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Assessment of air quality trends and pollution hotspots in Vidarbha region of Maharashtra using Geospatial Techniques

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Abstract
Atmospheric pollution is a major problem, amplified by faster urbanizing and industrial development. This trend is particularly witnessed in the State of Maharashtra, India, with focus on the Vidarbha region. The analysis for the years 2023 and 2024 uses the Inverse Distance Weighting (IDW) technique of analysis through GIS mapping analysis. The analysis of the data indicates a high variation in concentrations of air pollutants over the Vidarbha region. The observations reveal a substantial rise in the concentration of particulate matters in the year 2024, from 8-52 µg/m³ to 9-109 µg/m³ for $PM_{2.5}$ and from 30-115 µg/m³ to 26-185 µg/m³ for PM_{10}. The concentrations of SO_2 decreased from 5-15 µg/m³ to 5-10 µg/m³, and in NO_2 from 9-34 µg/m³ to 8-30 µg/m³. Both Nagpur and Chandrapur have turned out to be major pollution points for all parameters studied. This study proves the capability of GIS-based spatial modeling in the effective management of air quality in a city and reinforces the need for specific control measures in the polluted areas of the Vidarbha region.

Keywords: Air pollution, geographic information system (GIS), inverse distance weighting (IDW), spatial analysis, vidarbha region.

Introduction

Nearly 90% of the world population is vulnerable to ambient concentrations of air pollution exceeding the global health guidelines set out by WHO. Air pollution means the presence of harmful substances like particulate matter, gases, and chemicals, within the atmosphere, that tend to affect the environment and the world's population in a negative way. Air quality has remained one of the most threatening sources of environmental pollution that poses risks to the well-being of the people due to its harmful effects on the environment (Kankaria *et al*., 2015). Over the past few decades, the problem of air quality has remained at the top of the list of major sources of environmental pollution due to its toxicological and hazardous effects on the well-being of people. Fast urbanization, fast development of industries, and unprecedented growth of vehicular traffic have been largely responsible for deterioration in air quality in developing and emerging countries. By far, emissions from motor vehicles, industrial activities, fossil fuel combustion, and thermal power plants are significant sources of particulates ($PM_{2.5}$ and PM_{10}) and gases like sulfur dioxide (SO_2) and nitrogen dioxide (NO_2), as they are known to be largely associated with respiratory and cardiovascular ailments as well as mortality, largely within densely populated urban and industrial zones (McCubbin & Delucchi, 1999) [10]. Other than health-related impacts, air pollutants were also found to affect soil properties negatively (El Desouky *et al*., 1998) [4] as well as plant development positively (Zhang *et al*., 2000) [15], thus causing disbalances in nature.
Vidarbha in the state of Maharashtra in India has undergone a vast amount of economic development in the past decades accompanied by rapid urbanization, industrialization, coal-based power generation, and rising emissions from vehicular traffic. The cities in Vidarbha are becoming increasingly prone to air pollution because of a combination of industrial emissions, traffic flow, burning of biomass/wheat residues in rural areas, as well as unfavourable weather systems. Variations in seasons also tend to affect the concentration levels influenced by temperature inversion in winter and preseason periods because of lower dispersion in the atmosphere as well as modifications in wind patterns (Cheng Lam, 1997) [1].
According to the Indian Bureau of Indian Standards (BIS), air pollution is described as:
"The presence of substances in the ambient atmosphere, usually arising from human activities, in concentrations and for durations sufficient to adversely affect human health, welfare, property, or the environment" (Use the Geographic For this current research work, GIS spatial analysis tools are utilized to measure the air quality-related key parameter distributions in terms of $PM_{2.5}$, PM_{10}, SO_2, and NO_2 for the Vidarbha region in the year 2023 and 2024. The objective of this research work is to determine the pollution spots and make year-by-year comparisons to provide scientifically valid information to make strategies for air quality management in the concerned region.

Study Area

The Vidarbha region, which is the eastern part of Maharashtra state has geographical coordinates from 19°00′ N to 22°30′ N latitude and from 75°30′ E to 81°00′ E longitude. It has a geographical area of ~97,321 km2. The region is bounded by Chhattisgarh from the east, Telangana from the south, Vidarbha has 11 administrative districts: Nagpur, Amravati, Akola, Buldhana, Washim, Yavatmal, Wardha, Chandrapur, Gondia, Bhandar. Climatically, the territory of Vidarbha is characterized by a tropical dry to sub-humid, hot summer (March to June), a southwest monsoon season (June to September), and mild to cool winter (November to February). Summer temperatures can be above 45 °C, while winter temperatures range from 12 °C in some regions. Average annual rainfall is 700 to 1,200 mm, with higher amounts in the eastern and southeastern parts of the region, in and around Gadchiroli and Gondia, and lower in the western parts of the region, in and around Akola and Buldhana. The land features in Vidarbha are mostly platelike topography with an elevation 200m to 600m above mean sea level. The land supports agriculture with cotton, soybean, and pulses being the main products, whereas the forests form a significant portion in the eastern districts of the region, primarily in Gadchiroli and Gondia. Fast expansion of the city, the rising number of vehicles on the roads, high levels of emissions from industries, the use of coal, biowastes, and agricultural residue burning have affected the quality of the air in Vidarbha. Additionally, the availability of lower wind velocities and temperature inversion levels during the winter season have enhanced the concentration of air pollutants in the region of Vidarbha. Thus, the area of Vidarbha remains of high scientific value in determining the spatial variability of air quality parameters. For the current research, the region of Vidarbha was chosen to examine the geographical distribution of $PM_{2.5}$, PM_{10}, SO_2, & NO_2 concentrations for the years 2023 & 2024 by using GIS & Remote Sensing. The aim was to know the impact points of these pollutants as well as know the year-to-year variations.

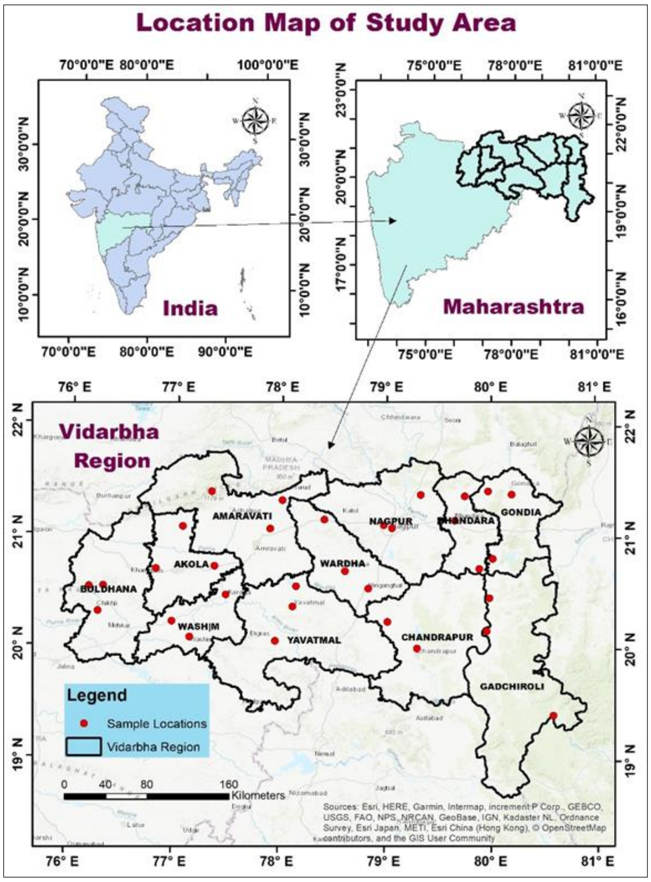

Fig 1: Location Map of Study Area

Materials and Methodology

1. Data Collection & Sources

Primary and secondary data sources are used in this current research to examine space variability as well as temporal variability of air quality variables for the Vidarbha region. Primarily, air quality monitoring data was obtained using a High-Volume Air Sampler that satisfies NAAQS standards and adheres to monitoring guidelines set by these standards by using Envirotech APM 460BL. This was done to ensure that these samplers are operated for a definite duration of 24 hours in ambient conditions outdoors. Initial as well as final airflow rates are measured for greater precision. The High-Volume Air Sampler is used for determining the levels of selected air pollutants like particulate matter, including $PM_{2.5}$ and PM_{10}, as well as gas pollutants like SO_2 and NO_2, through well-defined analytical procedures. Quality control procedures were adopted during air sampling and analysis. Secondary air quality information was also acquired, which was reliant on the Maharashtra Pollution Control Board, to supplement and confirm the primary air quality information. Combining primary air quality information with the long-term baseline information available with the MPCB helped in conducting an in-depth analysis of air quality. Moreover, a Digital Elevation Model (DEM) analysis was conducted to understand the effect of topography on air pollutant distribution. Digital Elevation Models allow elevation data to be used, which is employed in additional analysis in order for the role of topography in determining air pollutant transport in the area to be determined.

2. Software used

Analysis of air quality factors in terms of space and time was conducted utilizing ArcGIS Desktop software, version 10.8. The software tool assisted in the integration of data, interpolation, creation of maps, and illustration of the air pollutant concentrations in the Vidarbha region. The mapping tools in the Geographic Information System software assisted in the mapping of the air pollutant distribution in space for the period 2023 [9] to 2024.

3. Preparation of Thematic Maps

Thematic maps showing the spatial distribution of parameters of air quality were made to study the variations in concentrations of pollutants on a regional scale. Spatial analysis of data was performed by using GIS techniques, which enable combination of both discrete and continuous entities of geographic features of the phenomenon studied. The base maps were drawn using the layer boundaries of the Vidarbha region, and all the data were transformed into the same coordinate system. The topographic data was represented by Survey of India toposheets of 1:50,000 scale and Digital Elevation Model to help capture the effect of terrain factors on dispersion of air pollutants. The attribute information of air quality variables was assigned to geographical locations to formulate a continuous surface maps representing the concentration levels of pollutants.

4. Spatial Interpolation Technique

For the estimation of air pollutant concentrations in the unsampled spots, a spatial interpolation methodology was employed. Of all the existing methods for conducting interpolations, the Inverse Distance Weighting (IDW) method was chosen for use in this research. IDW gives more weights to nearby spots than the distant spots because it is believed that those spots, which are geographically close, share similar attributes. The formula used by the IDW is to determine unknown values through a weighted average of known sample values, where the weights reduce as the distance increases from the location of prediction. This formula is most useful in a scenario where there is not much data gathering in terms of monitoring stations, and also in instances where variations override global patterns. Kriging, though widely practiced in geostatistics as an interpolation technique, needs a comparatively dense dataset, which may not always be reliable in geostatistics. In the current research, owing to the smaller number of monitoring stations and imbalanced distribution of the monitoring points in space, IDW was found to be comparatively more suited to air quality parameter models in the Vidarbha region than Kriging.

5. Temporal Analysis of Air Quality Parameters

Variations in air quality on an average temporal basis were studied by using direct field measurements as well as secondary measurements from the Maharashtra Pollution Control Board (MPCB). Secondary measurements were used for supplementary spatial studies as well as for comparisons of yearly variations in mean concentrations of air pollutants. Comparison analysis between 2023 [9] and 2024 was done to determine changes in levels of air quality and new trends of pollution.

Results and Discussion

Table 1: Concentration of Air pollution data in the study region

Locations	PM2.5 2023	PM2.5 2024	PM10 2023	PM10 2024	SO2 2023	SO2 2024	NO2 2023	NO2 2024
Morshi	22	25	47	50	13	9	15	11
Wagholi (Sofia)	32	28	80	70	15	8	14	18
Chikhaldara	14	10	30	27	10	8	9	9
Akot	20	22	62	65	11	5	9	15
Paras Thermal Power Plant	40	34	76	78	12	7	15	27
Murtizapur	19	16	63	50	15	8	14	9
Buldhana City	18	20	61	55	12	8	15	12
MIDC Chikhali, Buldana	25	24	70	60	12	9	13	14
Gyanganga Wildlife Sanctuary	8	9	30	26	11	10	11	9
Karanja	12	14	55	55	9	8	10	11
MIDC AREA, WASHIM	22	19	65	62	12	9	11	14
Malegaon Jahangir	9	11	60	59	10	9	11	12
Babhulgaon	11	12	50	50	10	9	11	11
Yavatmal	22	22	61	61	10	8	12	12
Arni	9	15	45	55	9	10	10	9
Nagpur Airport	35	50	91	110	14	6	16	17
MIDC, Hingna Road Nagpur	52	110	98	186	14	7	34	30
Ramtek	32	40	85	98	10	6	9	9
Karanja (Ghadge)	15	14	37	40	10	8	9	9
Wardha-Waigaon Road	40	18	55	50	6	8	11	12
Hinganghat	33	29	45	41	9	8	10	10
Tumsar	21	21	60	60	9	9	11	11
Bhandara Bus Stand	25	29	56	68	10	8	19	15
Kinhala-Lakhandur	20	18	45	44	9	7	13	11
Gondia-Kohmara Road	20	19	43	60	5	5	9	8
Gumadhwada- Tiroda, Adani Power Plant	33	34	70	68	8	8	12	12
Arjuni	21	20	55	55	7	8	10	9
Armori	29	35	60	59	6	6	10	10
Kotgal Industrial area	35	40	98	72	11	10	12	15
Bhamragarh	27	30	79	68	9	8	10	10
Warora	45	46	112	129	12	7	24	18
Thermal Power plant, Chandrapur	51	55	115	137	15	8	23	20
Moharli, Tadoba Wildlife Sanctuary	30	28	99	51	7	8	18	7

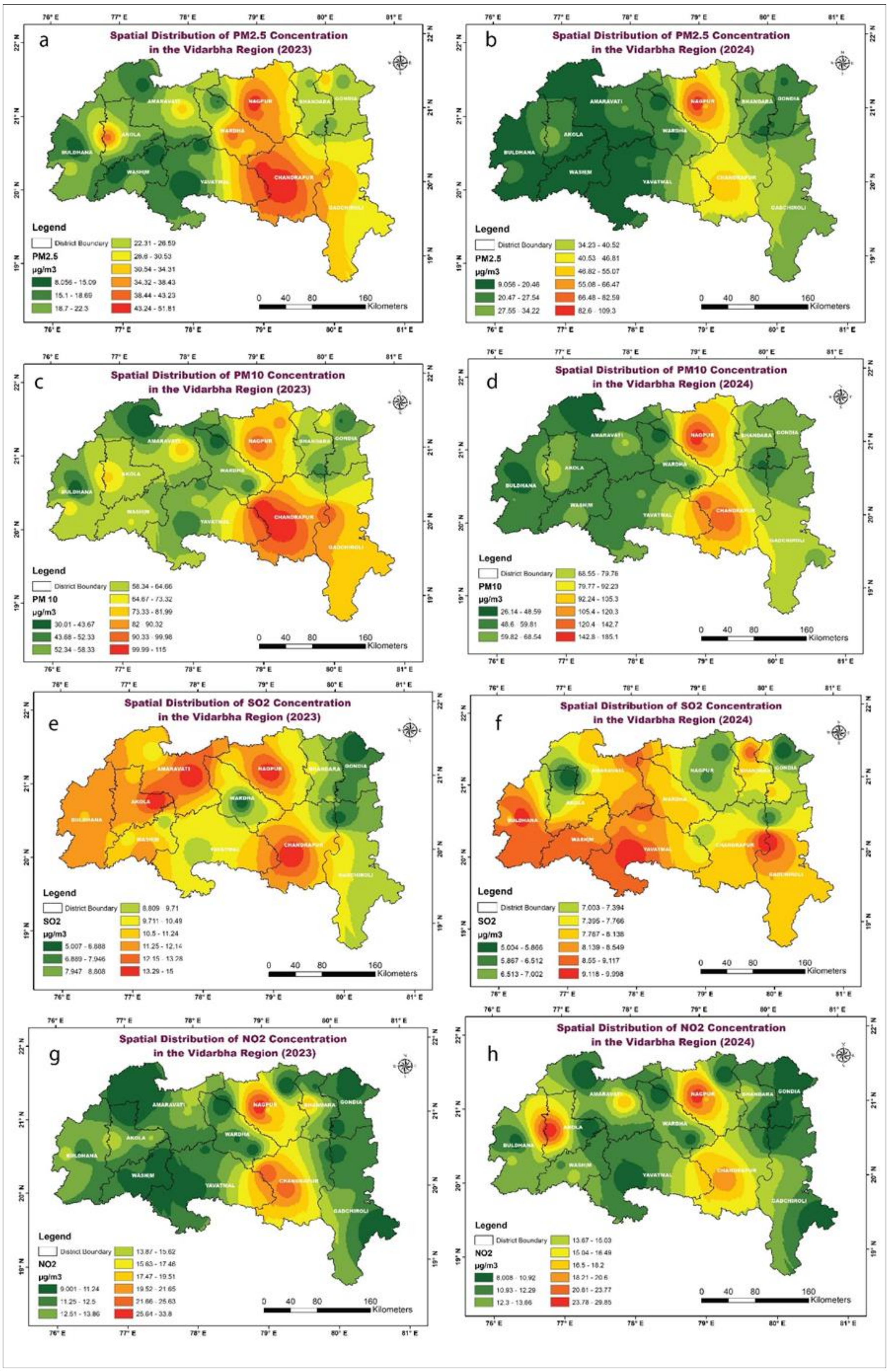

Fig 2: Spatial distribution map of PM2.5, PM10, SO2 and NO2 for 2023 and 2024 year

1. Spatial Distribution of Fine Particulate Matter $PM_{2.5}$

The geographical distribution of $PM_{2.5}$ levels in the Vidarbha area shows variations in values between different districts in both 2023 and 2024 (Figure 2 a and b). In the year 2023, lower values of $PM_{2.5}$ (~8-22µg/m³) were largely recorded in the western and southern parts of the region, including districts like Buldhana, Washim, and some areas of Yavatmal, implying clean air quality. Moderate values of $PM_{2.5}$ (~22-34µg/m³) were recorded in other areas, including Amravati, Akola, Bhandara, and Gondia. Higher proportions of $PM_{2.5}$ were markedly concentrated in the central as well as southeastern part of the region, pointing to Nagpur, Wardha, and Chandrapur as major air pollution pockets. Chandrapur recorded the maximum levels of $PM_{2.5}$, exceeding 43µg/m³, due to heavy coal-fired power production and mining.

There has been noticeable degradation in air quality in the year 2024, with significant overall increment in the concentration of $PM_{2.5}$ in the region. The large regions that were earlier safe with low to moderate levels of air pollution moved on to higher levels of concentration. The two districts that remain most critically polluted are Nagpur and Chandrapur, where the maximum levels of $PM_{2.5}$ are currently recorded above 80-100 µg/m³ in localized regions. The eastern parts of the regions, including Gadchiroli and Bhandara districts, also witnessed higher levels of $PM_{2.5}$ concentrations when compared with those of 2023 levels. The increase witnessed can be ascribed to increased levels of urbanization, increased emissions from vehicles, increased industrial activities, biomass burning, as well as poor atmospheric diffusion (CPCB, 2009).

2. Spatial Distribution of Particulate Matter (PM_{10})

Figs. 2 (c) and 4(d) depict the spatial distribution of PM_{10} concentrations over the Vidarbha region for 2023 and 2024, respectively. During 2023, ~30.0 µg/m³ to 115 µg/m³. The highest concentrations of PM_{10} are found in Chandrapur district, followed by Nagpur district, indicating the impact of coal mining activities, thermal power plants, industrial emissions, resuspension of road and construction dust-sources that are generally associated with coarse particulate pollution in the industrial belts. Moderate concentration levels of PM_{10} have been found in Amravati district, while Washim, Buldhana, and Akola. In 2024, the concentration of PM_{10} increased considerably, lying in the range from 26.1 µg/m³ to 185.1 µg/m³, which shows deterioration in air quality.

3. Spatial Distribution of Sulfur Dioxide (SO_2)

There is moderate variability in SO2 concentrations in Vidarbha, with hotspots in both industrial and urban area distributions in both 2023 and 2024 (Fig 2 e & f).

SO2 concentration 2023 levels in Vidarbha ranged between 5.0 and 15.0 µg/m³ in Amravati, Akola, Nagpur, and Chandrapur. Gondia, Bhandar, reflecting limited industrial activity and greater forest cover. In the year 2024, there has been an apparent shift in SO2 concentrations, which varied from ~5.0 to 10.0 µg/m³. Higher SO2 concentrations (>8.5 µg/m³) were recorded in Yavatmal, while had comparatively moderated levels. Despite SO2 levels not violating the national ambient air quality standards, the existence of sulfur-rich zones signifies the significance of fossil fuel burning and industrial emissions within the area.

4. Spatial Distribution of Nitrogen Dioxide (NO_2)

The spatial distribution of NO_2 concentration across the Vidarbha region for the years 2023 varied from ~9.0 - 33 µg/m³. Higher NO_2 concentrations have been recorded mostly in Nagpur and Chandrapur districts, which reflects the impact of heavy vehicular traffic, urbanization, and industrial combustion sources. Such sources are highly reported to be dominant contributors to NO_2 in the urban–industrial complexes of most regions. Moderate NO_2 concentrations are noted in Bhandara, Akola, and Amravati, whereas relatively lower concentrations were observed in Washim and Yavatmal. In 2024, A significant increase in NO_2 values was recorded in Akola, indicating traffic and increasing urban activities. NO_2 values measured during the two years were within the allowable limits set by National Ambient Air Quality Standards (CPCB, 2009) [2].

5. Inter annual comparison of Air Quality Parameters

A comparative assessment of air quality parameters in the current year 2023 [9] and previous year 2024 shows a use across the Vidarbha region, while gaseous pollutants showed relatively stable or slightly declining trends. Nagpur regional pollution gradients and hot-spot zones were interestingly captured using this GIS-based spatial interpolation approach, thus providing a holistic insight into the manner of variation both spatially and temporally in air quality across Vidarbha. This was in keeping with applications of GIS in mapping air pollution and urban environmental assessment, as per Weng & Yang (2006) [13].

Conclusion

The present study provides an integrated estimate of the spatial and temporal variations in ambient air quality of the Vidarbha region of Maharashtra using a GIS-based spatial analysis. Results distinctly show significant regional variability in pollutant concentrations, where in Nagpur and Chandrapur have been repeatedly found as major air-pollution hotspots because of the cumulative impact of urbanization, vehicular emissions, industrial activities, and coal-based power generation. Inter-annual comparison between 2023 and 2024 reveals a significant deterioration in particulate matter levels - $PM_{2.5}$ and PM_{10} - wherein the concentration of $PM_{2.5}$ has exceeded the national permissible limits in many districts, thus presenting a potential risk to public health. Gaseous pollutants, NO_2 and SO_2, remained relatively stable and mostly within National Ambient Air Quality Standards, although localized hotspots were evident near industrial clusters. A GIS-based interpolation technique has effectively captured the spatial gradients of pollution and identified high-risk zones. Overall, the study demonstrates the urgent requirement for specific air-quality management strategies, particularly in urban-industrial districts of Vidarbha, and elucidates the role of geospatial tools in encouraging informed environmental planning and policy formulation.

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