

Assessing the Impact of Land Use and Land Cover Change on Air Quality in East Baton Rouge—Louisiana Using Earth Observation Techniques

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Abstract

There has been significant research in recent decades on Land use Land cover (LULC) changes and their influence on biodiversity but little to no research on its impact on air quality. This research seeks to demonstrate how geospatial technologies such as geographic information system (GIS) and remote sensing can be used to assess the effects of LULC changes on particulate matter emissions and their impact on air quality in the East Baton Rouge area. In pursuit of these objectives, this study uses LANDSAT imageries from the past 30 years specifically Landsat Thematic Mapper (TM C2L2) and Landsat 8 Operational Land Imager/Thermal Infrared (OLI/TIRS C2L2) covering 1991, 2001, 2011 and 2021 were collected, processed, and analyzed for the LULC change analysis using QGIS software. Additionally, Sentinel 5P and the Air quality index from the U.S. Environmental Protection Agency (EPA) were used to assess the air quality trend over the years to establish the correlation between LULC and air quality. Results showed an increasing trend in air quality over the past 3 decades with concentrations of CO, NO₂, and PM_{2.5} abruptly falling however, urbanization and the population expanded throughout the time. The paper concludes by outlining a policy recommendation in the form of encouraging Louisiana residents to use alternative renewable energies rather than the over-dependence on coal-fired electric generating plants that have an impact on the environment.

Keywords

Google Earth Engine, Aerosol, Air Quality, Sentinel-5P, Land Use Land

Cover Change

1. Introduction

Poor quality of air is among the most serious environmental concerns in many cities throughout the world. Given that cities are home to more than half of the world's population, the impact of air pollution on human health must be addressed. Air pollution, a significant contributor to climate change, has been debated in most developed countries and local governments have made improving air quality a priority for health. Consumption of energy, emissions from industries, and automobile traffic all rise when cities expand in size and population, both of which can negatively impact the quality of air [1]. Emissions have increased by about 15% in every half-million growth in the human population and particulates are among the most well-known and controlled air contaminants (PM) [2].

Particulate Matter (PM) is a combination of both solid and liquid particles present in the air [3]. Dust, smog, soot, smoke, and soil are examples. Such particulates can originate from anthropogenic activities like biomass burning, fossil fuel combustion or radioactive isotopes like dust and sea salt. Also, various forms of Land Use Land Cover (LULC) activities prevalent in the major urban centers can affect the quantity of PM [4]. Consumption of energy, emissions from industries, and automobile traffic all rise when cities expand in size and population, both of which can negatively impact the quality of air [5]. PM is also caused by the generation of particles from released gases, including Nitroxide (NO₂), Volatile Organic Compound (VOC), and ammonia [5].

There are various forms of PM. PM_{2.5} refers to particles with a smooth diameter of not more than 2.5 m, which are tiny enough to be breathed. Numerous studies have linked extreme pollution episodes to a higher incidence of disease and fatalities over the last century [5]. In the past few decades, attention has switched to the effect of the extended contact with PM in the medium levels, as observed in populated areas. According to [6], frequent reference to PM_{2.5} has also been associated with a higher cardiovascular risk, respiratory disorders, and lung cancer. PM_{2.5} leads to various short-term health problems, including respiratory illnesses, nose, eye irritation, and headaches [6]. Individual particles limit visibility and constitute hazardous substances that can damage the environment through wet or dry deposition regarding health risks [4].

The form of PM and its intensity vary by region, but mostly around more developed urban centers, there is more variation. By substituting native vegetation cover with artificial pollution sources, the forms of LULC activities prevalent in the major urban centers can affect the quantity of PM [4]. The transformation of woodland, grasslands, and farms into industrial complexes, residential development, and vast commercial areas frequently results in increased pollution. Urban

sprawl has been the most extreme example of this sort of growth, defined by dispersed structures of low-density expansion, frequently in an electric car manner [7]. There have always been several primary causes of air pollution, but there are also secondary causes of pollution by particles that occur from chemical interactions in the lower stratosphere. PM is also caused by the generation of particles from released gases, including NO₂ and VOC, and ammonia [5]. Furthermore, air pollution can be carried from one place to another, making the matter much more complicated.

In remote areas where there is no ground-based instrumentation, global satellite observations enable the early identification and tracking of various atmospheric gases released by natural occurrences and human action [8]. This indicates that the rapid evolution of technology and the ever-advancing techniques of geospatial science these days have presented innovative solutions and appropriate tools through G.I.S applications for researchers and concerned institutions to contribute to better management of the environment. One of such ways is the study of land use and land cover change detection. Land cover changes are the various feature changes that occur on land for instance a change in vegetation patterns, and soil conditions amongst others, whereas land-use change is the change in the utilization of land. According to [9], worsening environmental air quality, loss of agricultural lands, destruction of wetlands, and loss of biodiversity and animal habitat have all become issues that need knowledge of land use/land cover. Therefore, studying land use/land cover (LU/LC) changes is critical for appropriate planning, usage, and management of natural resources [10]. In effect, LULC change studies and their influence on biodiversity and climate have been a subject of significant research in recent decades [11] [12] [13] [14] [15] but none on its impacts on air quality. Current scholarly work in Louisiana bothers on the use of various technologies to study changes in land areas and urban forest cover, distribution of toxic sites, various time series analysis on rainfall stations which carry equal importance, but all fail to take a dive on how the changes in land use and land cover affect air quality in the region over the years [16] [17] [18] [19] [20]. Therefore, the overall objective of this study is to demonstrate how geospatial technologies such as GIS and remote sensing can be used to assess the impact of LULC changes on particulate matter emissions and the emission of other harmful gases such as nitroxide and carbon monoxide, and their impact on air quality in the East Baton Rouge area. Specifically, this study will assess land use and land cover changes of the East Baton Rouge Parish from 1991 to 2021, using earth observation techniques; analyze the trend of air quality over the years specifically NO₂, CO, and PM_{2.5} using sentinel 5P imageries and air quality monitoring station data from the Environmental Protection Agency (EPA).

2. Methodology

2.1. The Study Area

East Baton Rouge is one of the parishes in Louisiana and it hosts the state's capi-

tal Baton Rouge (**Figure 1**). According to [21], the parish has an estimated population of 453,301 people in 2021, with 220,553 people living in Baton Rouge city. The climate is humid subtropical, with hot and humid summers, warm winters, and medium to heavy rains regularly. Baton Rouge's yearly estimated temperature is 67.5 degrees Fahrenheit, with an estimated temperature of 51.7 degrees Fahrenheit in January and an average temperature of 81.9 degrees Fahrenheit in August [22]. The mean annual precipitation in this area is 57.9 rain inches and 0.1 snow inches. In 2000, East Baton Rouge compared to its adjacent parishes like Livingston and Ascension was perhaps the most industrialized parish in the area, with about 18% of its territory classified as developed, compared to around 5% for the rest of the parishes [23]. Also, the East Baton Rouge region has seen substantial development in the previous half of the century, notably in its outskirts. Between 2000 and 2020, the town expanded by 174.2 miles, placing it 27th in the US city expansion [24]. The region is known for hosting a state college, two major universities, several prominent hospitals, and six medical research centers. East Baton Rouge is a significant manufacturing, medical, petrochemical, and scientific hub in the southern United States. The refinery company, ExxonMobil, the country's third-largest oil plant, is located in this parish (**Figure 1**). Because of its record of steel manufacturing and position as a heartland of industrial activities in the Southeast, East Baton Rouge has a lengthy history of air pollution issues.

In 2000, severe air pollution episodes prompted a few of the Federal Clean Air Act [4]. Whereas overall air quality is better from then, the Baton Rouge Metropolitan Statistical Area (MSA) remains in the top ten for worst particulate contamination. East Baton Rouge and its adjacent parishes, Livingston, and Ascension have consistently failed to meet the EPA quality of air guidelines. American Lung Association [25] ranked Baton Rouge as the 57th most polluted

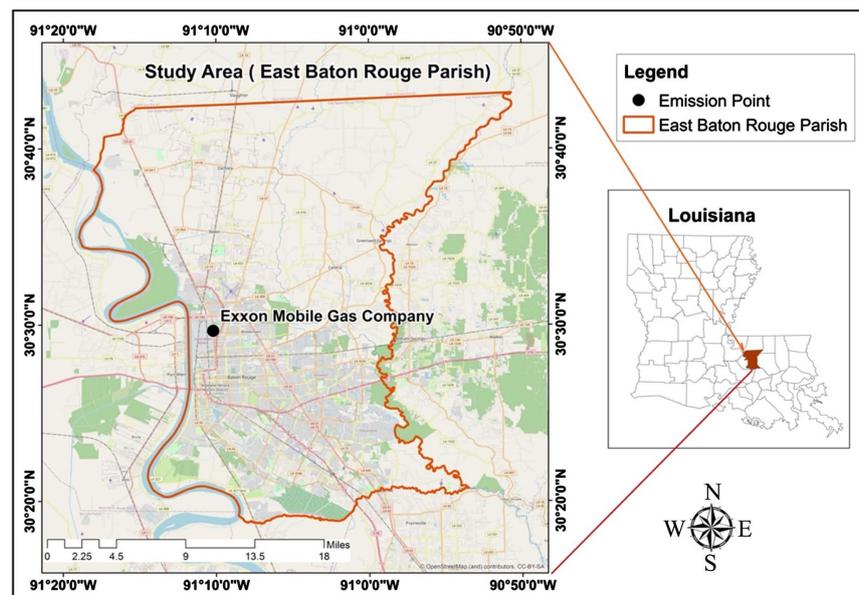


Figure 1. Location map of the study area.

and ranked 38th most polluted for ozone nationally. Three substantial coal-fired power stations run in those states which can be to blame for this. The expanding population of the region has prompted the construction of these power facilities and their development in the past few years. The parish has a complete PM tracking system due to its prior difficulties with the pollution of air. This, combined with its rapid expansion, makes it an obvious candidate for a first situation analysis.

2.2. Data Acquisition

This study used two types of data. Remote sensing data and Air Quality Index Summary data from the Environmental Protection Agency (EPA). Landsat level 2 images were acquired from the United States Geological Survey (USGS) earth explorer website and were used to study the changes within the landscape over the last three (3) decades [26]. Specifically, Landsat 5 Thematic Mapper (TM C2L2) satellite images for 1991 (date: 10/10/1991), 2001 (date: 05/14/2001), 2011 (date: 10/01/2011), and Landsat 8 Operational Land Imager/Thermal Infrared (OLI/TIRS C2L2) for the 2021 satellite image (date: 09/26/2021). The images were selected based on the availability of cloud-free images for the area of interest. This Landsat collection derived from the Level 2 product was atmospherically corrected and hence required no preprocessing [27]. It was loaded into QGIS and clipped using the study area boundary for further analysis.

2.3. Air Quality Analysis

For the air quality analysis, we extracted time-series information on carbon monoxide (CO), and nitrogen dioxide (NO₂) concentrations from the Sentinel-5P archives available on Google Earth Engine. This cloud-based free platform launched by Google in 2010 can host petabytes of satellite images and other geospatial datasets useful for mapping trends and detecting changes in the landscape [28]. The Sentinel-5P product launched by the European Space Agency (ESA) in 2017 has a spatial resolution of 1113.2 meters and daily global coverage. We focused on datasets for October 2018, 2020, and March 2022 to monitor the changes in these greenhouse gas concentrations over time. After applying the temporal and spatial filters in the GEE code, the NO₂ and CO products were generated for the study area. This was then exported into ArcMap for map composition.

Due to the lack of historical data associated with the Sentinel 5p satellite imageries, air quality (AQ) station data summarized in the Air Quality Index for the East Baton Rouge Report available on the EPA website was generated to analyze the air quality trends 30 years ago. This report considers all the criteria for air pollutants detected within a geographic region, hence making the Index a good indicator of overall air quality in a region. It specifically provides air quality standards-related summary data for carbon mono oxide, nitrox dioxide, ozone, sulfur dioxide, PM2.5 and 10, and lead by city or county.

2.4. Image Processing

In QGIS, the Semi-Automatic Classification Plugin (SCP) was used to analyze the data. Specifically, the supervised classification method was employed using the Random Forest classifier. This algorithm is made up of individual decision trees that work as an ensemble. Each tree in the random forest algorithm outputs a prediction based on the class and the class with the highest votes becomes the prediction of the model. By increasing the number of decision trees, the accuracy of the model is also increased [29]. This method can produce a highly accurate classification compared with other commonly used methods [30] [31]. The Random Forest classifier categorized the land cover into four different classes: water, vegetation, bare land, and urban areas for the selected years. The parameters required for the model included the band set, class ID, number of training samples, and number of decision trees. For this study, we used 5000 training samples and 100 decision trees to run the random forest model for each year.

3. Results and Discussion

3.1. Land Use Land Cover Analysis

As shown in the produced map (Figure 2), East Baton Rouge parish has sustained its pattern of expansion and land cover change since 1991. It was seen

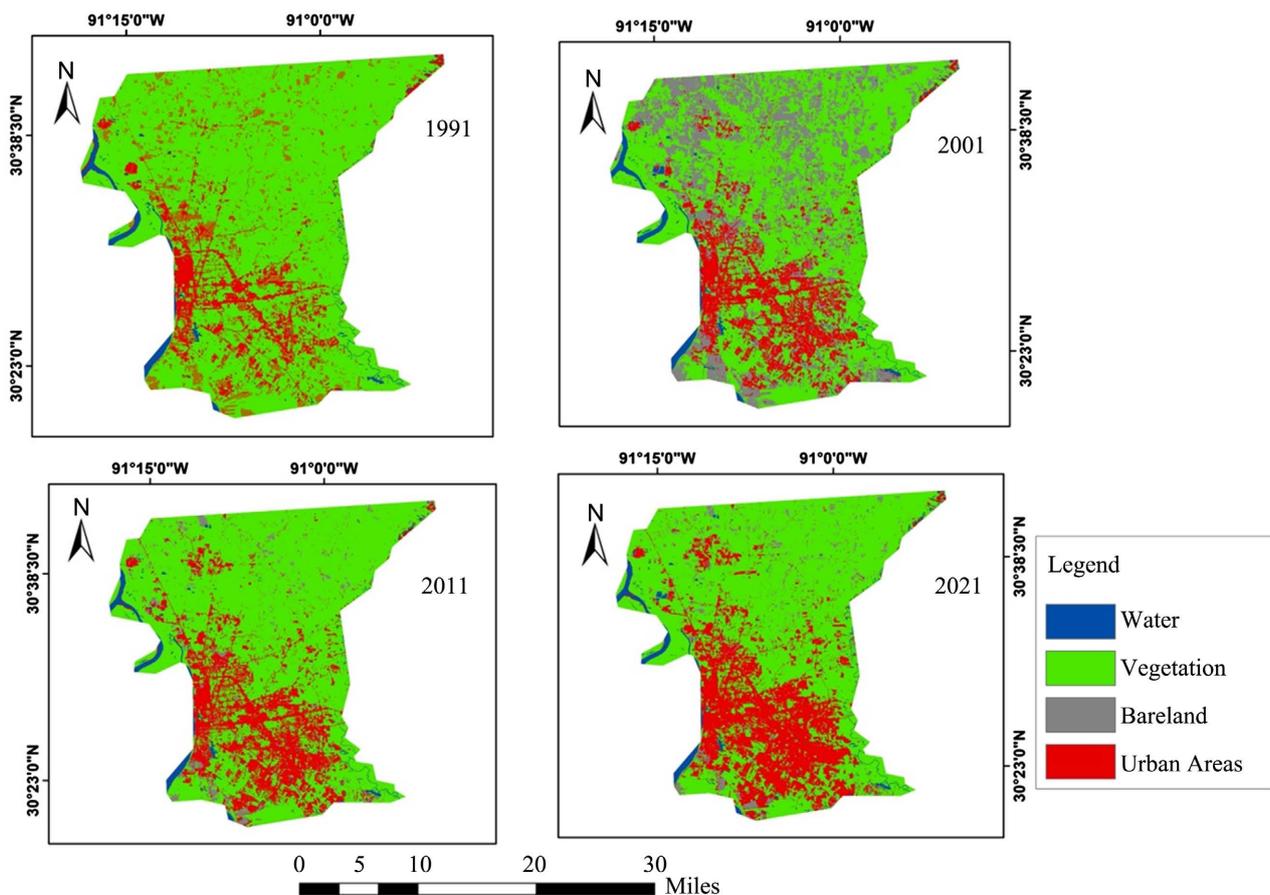


Figure 2. LULC map for the years 1991, 2001, 2011, and 2021 for East Baton Rouge.

that vegetation was the most dominated LULC class for all years from 1991, 2001, 2011 and 2021. However, over time, the growth of urban areas increased exponentially. **Table 1** gives the statistical results of LULC changes. Over the years, Urban areas in the East Baton Rouge parish increased exponentially from 10.48% in 1991 to 24.92% in 2021 due to urban expansion and population increase. The study area witnessed a large amount of agricultural land converted into settlements and other urban development activities. Vegetation and agricultural lands decreased from 79.93% (1991) to 67.81% (2021). Water spread area also increased from 2.13% in 1991 to 2.64% in 2021, Bare land decreased from 7.66% (1991) to 4.63% (2021) with a net decrease of 3.03% due to the gradual conversion of bare areas into built-up areas or human developmental areas as the population increased significantly during the past decades. This establishes changes in land use patterns in East Baton Rouge over the years and the gradual occurrence of urbanization.

3.2. Classification Accuracy Assessment

Overall LULC classification accuracy levels ranged from 92 to 97 percent for the four days the different satellite imageries were collected, with Kappa indices of agreement spanning from 90 to 95 percent (**Table 2**). This makes it acceptable for the research because it meets the Anderson categorization scheme's minimal accuracy requirement of 85% [32].

Table 1. LULC classes for the period 1991 to 2021 in percentages.

Land Use	Percentage (%)			
	1991	2001	2011	2021
Water bodies	2.13	2.50	2.38	2.64
Vegetation	79.73	55.65	73.30	67.81
Bare land	7.66	27.09	4.37	4.63
Urban Area	10.48	14.75	19.95	24.92

Table 2. Shows the accuracy assessment (in percent) of the LULC maps for the various years (1991, 2001, 2011 and 2021).

LULC Classes	1991		2001		2011		2021	
	User Accuracy (%)	Producer Accuracy (%)						
Water	100	100	86	100	100	100	100	100
Vegetation	93	93	92	95	98	100	97	100
Bare land	87	86	100	88	100	85	100	94
Urban Areas	100	100	100	98	100	100	92	92
Overall accuracy	94		92		94		97	
Kappa statistic	91		90		91		95	

3.3. Air Quality Trend Analysis

TROPOMI on the Sentinel 5 Precursor (S5P) satellite is designed to measure CO, NO₂, and other various atmospheric constituent abundance using clear-sky and cloudy-sky earth radiance observations in the 2.3 μm spectral area of the shortwave infrared (SWIR) sector of the solar spectrum. Out of that, we created a modest map (Figure 3) that shows the NO₂ spatial concentration from 2018 to 2022. The pixels in red and blue indicate areas where NO₂ concentrations are relatively higher or lower, respectively. This could be related to the prevailing land use pattern from east to the north over East Baton Rouge.

For carbon monoxide concentration in 2018, there was a high concentration of CO in the Northern parts of East Baton Rouge but a slight decrease in the south. However, 2020 saw a drastic decline in carbon monoxide concentration in almost every part of East Baton Rouge according to Figure 4 and this could be a result of the effect of the outbreak of COVID 19. The burning of fossil fuels, biomass, and the oxidation of methane and other hydrocarbons in the atmosphere are the primary sources of CO therefore the reduction in the production of these fuels as a result of a decline in demand and restriction of movement during the pandemic had a ripple effect on carbon monoxide concentration and this is evident in the map. Comparatively, 2022 experienced a somewhat increase in CO concentrations in most areas of East Baton Rouge (Figure 4) and this could also be attributed to our return to normalcy after the pandemic. The pixels in red and green indicate areas where the CO levels are relatively higher or lower, respectively.

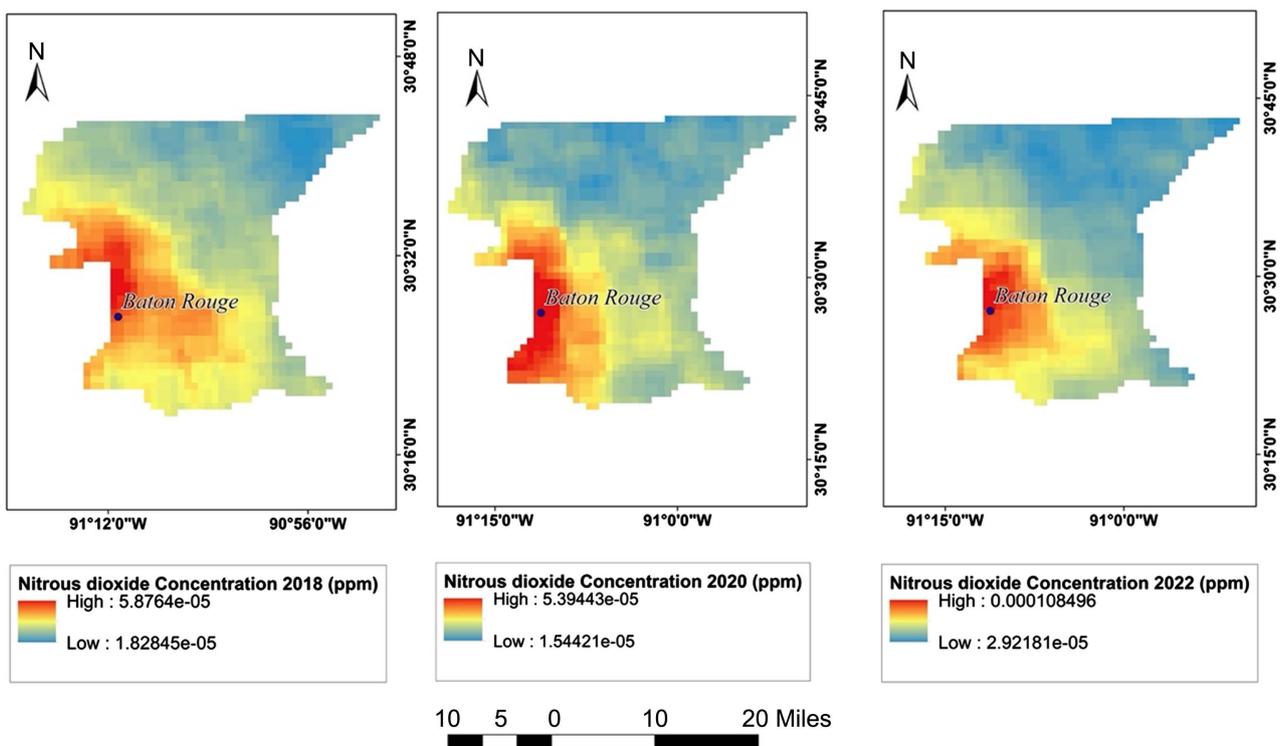


Figure 3. Nitrous dioxide concentration for East Baton Rouge Parish from 2018–2022.

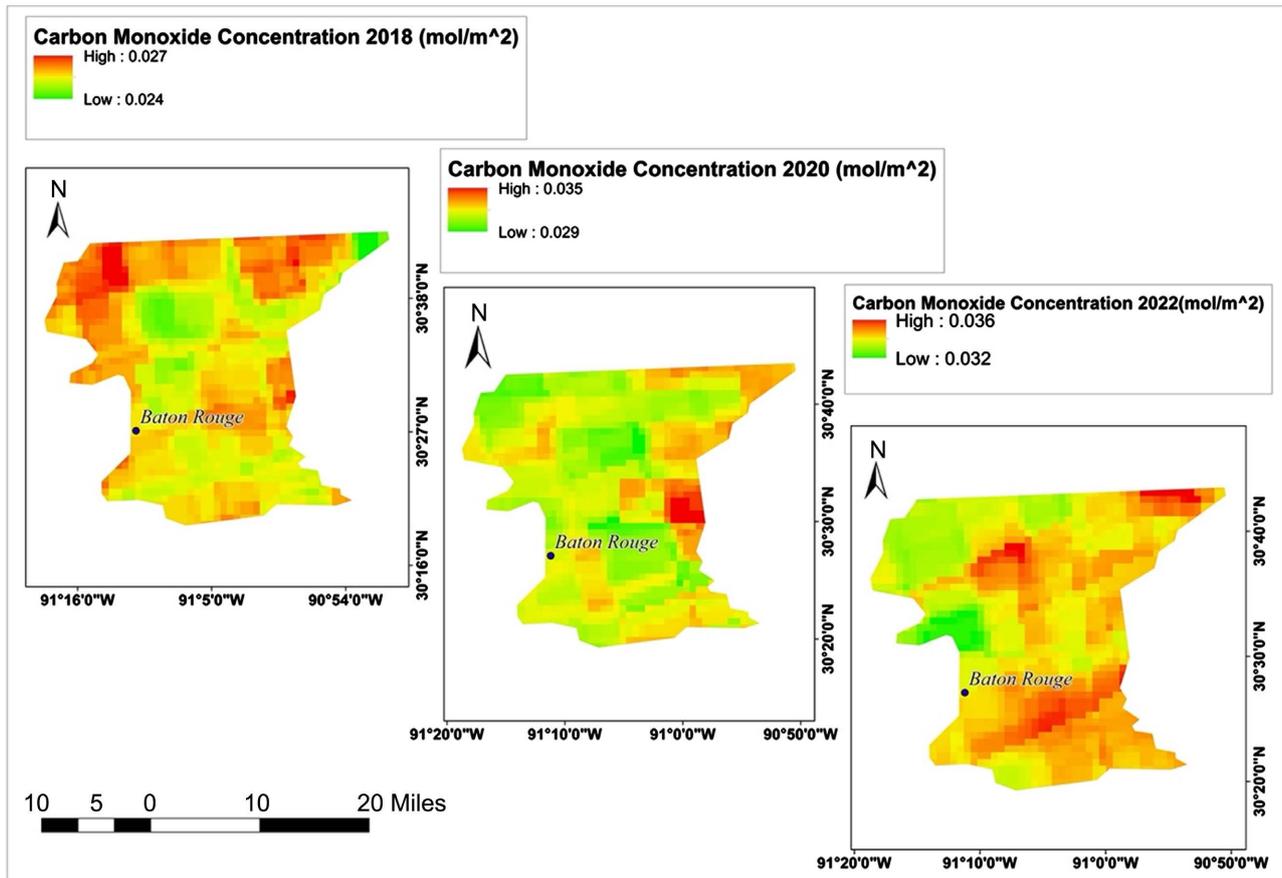


Figure 4. Carbon monoxide concentration for East Baton Rouge Parish from 2018–2022.

The Sentinel 5 Precursor (S5P) satellite was operational in 2017, hence lacking historical data. To supplement the loss, this study analyzed the EPA’s Summarized Air Quality Index for air quality trend analysis from 1991 to 2021. The air quality index is a daily air quality indicator that is used to report on the condition of the air we breathe. It indicates whether the air is clean or polluted, as well as any potential health risks that could be associated with the polluted air. It also provides yearly summaries of a city’s or county’s air pollution levels. The report displays the highest readings reported by all county monitors during the year and highlights text to identify values that exceed an air quality threshold as shown in [Table 3](#).

Focusing on PM_{2.5}, PM₁₀, NO₂, and CO trends over the years ([Figure 5](#)), the data collected for this investigation revealed situations where the concentration of these pollutants abruptly fell showing an increase in air quality in 2021 and this is represented in [Figure 5](#) below. When we compare NO₂ and CO emissions for East Baton Rouge in 1991 with those for the year 2021, we find a drop of roughly from 19 and 7 ppm to 7 and 1.4 ppm respectively in 2021. Regarding PM_{2.5} and PM₁₀, the same comparison indicates a reduction of approximately 60%, from 0 and 28 ppm annual mean in 1991 to 8.5 and 16 ppm in 2021. Considering that these decreases happened throughout rapid solid industrialization

Table 3. Shows the air quality index summary for east baton rouge between 1991, 2001, 2011 and 2021. CO 1-hr 2nd Max stands for Carbon Monoxide with the year's second-highest 1-hour measurement. NO₂ Annual Mean is the annual mean of all 1-hour measurements taken throughout the year whereas the PM2.5 wtd and PM10 Annual mean is the Weighted Annual mean for the calendar year. Statistics in **red** represent data readings above the respective air quality standard level.

County	CO 1-hr 2nd Max	CO 8-hr 2nd Max	NO ₂ 98th %ile	NO ₂ Annual Mean	O ₃ 1-hr 2nd Max	O ₃ 8-hr 4th Max	PM2.5 98th %ile	PM2.5 Wtd. Mean	PM10 24-hr 2nd Max	PM10 Annual Mean
East Baton Rouge, (1991)	7	4.8	77	19	0.14	0.097	.	.	54	28
East Baton Rouge, (2001)	6.5	4.8	64	17	0.11	0.082	32	14.2	52	26
East Baton Rouge, (2011)	1.7	1.4	56	12	0.12	0.083	26	12.5	73	33
East Baton Rouge, (2021)	1.4	0.9	37	7	0.09	0.063	19	8.5	46	16

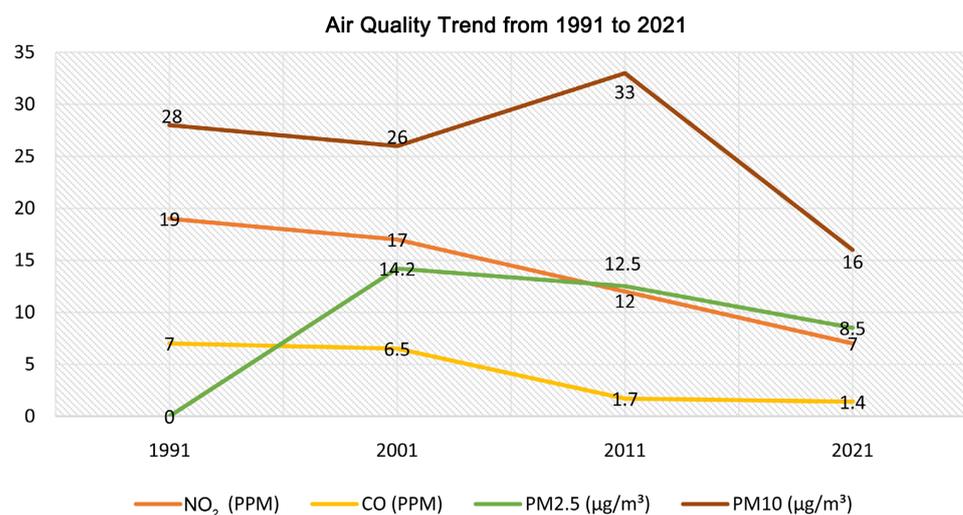


Figure 5. Shows the air quality trend of East Baton Rouge from 1991 to 2021 which reveals phases of modest decline in NO₂, CO, PM2.5, and PM10 levels.

in the area with three substantial coal-fired power stations running in the state (**Figure 6**), makes it even more astonishing. This clearly shows that these decreases over the span of thirty years cannot be accounted for just by land use, and several reasons could have contributed to this pattern. These reductions are most likely due to the state's adherence to US EPA guidelines rather than it being directly tied to development. These factors could disguise the actual influence of modernization on air quality in an area after analyzing the air quality pattern in the previous years and relating it to the rising quantity and population of city land construction. A study by [33] confirmed the concentration of PM2.5 declined dramatically with the establishment of PM2.5 limits in 2001 and their amendment in 2016 and this study affirms it.

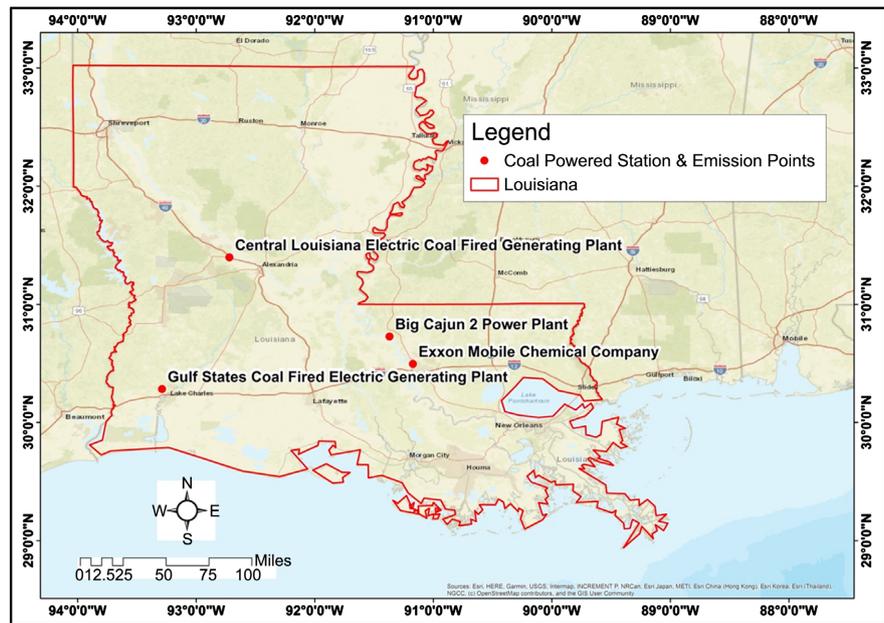


Figure 6. Shows the 3 coal-powered stations and an emission point in Louisiana.

4. Conclusions

The rapid evolution of technology and the ever-advancing techniques of Geospatial science presented innovative solutions and appropriate tools through G.I.S applications for researchers and concerned institutions to contribute to better management of the environment. Satellite imageries can be valuable in evaluating pollutant emissions in regions where surface sensors are non-existent or limited. As a result, we have a full view of individual concentrations of air pollutants, which allows us to analyze well LULC changes to air quality across a greater area, which will be hard to do with just surface data.

However, considering exterior impacts on every variable, establishing a relationship with changes in LULC and PM_{2.5} is a difficult task. Using East Baton Rouge and the southern Louisiana region as a case study, this research aimed at demonstrating how geospatial technologies such as GIS and remote sensing can be used to assess the effects of land use and land cover changes on particulate matter emissions and their impact on air quality. The data collected for this investigation revealed an increasing trend in air quality over the past 3 decades with a concentration of CO, NO₂, and PM_{2.5} abruptly falling however, urbanization and the population expanded throughout this time. This could be attributed to several external factors like the region's adherence to EPA Air quality regulations which is likely to muddle the association between the number and form of modification in LULC and the PM. This study has proven that the East Baton Rouge region has made significant progress in terms of air quality, and this should encourage policymakers on the effectiveness of federal and state regulations such as the Federal Clean Air Act. In the future, Louisiana residents can be encouraged on the use of alternative renewable energies rather than the over-dependence on coal-fired electric generating plants that have an impact on

the environment.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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