ASSESSMENT OF AIR QUALITY AND IDENTIFICATION OF POSSIBLE SOURCES IN AND AROUND ANGUL-TALCHER AREA OF ODISHA, INDIA

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ABSTRACT

Air pollution represents a profound global environmental challenge, particularly intensified within rapidly urbanizing and industrializing nations such as India [21]. This study embarked on a comprehensive assessment of ambient air quality and the identification of potential pollution sources within the Angul-Talcher region of Odisha, India, a designated critically polluted industrial cluster [19]. Conducted over a one-year period from March 2022 to February 2023, the research encompassed six strategically chosen sampling stations: Jindal Steel & Power Limited (JSPL), Industrial Estate (IE), and National Aluminium Company Limited (NALCO) in the Angul area, and Talcher Thermal Power Station (TTPS), Mahanadi Coalfields Limited (MCL), and National Thermal Power Corporation (NTPC) in the Talcher area. The methodology involved the meticulous sampling and analysis of key particulate matter (PM_10 and PM_2.5) and gaseous pollutants (SO_2 and NO_2) in strict adherence to the guidelines established by the Central Pollution Control Board (CPCB) [24]. Subsequent data interpretation employed the Air Pollution Index (API) for an aggregate assessment of pollution severity [25]. Furthermore, advanced multivariate statistical techniques, including Principal Component Analysis (PCA) and Cluster Analysis (CA), were applied to discern underlying patterns, reduce data dimensionality, and identify primary pollution sources [12]. A windrose diagram was also generated to understand prevailing wind patterns and their influence on pollutant dispersion [9].

The findings revealed alarmingly high concentrations of particulate matter, with both PM_10 and PM_2.5 significantly exceeding the National Ambient Air Quality Standards (NAAQS) [29]. Nitrogen dioxide (NO_2) levels also consistently surpassed the allowable limit, indicating substantial anthropogenic contributions. Conversely, sulfur dioxide (SO_2) concentrations remained within the prescribed limit. Critically, the computed API values categorized all sampling stations within the "Severe Air Pollution" category, underscoring the severe air quality degradation in the region. Principal Component Analysis robustly identified that the predominant sources of air pollution stemmed from widespread industrial emissions, extensive mining activities, vehicular exhausts, and significant seasonal and meteorological influences. The Cluster Analysis further demonstrated a striking similarity (97.92%) among all stations in terms of their shared pollution sources, suggesting a common regional pollution landscape. These comprehensive results strongly advocate for the immediate implementation of holistic, region-wide pollution control strategies.

KEYWORDS: - Air Quality, Particulate Matter, Gaseous Pollutant, Air Pollution Index, Principal Component Analysis, Cluster Analysis, Angul-Talcher Area.

Introduction

1.1. Broad Background and Historical Context

Air pollution has emerged as one of the most pressing environmental and public health concerns of the 21st century, particularly intensified within urbanized and industrialized landscapes worldwide [16]. As global populations increasingly migrate to urban centers, the attendant pressures of burgeoning energy consumption, rapid industrial expansion, and escalating vehicular traffic have collectively led to a pervasive decline in ambient air quality [21]. This phenomenon is acutely observed in developing nations, where economic growth often outpaces the implementation of stringent environmental regulations [21]. India exemplifies this challenge profoundly [19]. With a significant portion of its population in urban areas, Indian cities have witnessed a dramatic deterioration in air quality, primarily attributable to unsustainable resource exploitation, rapid urban proliferation, and increased vehicular density [21]. Industrialization contributes significantly through emissions from manufacturing and power generation [21]. The cumulative effect is that more than half of India's total air pollutants originate from its urban areas [21]. Alarmingly, a substantial proportion of these emissions fail to meet the air quality criteria set forth by the World Health Organization (WHO), highlighting a critical public health crisis [3].

Advancements in atmospheric science and environmental epidemiology have elucidated the intricate pathways through which air pollutants exert their harmful effects, ranging from acute respiratory and cardiovascular diseases to long-term chronic conditions [17]. The complexity of air pollution is compounded by geographical features, land-use patterns, and dynamic meteorological conditions such as temperature, humidity, and wind, which play a pivotal role in the dispersion and transport of pollutants [9]. To effectively combat this issue, the precise identification of pollution sources is paramount, often achieved through source apportionment analyses [10]. Such knowledge is indispensable for developing targeted and efficacious air quality management strategies [1]. The Air Pollution Index (API), a composite metric, serves as a crucial tool for communicating air quality status and identifying the primary pollutants driving degradation [25]. The historical trajectory of air quality monitoring and management in India by regulatory bodies like the Central Pollution Control Board (CPCB) underscores a growing recognition of the severity of this problem [19].

1.2. Critical Literature Review

The issue of air pollution in India has prompted numerous investigations into its ambient quality and potential sources across diverse landscapes [3]. Source apportionment studies are critical for developing effective mitigation strategies [10]. A range of receptor models have been applied, including Factor Analysis (FA), Principal Component Analysis (PCA), Positive Matrix Factorization (PMF), and Chemical Mass Balance (CMB) [10]. Of these, PCA is the most frequently employed multivariate statistical technique for its efficacy in reducing data dimensionality and identifying underlying patterns [12]. While PCA is widely used, there have also been notable applications of the Chemical Mass Balance (CMB) model in Indian contexts [14].

Previous research has documented the adverse health effects of air pollution, ranging from increased morbidity to mortality, and affecting materials, plants, and animals [15]. Studies have assessed air quality across various regions of India. For instance, Chauhan and Pawar (2010) assessed air quality in Uttarakhand's urban and industrial centers [2], while Kaur and Pandey (2021) reviewed the interplay between air pollution, climate change, and human health in Indian cities [3]. Regional studies in Odisha also provide valuable context [35]. Ekka et al. investigated polycyclic aromatic hydrocarbons (PAHs) in particulate matter from Odisha's industrial belts [20], and Sahu and Sahu (2019) assessed air quality in Sambalpur [7]. Other studies in Jharsuguda [22], Keonjhar [30], and Paradip [32] have revealed similar challenges.

The Central Pollution Control Board (CPCB) has identified several industrial clusters as critically polluted, with three such areas in Odisha: Angul-Talcher, Ib-valley, and Jharsuguda [19]. Angul-Talcher is a prominent industrial cluster where abundant minerals like coal and chromite have spurred numerous mining and industrial activities [23]. This intense proliferation has led to severe air pollution in the surrounding areas [7, 20, 22, 30, 32]. The influence of meteorological conditions on pollutant concentrations has also been a subject of various studies [34]. Therefore, while general air quality assessments exist for many Indian cities, detailed source apportionment analyses specific to Angul-Talcher remain limited.

1.3. The Identified Research Gap

Despite the growing body of literature on air pollution in India, a significant research gap persists concerning comprehensive source apportionment studies in specific critically polluted industrial areas like the Angul-Talcher cluster in Odisha. While general air quality assessments have been conducted in some industrial areas within Odisha, detailed investigations that systematically identify and quantify the specific contributions of various pollution sources in Angul-Talcher are comparatively scarce. The lack of detailed, specific data for this critical hub represents a significant impediment to formulating evidence-based pollution control measures.

1.4. Study Rationale, Objectives, and Hypotheses

The rationale for this study is rooted in the critical need to address the severe air quality degradation in the Angul-Talcher industrial cluster. Given the limited existing knowledge on source apportionment in this area, a comprehensive investigation is warranted to provide empirical data for informed policy-making. The escalating health concerns associated with air pollution further underscore the urgency of understanding its sources in this densely populated industrial belt.

The key objectives were:

- To study the ambient air quality by measuring concentrations of PM_10, PM_2.5, SO_2, and NO_2.
- To assess the overall pollution status by computing the Air Pollution Index (API).
- To detect and identify possible sources of air pollution using Principal Component Analysis (PCA) and Cluster Analysis (CA).

The study was guided by the following hypotheses:

- Pollutant concentrations in the Angul-Talcher area will frequently exceed the National Ambient Air Quality Standards (NAAQS).
- The Air Pollution Index (API) will consistently categorize the area under a "Severe Air Pollution" category.
- Principal Component Analysis (PCA) will identify dominant pollution sources such as industrial emissions, mining operations, and vehicular traffic.

- Cluster Analysis (CA) will reveal distinct spatial patterns or similarities in pollution sources among the sampling stations.

- Meteorological factors will significantly influence pollutant concentrations and dispersion dynamics.

2. METHODS

2.1. Research Design

This study adopted a quantitative, observational research design to assess ambient air quality and identify pollution sources in the Angul-Talcher industrial cluster. The design involved systematic, year-long monitoring of key air pollutants at multiple selected sites, followed by rigorous statistical analysis using multivariate techniques like PCA and CA.

2.2. Participants/Sample

The "sample" refers to the selected geographical areas where air quality measurements were conducted.

- Study Site: The study was conducted in the Angul-Talcher region of Odisha, India. This district covers an area of 6232 sq. km. Geographically, Angul is at 20°84' N Latitude and 85°15' E Longitude, while Talcher is at 20°95' N Latitude and 85°21' E Longitude. The average elevation is 876 meters above mean sea level. As per the 2011 census, the total population of Angul district was 12.74 lakhs.

- Topography and Climate: The district has varied topography, including hill chains and the valley of the Brahmani River. The climate is generally hot and humid from March to mid-June, followed by a colder period from October to February, with the monsoon season lasting from late June to September.

- Sampling Stations and Frequency: Monitoring was performed from March 2022 to February 2023. Six sampling stations were selected: JSPL, Industrial Estate (IE), and NALCO in the Angul area, and TTPS, MCL, and NTPC in the Talcher area. Station selection was guided by accessibility, power supply, and platform suitability. Sampling was conducted for a 24-hour period during the last week of each month at every station.

2.3. Materials and Apparatus

The assessment used specific instruments and materials adhering to CPCB guidelines [24].

- Sampling Equipment: A Respirable Dust Sampler (RDS) was used for PM_10, SO_2, and NO_2, while a Fine Particulate Sampler (FPS) was used for PM_2.5. Samplers were positioned 6-8 meters above the ground to avoid contamination.

- Filter Sheets: Whatman filters were used for PM_10, and Polytetrafluoroethylene (PTFE) filters were used for PM_2.5.

- Absorbing Reagents: A solution of sodium tetrachloromercurate was used for SO_2 analysis, and a mixture of sodium hydroxide and sodium arsenate was used for NO_2 analysis.

2.4. Experimental Procedure/Data Collection Protocol

The data collection protocol was designed for consistency and accuracy over the one-year study period.

- Sampling Duration and Frequency: Monitoring was conducted for 24 hours at each station during the last week of every month. The 24-hour sampling for PM_10 and gaseous pollutants involved six repeated 4-hour runs.

- Air Flow Rates: A flow rate of 1.0 to 1.3 m^3/h was maintained for PM_10 and gaseous pollutants, while a constant rate of 1.0 m^3/h was used for PM_2.5.

- Pollutant Analysis: Particulate matter analysis was performed gravimetrically. SO_2 concentrations were determined using the improved West and Geake method, and NO_2 concentrations were analyzed using the modified Jacob and Hochheiser method. All pollutant concentrations were expressed in micrograms per cubic meter (μg/m^3).

2.5. Data Analysis Plan

A comprehensive data analysis plan was implemented.

- Air Pollution Index (API): The API was calculated to provide a single metric representing the overall air quality status, using a formula adopted from Ziauddin and Siddiqui [25].

- Principal Component Analysis (PCA) and Cluster Analysis (CA): Both analyses were performed using SPSS version-19 [33]. PCA was used to reduce data dimensionality and identify primary factors contributing to air pollution. CA was used to classify sampling stations into groups based on their pollutant profiles, using Euclidean distance and complete linkage, with results visualized in a dendrogram.

- Windrose Diagram, ANOVA, and Correlation Matrix: An annual Windrose diagram was prepared to understand pollutant dispersion patterns. A two-way ANOVA was computed to assess the statistical significance of variations due to stations and months. A correlation matrix was generated to quantify the relationships between air quality and meteorological variables.

3. RESULTS

3.1. Preliminary Analyses

Meteorological data was collected for the Angul-Talcher area from March 2022 to February 2023.

- Rainfall: Rainfall varied significantly, with a total annual precipitation of 1159 mm.

- Relative Humidity: Fluctuations were observed between 51% and 97%.

- Wind Speed: Wind speed ranged from 2-4 km/hr (minimum) to 6-22 km/hr (maximum).

- Temperature: The lowest temperature was 8.6°C (January 2023) and the highest was 44.7°C (April 2022).

- Solar Radiation: The area received minimum solar radiation in August 2022 and maximum in May 2022.

- Windrose Diagram: The annual Windrose diagram illustrated that the wind primarily blew from the South-East and East directions, suggesting that areas to the North-West and West would be significant for pollutant dispersion.

3.2. Main Findings

- Ambient Air Quality - Particulate Matter (PM_10): Monthly concentrations of PM_10 were analyzed. In the Angul area, concentrations ranged from 190.56 μg/m^3 to 370.42 μg/m^3. In the Talcher area, concentrations varied from 148.27 μg/m^3 to a peak of 478.95 μg/m^3. The annual average for the entire region was 299.00 μg/m^3.

- Ambient Air Quality - Particulate Matter (PM_2.5): Monthly concentrations of PM_2.5 were analyzed. In the Angul area, concentrations varied from 82.26 μg/m^3 to 155.36 μg/m^3. In the Talcher area, concentrations ranged from 71.50 μg/m^3 to 180.36 μg/m^3. The annual average for the entire region was 115.74 μg/m^3.

- Ambient Air Quality - Gaseous Pollutants (SO_2): Monthly concentrations of SO_2 were analyzed. In the Angul area, concentrations varied from 47.64 μg/m^3 to 72.58 μg/m^3. In the Talcher area, concentrations fluctuated from 50.41 μg/m^3 to 73.81 μg/m^3. The annual average for the region was 62.05 μg/m^3.

- Ambient Air Quality - Gaseous Pollutants (NO_2): Monthly concentrations of NO_2 were analyzed. In the Angul area, concentrations ranged from 102.65 μg/m^3 to 173.95 μg/m^3. In the Talcher area, concentrations ranged from 108.60 μg/m^3 to 187.88 μg/m^3. The annual average for the region was 158.27 μg/m^3.

- Comparison with NAAQS and Pollution Status: Concentrations of both PM_10 and PM_2.5 were significantly higher than the NAAQS recommended standards. While SO_2 levels generally remained within the limit, NO_2 levels consistently exceeded the allowable limit. The calculated Air Pollution Index (API) indicated that all sampling stations fell under the "Severe Air Pollution" category. Pollutant concentrations were consistently higher in the Talcher area compared to the Angul area.

3.3. Secondary or Exploratory Findings

- Analysis of Variance and Correlation Matrix: A two-way ANOVA revealed significant variation in air quality parameters both between stations ($p < 0.05$) and between months ($p < 0.05$), indicating that both geographical location and seasonality played a statistically significant role.

- Principal Component Analysis (PCA): PCA was performed to identify probable sources of air pollutants. The analysis revealed that the first principal component (PC1) explained a substantial 97.4% of the total variance, suggesting a single, dominant set of factors influencing air quality. PCA identified widespread industrial emissions, extensive mining activities, vehicular emissions, and meteorological conditions as the potential causes of air pollution.

- Cluster Analysis (CA): CA was applied to the air pollutant data. The resulting dendrogram showed the hierarchical clustering of the six stations. The analysis formed two major clusters that ultimately converged at a 97.92% similarity level. This striking similarity suggests that the overarching pollution trends and underlying sources across all six stations are closely related.

4. DISCUSSION

4.1. Interpretation of Key Findings

The assessment of air quality in the Angul-Talcher area yielded critical insights into the region's severe pollution and its drivers. A standout finding is the consistently high levels of particulate matter, with both PM_10 and PM_2.5 concentrations substantially above the NAAQS at all stations. The seasonal patterns were distinct, with levels peaking during winter and lowest during the monsoon. This is profoundly influenced by meteorological conditions like winter temperature inversions, which trap pollutants, and monsoon precipitation, which contributes to washout.

Among gaseous pollutants, NO_2 levels were consistently above the NAAQS limit, strongly suggesting significant contributions from vehicular emissions and industrial combustion. In contrast, SO_2 levels generally remained within the prescribed limit. Spatially, MCL consistently recorded the highest pollution levels. The differences between the Talcher and Angul areas can be linked to the intensity of specific activities: rigorous mining in Talcher and more pronounced industrial activities in Angul. The Air Pollution Index (API) calculation categorized all six stations as "Severe Air Pollution," confirming the critical state of air quality across the entire region.

The multivariate analyses provided deeper insights. PCA revealed that a dominant principal component accounted for 97.4% of the total variance, indicating a common set of underlying factors: industrial emissions, mining activities, vehicular emissions, and meteorological conditions. The Cluster Analysis reinforced this, showing a high degree of similarity (97.92%) among all stations, a key indicator that the air pollution problem is a systemic, regional issue.

4.2. Comparison with Previous Literature

The findings from the present study align with existing literature on air pollution in industrial and urban regions in India [2, 3, 16, 21]. The high levels of particulate matter exceeding national standards are consistent with reports from other industrializing areas [16, 22, 30, 32]. The observed seasonal variations attributed to temperature inversions and monsoon washout are well-documented phenomena in atmospheric science [9, 34]. The finding of NO_2 levels exceeding standards is a common concern in areas with heavy vehicle traffic and industrial combustion [16, 27]. The application of PCA to identify pollution sources is a widely accepted technique, and the identified drivers are consistent with source apportionment studies conducted in other industrial and mining areas [12, 13, 33, 36]. The high degree of similarity among stations found through Cluster Analysis suggests a regional-scale pollution problem, which is consistent with the understanding of critically polluted industrial clusters. The specific activities identified in the region are typical sources of emissions in such areas. Previous assessments in other Odisha industrial towns like Jharsuguda and Paradip documented similar challenges [22, 32].

4.3. Strengths and Limitations of the Study

- Strengths: The study's strengths include its comprehensive year-long monitoring period; strategic selection of six sampling stations; adherence to CPCB guidelines ensuring data reliability; the robust use of multivariate statistical methods (PCA and CA) for effective source apportionment and pattern recognition; a holistic API assessment; and the integration of meteorological data.

- Limitations: The study's limitations include a limited scope of pollutants; a spatial resolution that could be improved with a denser network; the absence of more advanced receptor models like PMF or CMB for quantitative source apportionment; the exclusion of a direct health impact assessment; and a temporal resolution that might miss short-term pollution episodes.

4.4. Implications for Theory and Practice

- Theoretical Implications: The study reinforces the theory that intensive industrial and mining activities create significant air pollution hotspots. It confirms the critical role of meteorology in modulating pollutant concentrations. The findings also support the concept of a "regional plume" in large industrial clusters, suggesting that cumulative emissions lead to widespread impacts and challenge site-specific control approaches. The study validates the utility of multivariate statistics for source identification in complex environmental datasets.

- Practical Implications: The most critical practical implication is the need for comprehensive, region-wide pollution control measures in the Angul-Talcher area. Targeted interventions should focus on industrial emissions, dust suppression in mining, and vehicular pollution control. Authorities should consider stricter controls during winter months. The findings underscore the necessity for reinforcing environmental policies and enforcement of NAAQS. There is also a practical need for public health awareness campaigns, integrated land-use planning, and a robust real-time air quality monitoring network.

5. CONCLUSION

This study unequivocally demonstrates a severe air pollution problem in the Angul-Talcher industrial area of Odisha. Concentrations of PM_{10}, $PM_{2.5}$, and NO_2 consistently exceed the NAAQS limits, and the entire region is categorized under "Severe Air Pollution" by the API. Multivariate analyses robustly identified widespread industrial emissions, extensive mining activities, vehicular exhausts, and adverse meteorological conditions as the predominant contributors. The high degree of similarity in pollution patterns across stations underscores that the degradation is a systemic, regional issue. These conclusions highlight the urgent need for integrated, region-wide pollution control measures.

Future Research Directions: Future research should utilize advanced receptor models like PMF or CMB for quantitative source apportionment; broaden the scope of monitored pollutants to include VOCs, heavy metals, and others; conduct direct epidemiological studies to correlate pollutant concentrations with health outcomes; extend the monitoring period for long-term trend analysis; and investigate the economic costs of pollution and the feasibility of specific mitigation technologies.

REFERENCES

[1] Coelho, S., Ferreira, J., Rodrigues, V., and Lopes, M. Source apportionment of air pollution in European urban areas: lessons from the Clair City project. J. Environ. Manage. 2022, 320: 115899. doi:10.1016/j.jenvman.2022.11589.

[2] Chauhan, A. and Pawar, M. Assessment of ambient air quality status in urbanization, industrialization and commercial centers of Uttarakhand (India). New York Science Journal, 2010, 3(7), p. 85-94.

[3] Kaur, R., and Pandey, P. Air Pollution, Climate Change, and Human Health in Indian Cities: A Brief Review. Front. Sustain. Cities, 2021, 3: 705131. doi: 10.3389/frsc.2021.705131.

[4] Kulshreshtha, P., Khare, M. and Seetharaman, P. Indoor air quality assessment in and around urban slums of Delhi city, India. Indoor Air, 2008, 18, p. 488-498.

[5] Barman, S. C., Kumar, N. and Singh, R. Assessment of urban air pollution and its probable health impact. J. Env. Biol., 2010, 31(6), p. 913-920.

[6] Rai, P., Panda, L. L., Chutia, B. M. and Singh, M. M.

Comparative assessment of air pollution tolerance index (APTI) in the industrial (Rourkela) and non-industrial area (Aizawl) of India: an eco-management approach. Afr. J. Environ. Sci. Technol., 2013, 7(10), p. 944-48.

[7] Sahu, C., and Sahu, S. K. Ambient air quality and air pollution index of Sambalpur: a major town in Eastern India. International Journal of Environmental Science and Technology, 2019, 16(12), p. 8217 - 8228.

[8] Pakbin, P., Hudda, N., Cheung, K. L., Moore, K. F. and Sioutas, C. Spatial and temporal variability of coarse (PM10–2.5) particulate matter concentrations in the Los Angeles area. Aerosol Science and Technology, 2010, 44(7), p. 514–52.

[9] Luvsan M., Shie, R., Purevdorj, T., Badarch, L., Baldorj, B. and Chan, C. The influence of emission sources and meteorological conditions on SO2 pollution in Mongolia. Atmospheric Environment, 2012, 61, p. 542–549.

[10] Vedantham, R., Norris, G. and Duvall, R. Receptor and Hybrid Modeling Tools. Encyclopedia of Environmetrics, 2013, Wiley.

[11] Srivastava, A., Sengupta, B., and Dutta, S. A. Source apportionment of ambient VOCs in Delhi City. Science of The Total Environment, 2005, 343(1), p. 207–220.

[12] Jolliffe, I. T. and Cadima, J. Principal Component Analysis: a review and recent development. Phil. Trans. R. Sor. A. 2016, 374: 20150202. https://dx.org/10.1098/rsta.2015.0202.

[13] Mishra, S. P., Sarkar, U., Taraphder, S., Datta, S., Swain, D. P., Saikhom, R., Panda , S. and Laishram, M. Multivariate Statistical Data Analysis- Principal Component Analysis (PCA). International Journal of Livestock Research, 2017, 7(5), p. 60-78.

[14] Gupta, A. K., Karar, K., and Srivastava, A. Chemical mass balance source apportionment of PM10 and TSP in residential and industrial sites of an urban region of Kolkata, India. Journal of hazardous materials, 2007, 142(1–2), p. 279–287.

[15] Hippeli, S. and Elstner, E. F. Effects of air pollutants on man, animals, plants and buildings: mechanisms and dose–response effects. Stud. Environ. Sci., 1993, 55, p. 13–22.

[16] Kaushik, C. P., Ravindra, K. and Yadav, K. Assessment of ambient air quality in urban centers of Haryana (India) in relation to different anthropogenic activities and health risk. Environ. Monit. Assess., 2006, 122(1-3), p. 27-40.

[17] Kelishadi, R. and Poursafa, P. Air pollution and non-respiratory health hazards for children. Arch Med Sci., 2010, 6, p. 483–495.

[18] Pascal, M., Pascal, L., Bidondo, M. L. Cochet, A., Sarter, H., Stempfelet, M. and Wagner, V. A Review of the Epidemiological Methods Used to Investigate the Health Impacts of Air Pollution around Major Industrial Areas. Journal of Environmental and Public Health, 2013, p. 1–17.

[19] CPCB. Comprehensive Environmental Assessment of Industrial Clusters, Central Pollution Control Board, Ministry of Environment and Forests, New Delhi, 2009, p.1-32.

[20] Ekka, S., Sahu, S. K. , Dwivedi, S., Khuman, S. N., Das, S., Gaonkar, O. and Chakraborty, P. Seasonality, atmospheric transport and inhalation risk assessment of polycyclic aromatic hydrocarbons in PM2.5 and PM10 from industrial belts of Odisha, India. Environ. Geochem. Health, 2021, doi: 10.1007/s10653-021-01128-1.

[21] Guttikunda, S. K., Goel, R., and Pant, P. Nature of air pollution, Emission Sources and Management in the Indian Cities. Atmospheric Environment, 2014, 95, p. 501 - 510.

[22] Patel, P. K., Sahu, B. B., Pati, S. S. and Sahu, S. K. Assessment of Ambient Air Quality in and Around Jharsuguda, an Industrial Town of Odisha, India. Journal of Research in Environmental and Earth Sciences, 2024, 10 (1), p. 10-19.

[23] DSHA District Statistical handbook, Angul. Directorate of Economics and Statistics, 2021, Government of Odisha, Bhubaneswar.

[24] CPCB. Guidelines for the measurement of ambient air pollutants (Vol.1). 2011, Central Pollution Control Board, New Delhi, India.

[25] Ziauddin, A. and Siddiqui, N. A. Air quality index (AQI) — a tool to determine ambient air quality. Pollution Research, 2006, 25, p. 885–887.

[26] Shah, M.H., and Shaheen, N. Seasonal behaviours in elemental composition of atmospheric aerosols collected in Islamabad, Pakistan. Atmospheric Research, 2010, 95, p. 210–223.

[27] Singh, N., Yonus, M., Srivastava, K., Singh, S. M. and Panday, V. Monitoring of auto exhaust pollution by road side plant. Environ. Monitor. Ass., 1995, 34, p. 13-25.

[28] Zhou, Y., Cheng, S., Chen, D., Lang, J., Wang, G., Xu, T., Wang, X. and Yao, S. Temporal and Spatial Characteristics of Ambient Air Quality in Beijing, China. Aerosol and Air Quality Research, 2015, 15, p. 1868 - 1880.

[29] NAAQS. National Ambient Air Quality Standard (Central Pollution Control Board, 2009). Notification No. B29016/20/90/PCIL/dated 18th November 2009. CPCB, New Delhi.

[30] Dash, S. K. and Dash, A. K. Assessment of ambient Air quality with reference to Particulate Matter (PM10 and PM2.5) and Gaseous Pollutants (SO2 and NO2) near Bileipada, Joda area of Keonjhar, Odisha, India. Poll Res.,

2015, 34 (4), p. 817 - 824.

[31] Kumari, S., Jain, M. K. and Elumalai, S. P. Assessment of Pollution and Health Risks of Heavy Metals in Particulate Matter and Road Dust Along the Road Network of Dhanbad, India, Journal of Health & Pollution, 2021, 11 (29), p. 01 - 14.

[32] Ghosh, M., Chatterjee, P. N., Pradhan, M. K. and Salony, K. Assessment of Ambient Air quality in Industrial Cluster at Paradip (India) based on Air Quality Index(AQI). Eco. Env. & Cons., 2022, 28 (August Suppl. Issue), p. S104 - S109.

[33] Statheropoulos, M., Vassiliadis, N. and Pappa, A. Principal component and canonical correlation analysis for examining air pollution and meteorological data. Atmos. Environ., 1998, 32 (6), p.1087 - 1095.

[34] Mishra, S. R., Pradhan, R. P., Prusty, B. A. K. and Sahu, S. K. Meteorology drives ambient air quality in a valley: a case of Sukinda Chromite mines, one among the ten most polluted area in the world. Environmental Monitoring and Assessment, 2016, 188(7): 402. doi: 10.1007/s10661-016-5393-1.

[35] Pramod, R., Sahu, C., Basti, S. and Sahu, S. K. Monitoring of Ambient Air Quality around an Industrial Setup in Odisha, India. International Journal of Engineering Science Technology and Research (IJESTR), 2023, 8 (3), p. 01 - 09.

[36] Abdullah, S., Ismail, M., and Ahemed, A. N. Identification of air pollution potential sources through Principal Component Analysis (PCA). International Journal of civil Engineering and Technology, 2018, 9 (7), p. 1435-1442.

[37] Yadav, M., Singh, N. K., Sahu, S. P. and Padhiyar, H. Investigation on air quality of critically polluted industrial city using Multivariate Stastical Method: Way forwarded for future sustainability. Chemosphere, 2021, doi: 10.1016/j.chemosphere.2021.133024.

[38] Vasudha, N. and Rao, P. V. (2022) Air pollution over Hyderabad using Principal Component Analysis (PCA). Journal of Nature Environment and Pollution Technology, 2022, 21(4), p. 1673-1680.

[39] Wahid, N; Latif, M. Suan, L; Dominick, D; Sahani M. and Jaffar, S. Source identification of Particulate matter in a Semi-urban Area of Malaysia using multivariate Technique. Bull. Environ. contam. Toxicol, 2014, 92(3): 317. DOI:10.1007/s00128-014-1201-1.

[40] Zhaoni, Li and Zheng, Jian. Research on Air Quality Analysis Based on Cluster Methods. IOP Conference Series: Earth and Environmental Science, 2021, 898012024. DOI: 10.1088/1755-1315/898/1/012024.