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Statistical Assessment of Environmental Indicators Associated with Ecotourism Activities in Pilibhit Tiger Reserve (PTR), Uttar Pradesh, India

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ABSTRACT

Ecotourism can support conservation financing and rural livelihoods in protected areas, but visitor movement, vehicle traffic and localized resource use may also affect ambient environmental conditions. This study statistically evaluated environmental indicators measured in ecotourism zones of Pilibhit Tiger Reserve (PTR), Uttar Pradesh, India, using a multi source monitoring dataset covering year 2022–2025. The compiled dataset included 1,456 weekly noise observations from 7 selected ecotourism sites, 144 weekly air-quality observations, 144 seasonal water-quality observations from 12 aquatic sites and 72 seasonal climate observations from 6 field locations. Descriptive statistics, Pearson correlation analysis and one-way analysis of variance (ANOVA) were applied to examine temporal variability and inter-parameter relationships. Mean total weekly noise was 57.13 ± 1.98 dB, with higher values in spring than in other seasons. Mean PM2.5 and PM10 concentrations were 91.52 ± 21.68 and 146.16 ± 41.21 µg/m³, respectively. ANOVA indicated significant seasonal differences for PM2.5 ($F = 31.20$, $p < 0.001$) and PM10 ($F = 28.54$, $p < 0.001$). PM2.5 was negatively correlated with wind speed ($r = -0.57$, $p < 0.001$) and temperature ($r = -0.59$, $p < 0.001$). Water quality showed moderate variation with mean pH of 6.97, dissolved oxygen (DO) of 5.72 mg/L, and biological oxygen demand (BOD) of 3.16 mg/L. The results show clear variability in environmental conditions across monitored ecotourism zones. The study supports continued monitoring and adaptive visitor-management measures, while also noting that the observational design identifies association rather than direct causation.

Keywords Ecotourism, Protected areas, Environmental indicators, Assessment, Pilibhit Tiger Reserve.

INTRODUCTION

Protected areas increasingly rely on ecotourism and other forms of nature-based tourism to support conservation, local employment (Acharya 2020) and public engagement (Streimikiene *et al*. 2021). At the same time, tourist movement, vehicle traffic, informal waste generation and localized pressure on shared resources can affect environmental quality if use is not well managed. Recent literature emphasizes that protected areas are now major destinations for nature-based

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tourism and that sustainability outcomes depend on how visitor pressures are monitored and managed (Baloch *et al.* 2023). Environmental pressures reported across protected areas include traffic-related air pollution, elevated noise, solid-waste generation and water-quality stress in high-use recreation zones (Iqbal *et al.* 2025). Pilibhit Tiger Reserve (PTR), Uttar Pradesh in the Terai Arc Landscape of Uttar Pradesh, contains sal forest, grassland, wetland and riverine habitats and has become an important ecotourism destination. Its tourism nodes include safari gates, interpretation points and water-associated visitor sites. Because these areas concentrate human movement and vehicles, routine environmental monitoring can provide a useful evidence base for visitor-management decisions. Ecotourism is widely recognized as a conservation strategy that can generate economic benefits while promoting environmental awareness and supporting sustainable development when managed effectively (Kumar *et al.* 2023). Nevertheless, increasing tourist arrivals in protected areas may also contribute to localized environmental pressures, including deterioration of air quality, increased particulate matter emissions, habitat disturbance and greater demand on natural resources. Studies have shown that ecotourism intensity is associated with elevated concentrations of fine particulate matter ($PM_{2.5}$), highlighting the importance of continuous air quality assessment in ecologically sensitive destinations (Hemmati *et al.* 2020). Similar concerns have been reported from protected landscapes in India, where unmanaged tourism infrastructure and visitor activities have affected ecosystem integrity and environmental quality (Kumar 2022). Advances in environmental monitoring, including the application of statistical tools, R and Python-based analytical approaches, have improved the capacity to evaluate multi-parameter environmental datasets and support evidence based conservation management (Hackenberger *et al.* 2025). Furthermore, maintaining high environmental quality is essential for sustaining the long term economic and recreational value of ecotourism, as demonstrated in ecosystem valuation studies from the Sundarbans (Nobi *et al.* 2021). This study aimed to statistically assess environmental indicators measured in ecotourism-use zones of PTR using multi-year monitoring data. Specifically, the study examined (i) weekly noise patterns across tourism locations, (ii) seasonal variation in particulate air pollution, (iii) relationships between air-quality and meteorological variables and (iv) seasonal characteristics of surface water quality. A key correction in the present manuscript is that findings are interpreted as conditions associated with monitored ecotourism zones rather than direct proof of tourism-driven causation.

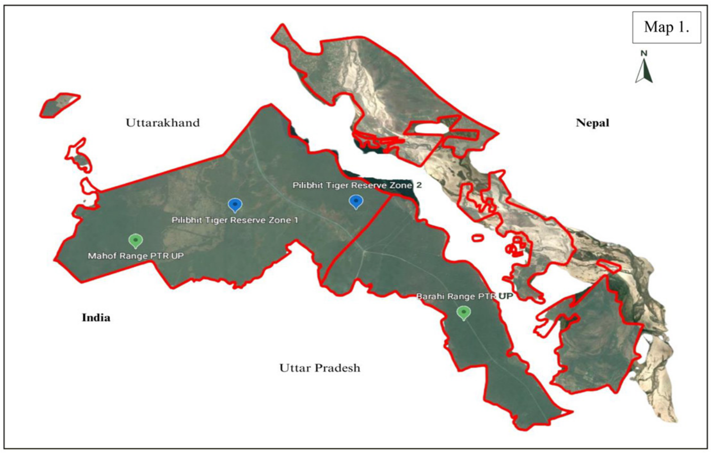
Study area

PTR is located in Uttar Pradesh, India, along the Indo - Nepal border within the Terai Arc Landscape (Map 1). The reserve lies in the upper Gangetic Plain bio geographic province and includes sal forest, tall grassland, swamps and canal and river linked aquatic habitats. Ecotourism activity in the reserve is concentrated around booking centres, access gates, visitor stops and scenic water associated sites. For the present analysis, climate-site coordinates in the monitoring dataset ranged from 28.58° to 28.64° N and 79.78° to 79.85° E, with elevations of approximately 178–185 m above mean sea level.

Map 1 illustrates the forest ranges within Pilibhit Tiger Reserve that encompass the principal ecotourism zones. These ranges form an important part of the reserve's management units and represent areas where ecotourism activities such as safari routes and visitor movement are concentrated. The spatial layout of the ranges highlights the distribution of forest landscapes, wetlands and riverine habitats that support ecotourism infrastructure while maintaining ecological integrity. The map also provides a geographic reference for understanding the zones of ecotourism sites that established across these ranges, enabling ecotourism.

MATERIALS AND METHODS

The analysis integrated four datasets: Similar environmental monitoring approaches have been widely adopted for assessing ecological conditions in protected areas (Minehart *et al.* 2025). A weekly noise-monitoring datasets, weekly air-quality records, seasonal water-quality records and seasonal climate observations. Each dataset has mentioned (in Table 1) & cross checked variable names, site labels and internal consistency before statistical analysis. Noise monitoring comprised 1,456 records repre-

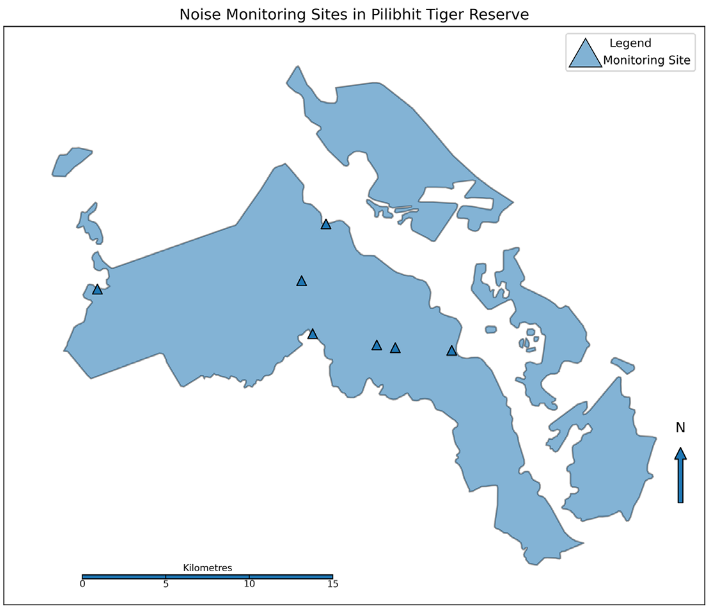


Map 1. Forest ranges of Pilibhit Tiger Reserve showing the distribution of the principal ecotourism.

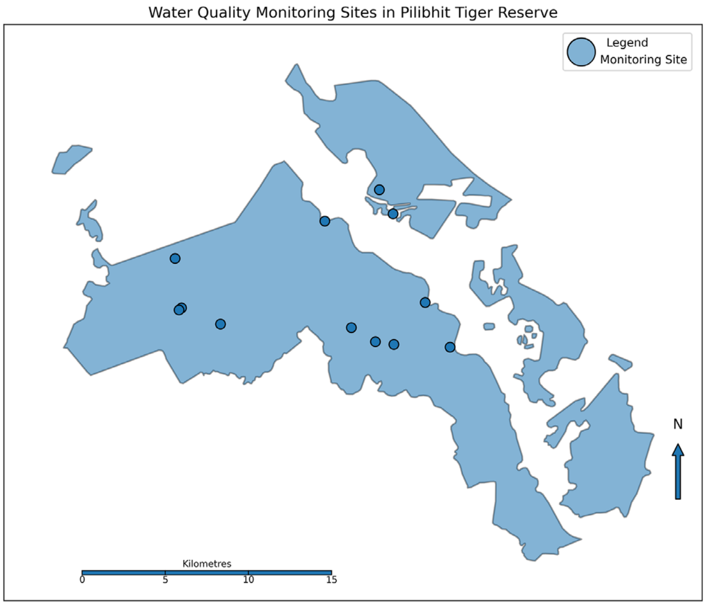
Table 1. Monitoring design used in the study.

Dataset	Sampling frequency	No. of observations	Monitoring locations
Noise	Weekly (2022–2025)	1,456	7
Air quality	Weekly (2022–2025)	144	-
Water quality	Seasonal (2022–2025)	144	12
Climate	Seasonal (2022–2025)	72	6

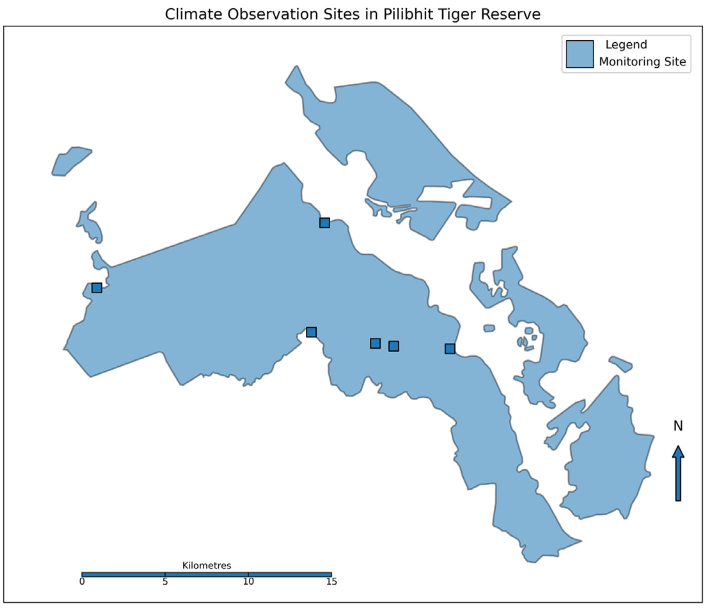
senting weekly observations over 3 annual cycles (2022–2025) across 7 ecotourism location (as shown in map 2). The dataset included species noise, human noise, vehicle noise, water noise and an overall total average noise value. The total average noise metric was used for the principal descriptive and inferential analyses because it represents the combined ambient condition at each sampling point. Air-quality monitoring comprised 144 weekly records and included PM2.5, PM10, NO_2, SO_2, CO, O_3, AQI, temperature, humidity, wind speed and rainfall. Water-quality monitoring comprised 144 seasonal observations collected from 12 aquatic sites over three annual cycles (as shown in map 3). The dataset included pH,



Map 2. Spatial distribution of noise monitoring sites across ecotourism zones of Pilibhit Tiger Reserve, Uttar Pradesh.



Map 3. Spatial distribution of water monitoring sites across ecotourism zones of Pilibhit Tiger Reserve, Uttar Pradesh.



Map 4. Spatial distribution of climate data sites across ecotourism zones of Pilibhit Tiger Reserve, Uttar Pradesh.

dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), TDS and turbidity. Seasonal climate observations comprised 72 records from 6 field locations (as shown in map 4) and were used to summarize site coordinates and contextualize seasonal conditions in the reserve.

Map 2 illustrates the spatial distribution of the seven environmental noise monitoring sites established within the principal ecotourism zones of Pilibhit Tiger Reserve. The selected locations include safari booking centres, visitor access points, and major recreational destinations that experience varying levels of tourist activity and vehicular movement. These monitoring stations were used to collect weekly ambient noise data from 2022 to 2025, providing the spatial framework for evaluating seasonal patterns and statistical variation in acoustic conditions associated with ecotourism activities. Map 3 illustrates the distribution of the water quality monitoring locations selected across major aquatic ecosystems within Pilibhit Tiger Reserve, Uttar Pradesh. The sampling sites include rivers, canals, wetlands, Ponds and other water bodies situated in ecotourism-use areas. These locations were monitored from 2022 to 2025 to evaluate physicochemical parameters including pH, dissolved oxygen, biological oxygen demand, chemical oxygen demand, turbidity and total dissolved solids, providing the spatial basis for assessing water quality variation in ecotourism area throughout the reserve. Map 4 depicts the locations of the seasonal climate monitoring stations established across different ecotourism zones of Pilibhit Tiger Reserve. These observation points were selected to represent the reserve's environmental and topographic variability and were used to record meteorological parameters including temperature, relative humidity, rainfall, wind speed, and other climatic variables during the study period from 2022 to 2025. The monitoring network provides essential spatial information for interpreting seasonal climatic variation and associated environmental conditions within the reserve.

Statistical analysis

Prior to analysis, the datasets were screened for missing values, outliers and consistency of observations. Descriptive statistics including mean, standard deviation (SD), minimum, maximum and sample size (N) were calculated for all environmental variables. One-way Analysis of Variance (ANOVA) was employed to determine whether significant seasonal differences existed in environmental parameters measured across the monitoring period (2022–2025). The independent variable was season, whereas the dependent variables included weekly average noise levels, $PM_{2.5}$ concentrations, PM_{10} concentrations and selected water-quality parameters where applicable. Before conducting ANOVA, the assumptions of normality and homogeneity of variances were evaluated using the Shapiro–Wilk test and Levene's test, respectively. When ANOVA indicated statistically significant differences among seasons ($p < 0.05$), Tukey's Honest Significant Difference (HSD) post hoc test was used to identify which seasonal groups differed significantly. Pearson's correlation coefficient (r) was calculated to evaluate linear relationships among particulate pollutants, meteorological variables, and water-quality parameters. Correlation coefficients ranged from −1 to +1, with statistical significance assessed at $\alpha = 0.05$. Results are presented as mean ± standard deviation unless otherwise stated, and statistical significance was accepted at $p < 0.05$. The selected statistical methods have been extensively applied in environmental monitoring studies to evaluate temporal variation and relationships among environmental variables (Rodríguez-Trejo *et.al.* 2024).

The one-way ANOVA model used in this study is expressed as: F = MSBetween / MSWithin

Where: SBetween = Mean Square between Groups
MSWithin = Mean Square within Groups

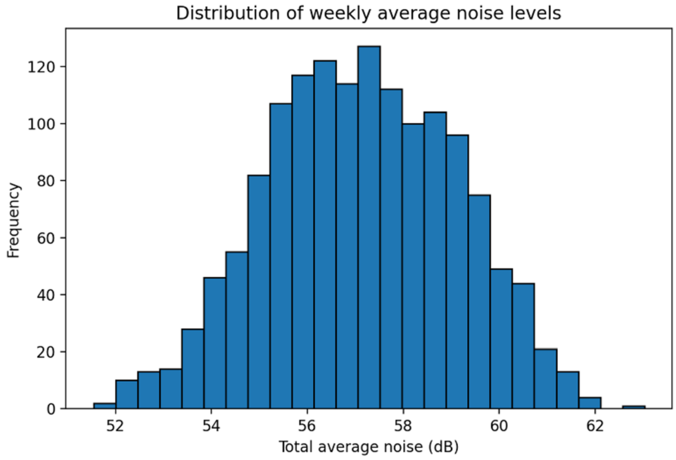
The null hypothesis tested was: H_0: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5$ (μ represent mean of group)
Where: μ_1 = Group 1, μ_2 = Group 2 , μ_3 = Group 3 , μ_4 = Group 4 , μ_5 = Group 5

It means, there is no significant seasonal difference among the measured environmental variables.

RESULTS

Noise pollution

Across all 1,456 weekly observations, total average noise ranged from 51.54 to 63.03 dB, with a mean of 57.13 ± 1.98 dB as shown in Table 2. The highest mean site-level noise was recorded at Mahoff Gate Safari Booking Center (57.92 dB), followed by Mustafabad Safari Booking Center (57.83 dB). Seasonal averages were highest in spring (58.94 dB) and winter (57.98 dB), and lower in autumn (55.76 dB) and summer (55.77 dB). Seasonal differences in weekly total noise were statistically significant ($F = 473.52$, df = 4,1451, $p < 0.001$). Similar seasonal patterns of visitor-generated noise have been reported in protected areas worldwide (Potvin *et al.* 2024).



Graph 1. Distribution of weekly total average noise levels in monitored ecotourism zones.

Graph 1 illustrates the distribution of ambient noise levels recorded along major ecotourism routes within PTR. The results indicate moderate variability in sound intensity, with most observations concentrated around the mean noise level. Occasional higher values correspond to periods of increased tourist activity and safari vehicle movement. The distribution suggests that noise levels remain within a relatively narrow range across monitoring sites, although localized peaks may occur during peak visitation periods. These findings highlight the influence of ecotourism activities on acoustic conditions and emphasize the importance of monitoring noise minimize potential disturbances to PTR.

Air quality and seasonal variation

The weekly air-quality dataset (n = 144) showed mean concentrations of 91.52 ± 21.68 µg/m³ for PM 2.5 and 146.16 ± 41.21 µg/m³ for PM10. Seasonal means indicated that winter had the highest average PM2.5 (105.54 µg/m³) and PM10 (183.18 µg/m³), whereas summer had the lowest values for both pollutants. These findings agree with previous studies demonstrating greater particulate accumulation during cooler seasons due to reduced atmospheric dispersion (Amesho *et al.* 2021). One-way ANOVA (as depicted in Table 3) confirmed significant seasonal differences for PM 2.5 (F = 31.20, df = 4,139, p < 0.001) and PM10 (F = 28.54, p < 0.001).

Table 2. Descriptive statistics for weekly total average noise.

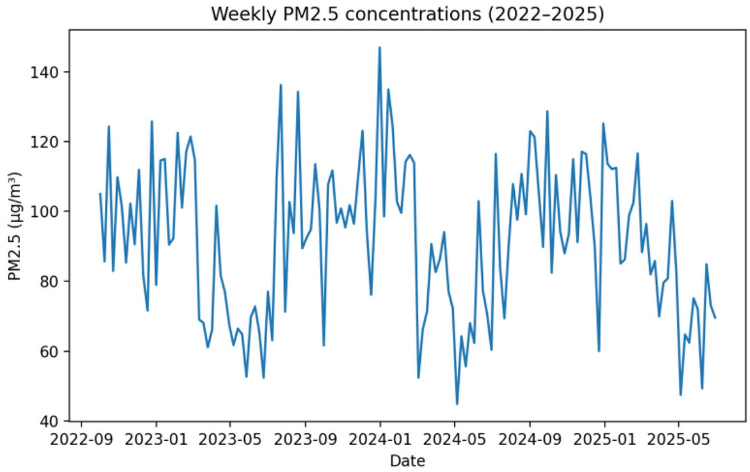
Mean (dB)	SD	Min	Max	N
57.13	1.98	51.54	63.03	1,456

Pearson correlation analysis demonstrated a significant negative relationship between $PM_{2.5}$ concentration and wind speed ($r = -0.57$, $p < 0.001$) as well as temperature ($r = -0.59$, $p < 0.001$). Conversely, $PM_{2.5}$ exhibited a significant positive association with relative humidity ($r = 0.53$, $p < 0.001$). PM_{10} also showed a significant negative correlation with wind speed ($r = -0.58$, $p < 0.001$). Comparable relationships between particulate matter and meteorological variables have been documented in recent environmental monitoring studies (Puig and Darbra 2024). These patterns suggest that seasonal meteorology strongly influences pollutant accumulation and dispersion in the monitored landscape.

The above Graph 2 presents the temporal variation in PM2.5 concentrations. The data show noticeable fluctuations across different seasons. Elevated concentrations were generally observed during

Table 3. ANOVA results for seasonal variation in particulate pollution.

Parameter	df value	F value	p value
PM2.5	4,139	31.20	<0.001
PM10	4,139	28.54	<0.001

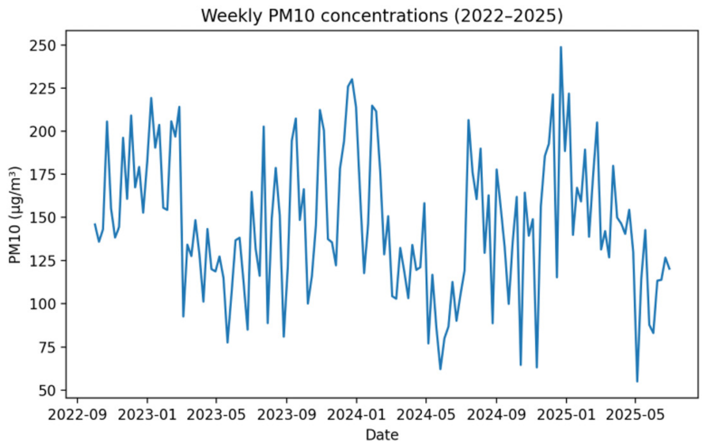


Graph 2. Weekly PM 2.5 concentrations from 2022 to 2025.

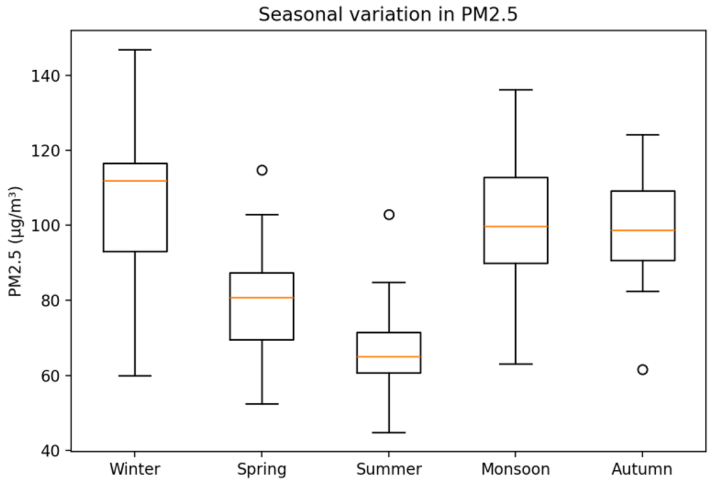
dry periods, while relatively lower values occurred during the monsoon season. This pattern reflects the influence of meteorological factors such as rainfall, humidity and wind speed on particulate matter dispersion. Rainfall events likely contributed to the removal of airborne particles through wet deposition, while dry seasons allowed accumulation of fine particulate.

Graph 3 illustrates the variation in PM10 concentrations throughout the study period. PM10 levels exhibited clear temporal variability influenced by seasonal conditions. Higher concentrations were typically associated with dry weather conditions and increased vehicular movement within ecotourism zones. During the monsoon season, particulate concentrations declined due to atmospheric cleansing processes. It indicates that both anthropogenic activities and climatic factors contribute to variations in particulate pollution within the reserve.

Graph 4 shows the relationship between dissolved oxygen (DO) and biological oxygen demand (BOD) in water sites. The results indicate an inverse relationship between these two parameters, where higher BOD values correspond to lower dissolved oxygen concentrations. This pattern is consistent with established ecological principles, as increased microbial decomposition of organic matter consumes dissolved oxygen in aquatic systems. The observed relationship provides insight into the ecological condi-



Graph 3. Weekly PM10 concentrations from 2022 to 2025.

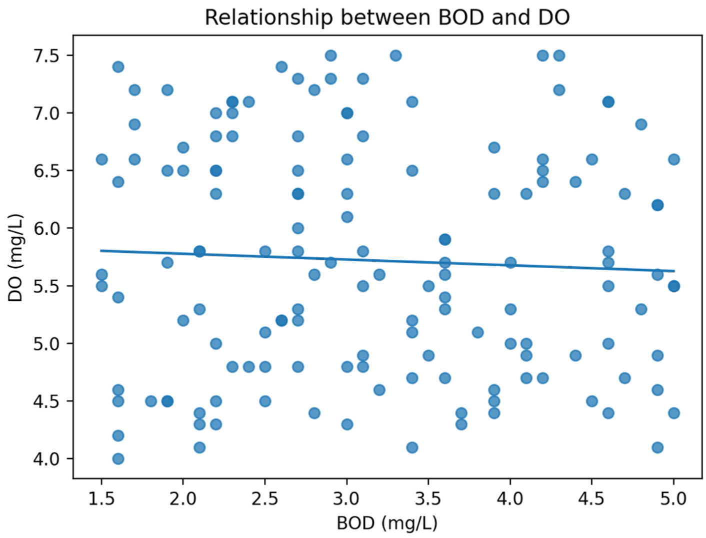


Graph 4. Seasonal variation in PM 2.5 concentrations.

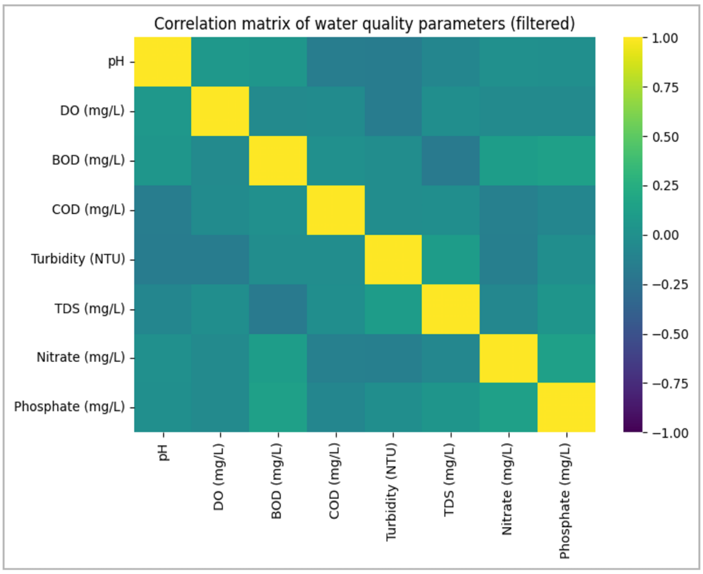
tion of water bodies within the reserve and highlights the importance of monitoring organic indicators.

Water quality

The seasonal water-quality dataset (n = 144) showed (in Graph 5) an average pH of 6.97 ± 0.31, DO of 5.72 ± 1.00 mg/L, and BOD of 3.16 ± 1.03 mg/L. Mean COD was 14.85 mg/L, turbidity was 6.70 NTU and TDS was 311.30 mg/L. Pearson correlation analysis indicated weak linear relationships among most water-quality variables. For example, the association between dissolved oxygen (DO) and biological oxygen demand (BOD) was weak and statistically non-significant (r = –0.05, p = 0.538), indicating that seasonal variability rather than a consistent oxygen-demand gradient explained most of the observed variation. For example, the correlation between DO and BOD was small and not statistically significant (r = -0.05, p = 0.538). This suggests that the monitored aquatic sites experienced moderate variation but not a strong, system-wide linear oxygen-demand gradient across



Graph 5. Relationship between biological oxygen demand (BOD) and dissolved oxygen (DO).



Graph 6. Correlation matrix of major water-quality variables.

seasons and locations. Similar observations have been reported for protected freshwater ecosystems where seasonal hydrological processes exert stronger influence than tourism intensity.

The above Graph 5 depicts a seasonal comparison of PM2.5 concentrations across summer, monsoon and winter periods. The box plot illustrates differences in median values and variability between seasons. Higher concentrations were generally recorded during winter and summer months, while the monsoon season exhibited comparatively lower particulate levels. The reduced concentrations during monsoon are likely associated with increased precipitation and atmospheric mixing, which facilitate the removal and dispersion of airborne pollutants. Seasonal variability in particulate matter highlights the role of climatic conditions in shaping air quality patterns within protected landscapes.

Graph 6 displays the correlation matrix among selected environmental parameters, including particulate matter concentrations, meteorological variables and water quality indicators of the selected water bodies. The analysis reveals varying degrees of positive and negative relationships among the variables. Notably, particulate matter concentrations show negative correlations with wind speed, suggesting that stronger winds enhance pollutant dispersion. Conversely, some parameters exhibit moderate positive relationships, indicating potential interactions among environmental variables. The correlation analysis provides a broader understanding of the complex environmental dynamics influencing ecological conditions.

DISCUSSION

The present study statistically evaluated environmental indicators associated with ecotourism zones in PTR using descriptive statistics, one-way ANOVA and Pearson correlation analysis. The results demonstrate measurable seasonal and spatial variability in environmental conditions, highlighting the importance of continuous environmental monitoring for sustainable ecotourism management. Although the observational design does not permit direct causal attribution, the statistical analyses provide robust evidence of associations between environmental conditions and monitored ecotourism areas.

Descriptive statistical analysis revealed moderate variation in ambient noise levels across the monitored ecotourism sites, with an overall mean of 57.13 ± 1.98 dB. One-way ANOVA further confirmed that seasonal differences in weekly noise levels were highly significant ($F = 473.52$, $p < 0.001$), indicating that acoustic conditions varied substantially throughout the year. Higher noise levels recorded during spring and winter coincided with periods of greater visitor activity, suggesting that seasonal tourism intensity and associated vehicle movement may contribute to localized increases in ambient sound levels. Similar patterns of visitor-related noise have been reported in protected areas worldwide, where elevated anthropogenic noise has been associated with behavioral changes in wildlife and reduced habitat quality.

Air-quality analysis produced the strongest statistical evidence of seasonal environmental variation. Descriptive statistics showed mean concentrations of 91.52 ± 21.68 µg/m³ for $PM_{2.5}$ and 146.16 ± 41.21 µg/m³ for PM_{10}. One-way ANOVA demonstrated highly significant seasonal differences for both pollutants ($PM_{2.5}$: $F = 31.20$, $p < 0.001$; PM_{10}: $F = 28.54$, $p < 0.001$), confirming that particulate concentrations differed significantly among seasons. These findings indicate that climatic conditions play an important role in determining air quality within the reserve. Higher winter concentrations are consistent with reduced atmospheric mixing, lower boundary layer height and limited pollutant dispersion during cooler months, as reported in previous environmental monitoring studies.

Pearson correlation analysis further clarified the relationships between air pollutants and meteorological variables. $PM_{2.5}$ exhibited significant negative correlations with wind speed ($r = –0.57$, $p < 0.001$) and temperature ($r = –0.59$, $p < 0.001$), whereas a significant positive correlation was observed with relative humidity ($r = 0.53$, $p < 0.001$). Similarly, PM_{10} showed a negative relationship with wind speed ($r = –0.58$, $p < 0.001$). These statistically significant correlations indicate that meteorological conditions strongly influence particulate dispersion and accumulation within ecotourism landscapes. Increased wind speed promotes atmospheric mixing and pollutant dilution, while cooler temperatures and higher humidity favor the persistence of suspended particulate matter.

Water quality parameters exhibited comparatively lower variability than air quality indicators. Descriptive statistics indicated that pH, dissolved oxygen, biological oxygen demand, chemical oxygen demand, turbidity and total dissolved solids generally remained within moderate ecological ranges during the monitoring period. Pearson correlation analysis revealed only a weak and statistically non-significant relationship between dissolved oxygen and biological oxygen demand ($r = –0.05$, $p = 0.538$), suggesting that seasonal hydrological processes, natural environmental variability, and site-specific ecological conditions exert greater influence on aquatic ecosystems than a consistent organic pollution gradient. These findings are comparable with observations from other protected freshwater ecosystems where seasonal hydrology rather than tourism pressure primarily governs water quality dynamics.

Overall, the statistical analyses collectively indicate that environmental conditions within the monitored ecotourism zones exhibit clear seasonal variability, particularly for ambient noise and particulate air pollution. The significant ANOVA results and Pearson correlation coefficients demonstrate that environmental parameters respond strongly to seasonal meteorological conditions while also reflecting localized patterns associated with ecotourism infrastructure and visitor movement. These findings support the implementation of adaptive management measures, including seasonal visitor regulation, improved traffic management near safari entry points, routine air-quality monitoring, and continued surveillance of aquatic ecosystems to minimize potential environmental impacts.

Despite the significant statistical relationships observed, the findings should be interpreted cautiously. The study relied on environmental monitoring data collected from ecotourism use zones and did not include control sites with minimal visitor activity or direct measures of tourist intensity. Consequently, the statistical analyses identify associations rather than direct cause-and-effect relationships between ecotourism activities and environmental conditions. Future studies integrating visitor counts, traffic volume, wildlife response data and advanced multivariate statistical models would provide a more comprehensive understanding of the ecological effects of ecotourism in protected landscapes.

CONCLUSION

This study provides a statistical evaluation of key environmental indicators associated with ecotourism activities in Pilibhit Tiger Reserve. Analysis of noise levels, particulate air pollution (PM2.5 and PM10) and water quality parameters revealed measurable environmental variability across seasons. Significant seasonal variation in particulate matter concentrations indicates the influence of climatic factors such as rainfall and wind speed on pollutant dispersion. Noise levels showed moderate fluctuations along ecotourism routes, while water quality parameters remained largely within acceptable ecological ranges with minor spatial variation. These findings highlight the importance of continuous environmental monitoring to support sustainable ecotourism management and conservation planning in protected areas (Reymond 2022). These findings support recommendations for sustainable ecotourism planning and adaptive environmental management in protected areas (Lyu *et al.* 2025).

Limitations

Despite providing useful insights, this study has several limitations. Environmental indicators were evaluated using selected parameters and additional ecological variables such as wildlife disturbance, vegetation response and soil qualities were not included. Monitoring locations were limited to major tourism zones, which may not fully represent environmental conditions across the entire reserve. Temporal coverage, although spanning multiple seasons, may still be insufficient to capture long-term environmental trends or extreme climatic events. Furthermore, statistical analyses focused on basic correlation and variance methods; advanced modeling approaches could provide deeper understanding of complex environmental interactions associated with tourism activities in protected landscapes.

SDGs

This research paper successfully addresses multiple Sustainable Development Goals (SDGs) through its content, including Goal 11: Sustainable Cities and Communities, Goal 13: Climate Action, Goal 14: Life below Water, Goal 15: Life on Land, and Goal 17: Partnerships for the Goals.

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REFERENCES

Acharya, P. (2020). Ecotourism and its impact on local community in Sauraha, Chitwan National Park, Nepal. *Scholars Journal of ties and Social Sciences,* 8(7), 353-360.

Amesho, K. T., Lin, Y. C., Gong, Z. W., Chou, F. C., Cheng, P., Wang, T. N., & Lee, C. H. (2021). Assessment of PM2. 5 chemical omposition and air quality monitoring: implications of air pollutants emissions from a night market in Kaohsiung City, Taiwan. *Aerosol and Air Quality Research,* 21(12), 210206.

Baloch, Q. B., Shah, S. N., Iqbal, N., Sheeraz, M., Asadullah, M., Mahar, S., & Khan, A. U. (2023). Impact of tourism development upon environmental sustainability: a suggested framework for sustainable ecotourism. *Environmental Science and Pollution Research,* 30(3), 5917-5930.

Hackenberger, B. K., Djerdj, T., & Hackenberger, D. K. (2025). Advancing environmental monitoring through AI: applications of R and Python. In *Environmental Resilience and Management Annual Volume* 2025. IntechOpen.

Hemmati, F., Dabbaghi, F., & Mahmoudi, G. (2020). Relationship between international tourism and concentrations of PM 2.5: an ecological study based on WHO data. *Journal of Environmental Health Science and Engineering,* 18(2), 1029-1035.

Streimikiene, D., Svagzdiene, B., Jasinskas, E., & Simanavicius, A. (2021). Sustainable tourism development and competitiveness: The systematic literature review. *Sustainable development,* 29(1), 259-271.

Iqbal, S., Ali, A., Umer, M., & Zhongjun, W. (2025). Integrated assessment of tourism driven ecological stressors in mountain ecosystems of Swat Valley Pakistan. *Journal of Cleaner Production,* 521, 146198.

Kumar, S., Hasija, N., Kumar, V., & Sageena, G. (2023). Ecotourism: a holistic assessment of environmental and socioeconomic effects towards sustainable development. *Current World Environment*, 18(2), 589 – 607.

Kumar, V. (2022). Environmental Impacts of Ecotourism Developments In Great Himalayan National Park, Kullu, Himachal Pradesh. *International Journal of Multidisciplinary Educational Research,* 11, 24-32.

Lyu, H., Yang, X., & Ji, X. (2025). Overtourism to Equilibrium: A System Dynamics & Multi-Objective Model for Sustain able Destinations. *arXiv preprint arXiv:*2511.14288.

Minehart, K., D'Antonio, A., & Wilkins, E. (2025). The mountains are calling, but will visitors go? Modeling the effect of weather and air quality on visitation to Pacific Northwest parks and protected areas using mobile device data. *PLOS Climate,* 4(4), e0000537.

Nobi, M. N., Sarker, A. R., Nath, B., Røskaft, E., Suza, M., & Kvinta, P. (2021). Economic valuation of tourism of the Sundarban Mangroves, Bangladesh. *Journal of Ecology and The Natural Environment,* 13(4), 100-109.

Potvin, D. A., Gilby, B. L., Anderson, M. K., & Watson, N. I. (2024). Effects of temporal variations in ecotourist noise on an avian community: a case study from a UNESCO world heritage site. *Journal of Ecotourism,* 23(3), 328-346.

Puig, M., & Darbra, R. M. (2024). Innovations and insights in environmental monitoring and assessment in port areas. *Current Opinion in Environmental Sustainability,* 70, 101472.

Reymond, D., Duvernay, D., Ely, F., & Glotin, H. (2022). The bioacoustic proof of the effects of raising awareness of noise pollution among visitors to the Port Cros National Park using binding communication. *arXiv preprint arX iv:*2203.16899.

Rodríguez-Trejo, A., Böhnel, H. N., Ibarra-Ortega, H. E., Salcedo, D., González-Guzmán, R., Castañeda-Miranda, A. G., & Chaparro, M. A. (2024). Air quality monitoring with low-cost sensors: A record of the increase of pm2. 5 during christmas and new year's eve celebrations in the city of Queretaro, Mexico. *Atmosphere,* 15(8), 879.