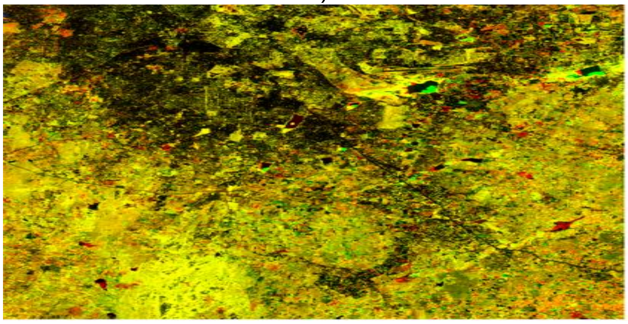
Following illustrations clearly highlight the above-mentioned details (Figure 11).



a)



b)



c)

Figure 11: Transition Analysis – NDVI composites of 2008-2011 (a), 2011-2014 (b), 2014-2016 (c)

Based on the above illustrations, following analysis and interpretations are brought out and highlighted below:

Interpretation of NDVI for 2008 & 2011

1. A color composite of 2 Bands data, NDVI 2008 and NDVI 2011 is done (NDVI 2008 in Band-1 and NDVI 2011 in Band-2).
2. The Band-1 is passed through the Red filter while Band-2 is passed through the Green filter.
3. Red color indicates vegetation presence in 2008 while absent in 2011; Green color indicates Vegetation presence in 2011 while absent in 2008; Yellow color indicates vegetation presence in both times. Dark color indicates Urban areas which are dominated with non-vegetated areas/ features. The following image shows many dominated green patches, which means more greenery in 2011 as compared to 2008.

Interpretation of NDVI for 2011 & 2014

1. A color composite of 2 Bands data, NDVI 2011 in Band-1 and NDVI 2014 in Band-2 is done. (NDVI 2011 in Band-1 and NDVI 2014 in Band-2).
2. The Band-1 is passed through the Red filter while Band-2 is passed through the Green filter.
3. Red color indicates vegetation presence in 2011 while absent in 2014; Green color indicates vegetation presence in 2014 while absent in 2011; Yellow color indicates vegetation presence

in both times. Dark color indicates urban areas which are dominated with non-vegetation features. Here, at an overall level, there are more red patches as compared to green patches, which shows that by 2014 many of the vegetation patches of 2011 are removed or do not exist as per image, which shows clear reduction in green cover.

Interpretation of NDVI for 2014 & 2016

1. A color composite of 2 Bands data, NDVI 2014 and NDVI 2016 is done (NDVI 2014 in Band-1 and NDVI 2016 in Band-2).
2. The Band-1 is passed through the Red filter while Band-2 is passed through the Green filter.
3. Red color indicates vegetation presence in 2014 while absent in 2016; Green color indicates Vegetation presence in 2016 while absent in 2014; Yellow color indicates vegetation presence in both times. Dark color indicates Urban areas which are dominated with non-vegetation features. This shows that by 2016 many of the vegetation patches of 2014 are also not present as per the processed image and the red patches are even more prominent as compared to earlier years, which shows that the vegetation reduction is more significant.

On the other hand**,** impact analysis brings out the details regarding the total vegetation change and at the cost of which other theme, say urbanization. This technique helps in clearly establishing long term changes occurring in a given area, not only qualitatively but also quantitatively. Hence, this is another method by which cumulative changes could be estimated and hence the impact due to anthropogenic activities could be established. Following illustration clearly highlights the increased Red patches all over the image which proves further reduction in vegetation (Figure 12).

The following illustration below clearly highlights the above-mentioned details.

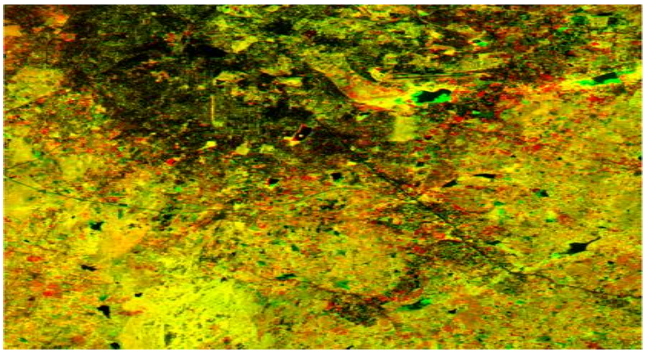


Figure 12: Impact Assessment on Vegetation (from 2008 – 2016).

Based on the above illustration, we have made the following impact interpretations shown below:

Impact Analysis of NDVI for 2008 & 2016

1. A color composite of 2 Bands data, NDVI 2008 and NDVI 2016 is done (NDVI 2008 in Band-1 and NDVI 2016 in Band-2).
2. The Band-1 is passed through the Red filter while Band-2 is passed through the Green filter.
3. Red color indicates vegetation presence in 2008 while absent in 2016; Green color indicates Vegetation presence in 2008 while absent in 2016; Yellow color indicates vegetation presence in both times. Dark color indicates Urban areas which are dominated with non-vegetation features. As seen from Fig-5 above, the Red patches dominate the entire image which shows the presence of vegetation in 2008 and the same do not exist in 2016 and hence the significant reduction in vegetation.

Further, NDVI images have further been used to bring out certain quantitative analysis of the data, that has resulted in dynamic behavior of vegetation against urbanization around Bengaluru.

Quantitative Analysis of NDVI (2008 to 2016)

Four-time NDVI images have been used to show the vegetation pattern and also certain linkages with water pollution and their reflectances (Figure 13).

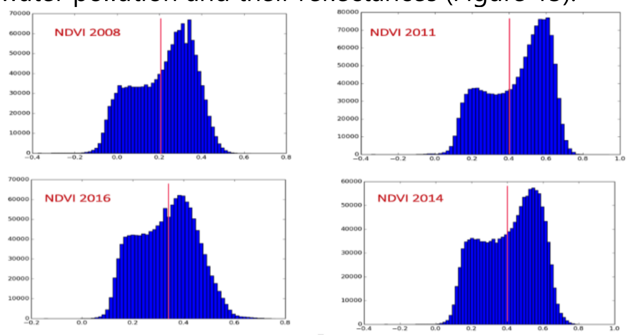


Figure 13: Histogram of Four NDVI images for pattern analysis (2008, 2011, 2014 and 2016)

The statistical analysis mentioned above clearly demonstrates the temporal changes on the ground, as seen from space images. While the x-axis represents NDVI values, the y-axis represents the frequency of NDVI values present in a given satellite image. The histograms computed from 4 different dates images is illustrated above.

It can be observed that 2008 NDVI depicts a nominal curve with a maximum NDVI of about 0.6, however the NDVI curve is much different in 2011 and 2014 which shows a second peak with the max NDVI ranging up to 0.8. This observation is predominantly due to dominant presence of "Water hyacinth", a free-floating perennial aquatic plant (or hydrophyte), in the satellite images across many waterbodies around the city. The NDVI values have gone up due to increase in polluting water hyacinth which is well represented in the above curves. This phenomenon is depicted in the following illustration (Figure 14).

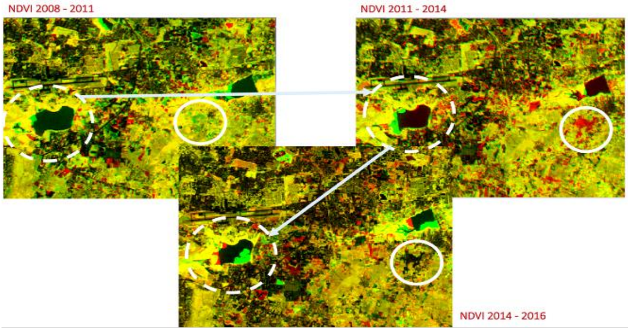


Figure 14: Change images highlights water pollution (water hyacinth-bright green) at different times.

The above images are all two-time image composites of NDVIs that depict water pollution clearly at different points of time. It also clearly highlights the urbanization spreading across the water channel in all times, with a drastic increase from 2008 to 2016 (8-year time period).

IV. CONCLUSION

The project clearly depicts the advantages of using Time Series Satellite Images in analyzing the dynamic changes taking place in any given area. In the present study, a portion of Bengaluru is considered for analysis using Image Analysis and GIS technologies. Digital Color Composites, image enhancements and NDVI images are computed to focus on the problem of water, vegetation and urbanization. These products are ingested into QGIS platform for detailed analysis of all data sets.

Conclusive evidence has been illustrated in the above findings, particularly the Transition analysis and Impact analysis. Both of the analyses clearly bring out the impact of increased urbanization on greenery, which is following a trend of reduction and at the same time pollution in the major string of waterbodies around Bengaluru. The techniques of simple multi-band color composites, vegetation indices and corresponding statistical analysis demonstrates facts, as shown above.

Hence, it could be concluded that GIS technology could be effectively adopted to regularly carry out such Change analysis or Time Series Analysis using multi-temporal satellite data to help the Government system or Public Administration to take proper corrective actions to conserve and preserve the environment for sustainable development of mega urban areas like Bengaluru. The techniques time series analysis could also be adopted to any other areas of interest, such as, urban or rural development, crop monitoring, forest monitoring, reservoir water monitoring and so on.

The project thus concludes by highlighting a unique mechanism to monitor our urban areas more effectively than ever before.

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