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Comparative Study of Different Types of Pollution and its Effect on Biodiversity across Balasore District of Odisha

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ABSTRACT

Pollution represents a growing yet frequently overlooked environmental pressure affecting land-based ecosystems, especially in fast-developing areas like Balasore district. This investigation offers a comparative examination of various pollution forms, mainly dust (airborne particulate matter) and water pollution, and assesses their joint impacts on plant diversity in urban, rural, roadside, agricultural, and semi-natural habitats throughout the district. Variations in dust deposition across space and time result from human-induced activities including vehicle emissions, construction activities, industrial processes, and unpaved roads, whereas water pollution stems from agricultural runoff, household waste discharge, and local industrial effluents. Dust develops on leaf surfaces greatly modifies plant physiological processes by limiting light capture, blocking stomatal openings, and interfering with transpiration and photosynthesis. Conversely, water pollution impacts plants via root absorption of pollutants including heavy metals, surplus nutrients, and organic compounds, resulting in metabolic disruptions and oxidative stress. The comparative method shows that, whereas dust pollution mainly affects aerial portions of plants and their photosynthetic performance, water pollution produces widespread consequences by disrupting internal biochemical pathways and nutrient interactions.

Prolonged exposure to these pollutants leads to diminished chlorophyll and carotenoid levels, impaired ascorbic acid content, stunted growth, and reduced reproductive success. These physiological stresses lead to ecological impacts, such as diminished species diversity, changes in species makeup, and the prevalence of species that tolerate pollution. Differences in plant diversity are especially noticeable along pollution gradients, where roadside and urban-industrial zones exhibit much lower diversity than less disturbed rural and semi-natural habitats. Moreover, alterations in soil characteristics caused by pollution including shifts in pH levels, nutrient disequilibrium, and buildup of heavy metals additionally affect the establishment of plants and the structure of communities. The interplay of dust and water pollution frequently generates synergistic impacts, heightening total environmental pressure and hastening the decline of biodiversity. This research underscores the susceptibility of plant diversity in Balasore district to various pollution pressures and stresses the need for comprehensive environmental monitoring and management approaches. Additionally, it highlights important gaps in research, especially the requirement for location-specific investigations that integrate physiological, biochemical, and ecological evaluations to gain a deeper insight into the effects of pollution. These insights are vital for devising robust conservation plans and maintaining the sustainable operation of ecosystems amid rising human-induced stresses.

INTRODUCTION

Environmental pollution has become one of the greatest dangers to biodiversity worldwide, especially in developing nations where fast urban expansion, industrial development, and intensified farming are taking place at the same time. Human-induced activities release various pollutants into natural ecosystems, thus disturbing ecological equilibrium and endangering the existence of numerous species. Within the diverse elements of biodiversity, plant diversity holds a pivotal role owing to its essential function in upholding the structure, operation, and equilibrium of ecosystems. Plants function as primary producers, help control biogeochemical cycles, supply habitats and nourishment to other organisms, and aid in regulating the climate. Due to their stationary lifestyle and direct susceptibility to environmental factors, plants exhibit high sensitivity to ecological disruptions and are broadly acknowledged as reliable bioindicators of environmental health. Many environmental studies have shown that pollutants, especially those in water and dust, have a major impact on the makeup of plant communities, species diversity, and functional traits, frequently causing ecological decline and diminished ecosystem resilience. (Farmer, 1993; Grantz, Garner, & Johnson, 2003).

Water pollution constitutes one of the most widespread types of environmental damage, mainly resulting from the release of untreated household sewage, farm runoff loaded with fertilizers and pesticides, and industrial waste laden with hazardous chemicals. These contaminants add too many nutrients, particularly nitrogen and phosphorus, to water-based ecosystems, causing eutrophication. Eutrophication leads to algal blooms, depletion of dissolved oxygen, and disruption of aquatic food webs, ultimately impacting both aquatic and terrestrial plant communities. Besides nutrient enrichment, the existence of heavy metals like cadmium (Cd), lead (Pb), mercury Hg), and arsenic (As) represents significant threats to plant health. These metals build up in plant tissues and disrupt vital physiological functions like photosynthesis, respiration, and nutrient absorption. Heavy metal toxicity triggers oxidative stress through the production of reactive oxygen species (ROS), which harm cellular structures, proteins, lipids, and nucleic acids, thus hindering plant growth and development (Nagajyoti et al., 2010) As a result, polluted environments frequently show a drop in plant species diversity, where sensitive species are supplanted by just a few tolerant ones, resulting in diminished ecological complexity and stability(Carpenter et al., 1998; Smith et al., 1999).

Water pollution also has significant impacts on wetland and riparian ecosystems, which rank among Earth's most productive and biologically rich habitats. These ecosystems are especially susceptible because of their location at the boundary between land and water habitats. Nutrient enrichment and pollution can change species makeup by giving an advantage to fast-growing pollution-tolerant species at the expense of native, sensitive plants. This change frequently leads to the homogenization of plant communities and a decline in biodiversity, thus undermining ecosystem services like water purification, flood control, and habitat provision (Mitsch & Gosselink, 2000). Moreover, irrigating with contaminated water can impair soil quality, diminish microbial activity, and negatively influence plant development in farming systems, thus affecting biodiversity and food security.

Dust pollution constitutes another major environmental stressor, especially in urban, roadside, and industrial areas. It comes from various sources, such as vehicle emissions, building projects, mining activities, and bare soil areas. Dust particles accumulate on leaf surfaces, creating a layer that disrupts vital physiological functions. This deposit diminishes light penetration, blocks stomatal openings, and hinders gaseous exchange, resulting in reduced photosynthetic efficiency and transpiration rates. Consequently, plants display diminished chlorophyll levels, hindered development, and heightened physiological strain. Extended contact with dust pollution has been demonstrated to greatly diminish the richness and variety of plant species, especially impacting vulnerable groups like herbs, epiphytes, and lichens, while encouraging the prevalence of more resilient species (Singh & Rao, 1981; Sharma & Roy, 1995). Besides its physical impacts, dust frequently includes hazardous materials like heavy metals, sulfates, and nitrates, which can be taken up by plant tissues and worsen stress conditions even more. These pollutants could also trigger morphological and anatomical changes in plants, such as decreased leaf area, thicker cuticles, and modified stomatal density, serving as survival mechanisms in harsh environmental conditions (Prusty et al., 2005)

On a broader ecological scale, environmental pollution not only affects individual plant species but also influences ecosystem processes and interactions. Changes in plant diversity can disrupt trophic relationships involving herbivores, pollinators, and decomposers, thereby affecting nutrient cycling, energy flow, and overall ecosystem functioning. Such disruptions can reduce ecosystem resilience and increase vulnerability to further environmental stressors (Chapin et al.,2000). These effects hold special significance in areas like the Balasore district in Odisha, where varied land-use practices such as urban zones, farming lands, industrial sites, and coastal habitats generate intricate gradients of pollution. These gradients result in spatial and temporal variations in environmental conditions, leading to heterogeneous vegetation patterns and varying levels of biodiversity across the region. Although it holds great ecological importance, few thorough comparative studies have assessed the joint impacts of water and dust pollution on plant diversity in this region.

Plants subjected to environmental pollution experience various physiological and biochemical alterations that indicate their reactions and adaptive strategies to stress. Examining biochemical parameters like chlorophyll content, carotenoids, ascorbic acid, pH, and leaf dust load offers important insights into plant health and resilience to environmental stress (Rai, 2016). Chlorophyll, the main pigment for photosynthesis, primarily occurs in two variants: chlorophyll a and chlorophyll b. Chlorophyll plays a direct role in transforming light energy into chemical energy, whereas chlorophyll b functions as a supplementary pigment that broadens the range of light absorption. Chlorophyll concentration serves widely as a measure of photosynthetic performance and plant health, and it is typically determined through the spectrophotometric technique created by Arnon (1949). Environmental contaminants, especially particulate matter and gaseous pollutants, can impair chlorophyll and harm chloroplast structures, resulting in diminished photosynthetic efficiency and overall plant productivity (Singh & Rao, 1983). Carotenoids are vital for photoprotection, as they dissipate surplus light energy and eliminate reactive oxygen species, thus averting oxidative harm to chlorophyll molecules. The method proposed by Lichtenthaler (1987) is the one commonly used to perform their estimation. Likewise, ascorbic acid (vitamin C) serves as a key non-enzymatic antioxidant, shielding plants from oxidative stress triggered by environmental pollutants. Elevated concentrations of ascorbic acid are frequently linked to greater resistance to pollution, since it assists in neutralizing reactive oxygen species and preserving cellular integrity (Keller & Schwager, 1977; Tripathi & Gautam, 2007). The equilibrium between reactive oxygen species production and the plant's antioxidant defense system plays a crucial role in determining its tolerance to environmental stress (Gill & Tuteja, 2010). Leaf pH represents a key factor that affects plant metabolism, enzyme function, and nutrient accessibility. Variations in pH could signal environmental stress and may greatly impact physiological functions. Tracking changes in pH can thus offer important insights into how plants react to pollution (Jackson, 1973). Dust accumulation on foliage is commonly employed as a measure of pollution intensity, since it impairs photosynthesis and vegetation development by hindering light uptake and gas exchange. Measuring the amount of dust on leaves offers understanding of plant resilience and the severity of environmental contamination (Farmer, 1993). Incorporating these biochemical factors has resulted in the creation of metrics like the Air Pollution Tolerance Index (APTI), which provides a thorough evaluation of how plants react to environmental pressures and aids in pinpointing pollution-resistant varieties ideal for city and factory settings (Singh & Rao, 1983; Rai, 2016). From a regional perspective, the Balasore district offers an ideal setting for studying the combined effects of water and dust pollution due to its diverse environmental conditions. Roadside areas are affected highly by vehicular emissions and dust deposition, agricultural lands are influenced by fertilizers and pesticides and coastal regions experience additional stress from salinity and industrial activities. These varying environmental conditions creates distinct ecological niches and influence plant diversity and distribution patterns across the region. Understanding how the plant communities respond to these environmental gradients is essential for the biodiversity conservation and sustainable ecosystem management. Comparative studies across different habitats can help identify pollution-tolerant and sensitive species, assess ecosystem health, and develop strategies for ecological restoration and environmental management. The uses of plants as bioindicators provides cost-effective and reliable method for monitoring environmental quality, as it reflects the cumulative effects of pollution over time. Such approaches are particularly valuable in developing regions where advanced monitoring technologies may not be available readily. Environmental pollution, particularly water and dust pollution, has profound impacts on plant diversity, physiological processes, and ecosystem functioning. The evaluation of biochemical parameters such as chlorophyll, carotenoids, ascorbic acid, pH, and dust load provides a comprehensive understanding of plant responses to environmental stress and their potential as bioindicators. The present study aims to evaluate these parameters in selected plant species and to comparatively assess the influence of water and dust pollution on plant diversity across different habitats in the Balasore district. The study demonstrates which contribute to the development of effective conservation strategies, support sustainable environmental management, and enhance our understanding of plant environment interactions in polluted ecosystems. The objectives of the present study are to assess and compare the levels of different types of pollution (water, and dust pollution) in selected areas of Balasore District. Also evaluate the effects of these pollution types on plant diversity across Balasore District.

MATERIAL & METHODS

Study Area and Site Selection

The present investigation was carried out in the Balasore district of Odisha, India, using two geographically and ecologically distinct locations for plant and water sample collection. Plant samples were collected from the industrial region of Balgopalpur, Remuna (21.5° N, 86.95° E) and the rural village area of Srijung, Balasore (21.39° N, 86.93° E). Similarly, water samples were collected from Chakulia, Remuna (21.5284° N, 86.8791° E) and Kuanpur, Remuna (21.5435° N, 86.9122° E). These sites were selected to compare the environmental conditions prevailing in industrial and rural ecosystems and their influence on plant physiological responses and water quality characteristics.

Climatic Conditions and Duration of Study

The study was conducted from January 2026 to March 2026, and all samples were collected between 9:00 AM and 12:00 PM to maintain uniformity in environmental conditions during sampling. The climate of Balasore during this period gradually changed from winter to warm and dry spring conditions. Daytime temperatures ranged between 25°C and 35°C, while relative humidity varied from 60% to 72%. Rainfall during the study period was minimal, ranging from 15–35 mm, indicating dry climatic conditions suitable for studying pollution stress responses in plants.

Plant Sample Collection and Identification

Fresh and healthy plant samples were collected from different locations of Balasore district following standard botanical collection procedures. The collected specimens were carefully packed in labelled sample bags to avoid contamination and misidentification. Plant identification was carried out in the Department of Botany, Fakir Mohan University, using standard floristic manuals including *The Flora of Orissa* and *Botany of Bihar and Orissa*. A total of ten plant species belonging to different families were selected for the present study based on their abundance and ecological significance in the study area.

Water Sample Collection

Water samples were collected from five different aquatic sources representing varied pollution gradients, namely groundwater (tube well), surface water (pond and river), domestic supply (tap water), and wastewater (drain water). Sampling was conducted at both Chakulia and Kuanpur sites to compare water quality conditions between the selected locations. The collected samples were transferred into clean sterile containers and transported immediately to the laboratory for further physicochemical analysis.

Preparation of Plant Samples

Healthy and mature leaves collected from the selected plant species were thoroughly washed under running tap water to remove adhering soil and dust particles, followed by rinsing with distilled water. The washed leaves were dried gently using tissue paper, and uniform leaf segments were prepared aseptically using sterilized blades to avoid contamination. Approximately 1 g of leaf tissue from each sample was weighed accurately using a calibrated digital balance for biochemical analyses.

Homogenization and Preparation of Leaf Extract

The measured leaf segments were transferred into a pre-chilled mortar and pestle and homogenized properly. Leaf extraction was carried out by grinding the tissues in 10 ml of 80% acetone until a smooth and uniform extract was obtained. The prepared extracts were subsequently used for the estimation of chlorophyll and carotenoid contents.

Estimation of Chlorophyll Content

Chlorophyll content was estimated following the spectrophotometric method described by Arnon (1949) and modified by Thimmaiah (1999). Fresh leaf samples (0.1 g) were homogenized with 80% acetone and centrifuged at 5000 rpm for 5 minutes. The supernatant was collected and the final volume was adjusted with 80% acetone. Absorbance was recorded at 663 nm and 645 nm using a UV–Visible spectrophotometer against acetone blank. Chlorophyll a, chlorophyll b, and total chlorophyll contents were calculated using standard equations based on absorbance values and expressed in mg/g tissue weight.

Estimation of Carotenoid Content

Carotenoid content was determined according to the method of Lichtenthaler (1987). Approximately 0.1 g of fresh leaf tissue was homogenized in 80% acetone and centrifuged at 5000 rpm for 5 minutes. The absorbance of the extract was measured at 470 nm using a UV–Visible spectrophotometer. Total carotenoid content was calculated using the standard formula incorporating absorbance values and chlorophyll concentrations. This method is widely used for assessing photosynthetic pigments and plant responses under environmental stress conditions.

Dust Accumulation Analysis

Dust accumulation on leaf surfaces was estimated using the gravimetric method described by Prusty et al. (2005). Initially, leaves covered with dust particles were weighed to obtain the dust-loaded weight (W_2). The dust particles were then carefully removed using a soft brush, and the leaves were weighed again to obtain dust-free weight (W_1). Leaf surface area was measured using the graph paper tracing method. Dust accumulation per unit leaf area was calculated using the difference between W_2 and W_1 divided by the total leaf area and expressed as mg/cm^2.

Estimation of Ascorbic Acid Content

Ascorbic acid content was estimated using the 2,6-dichlorophenol indophenol (DCPIP) colorimetric method described by Sadasivam and Manickam (2008). Fresh leaf tissue (0.25 g) was homogenized with extracting solution containing oxalic acid and EDTA. The homogenate was centrifuged at 6000 rpm for 15 minutes, and the supernatant was collected. One millilitre of the extract was mixed with DCPIP solution, and absorbance was measured at 520 nm before and after bleaching with standard ascorbic acid. The ascorbic acid content was calculated using the standard formula and expressed in mg/g fresh weight.

Determination of Leaf Extract pH

The pH of leaf extracts was determined following the method proposed by Singh and Rao (1983). Fresh foliar tissue (250 mg) was homogenized in 10 ml of distilled deionized water and centrifuged at 4000 rpm to obtain a clear supernatant. The pH of the extract was measured using a calibrated digital pH meter. This parameter was used to evaluate the physiological response of plants under pollution stress and for determining the Air Pollution Tolerance Index (APTI).

RESULTS

Comparative Study of Plant Species in Village and Industrial Ecosystems

The comparative survey of plant species from village and industrial ecosystems of Balasore district revealed noticeable differences in species composition and distribution patterns. A total of 20 plant species belonging to different families were recorded from both study sites. The occurrence pattern based on presence (+) and absence (−) indicated that several species were common to both ecosystems, whereas some species were restricted either to village or industrial areas.

Table 1. Distribution of plant species in village and industrial ecosystems.

Sl. No.	Plant Species	Village Site	Industrial Site
1	*Ficus racemosa* L.	+	+
2	*Cassia siamea* Lam.	−	+
3	*Ficus religiosa* L.	+	+
4	*Tamarindus indica* L.	+	−
5	*Emblica officinalis* Gaertn.	+	−
6	*Ficus benghalensis* L.	+	+
7	*Syzygium cumini* (L.) Skeels	+	−
8	*Mangifera indica* L.	+	+
9	*Eucalyptus globulus* Labill.	−	+
10	*Psidium guajava* L.	+	+
11	*Moringa oleifera* Lam.	+	−
12	*Azadirachta indica* A. Juss.	+	+
13	*Prosopis juliflora* (Sw.) DC.	−	+
14	*Bergera koenigii* L.	+	+
15	*Musa paradisiaca* L.	+	−
16	*Acacia mangium* Willd.	+	+

17	*Grevillea robusta* A. Cunn. ex R.Br.	−	+
18	*Aegle marmelos* (L.) Corrêa	+	+
19	*Artocarpus heterophyllus* Lam.	+	−
20	*Saraca asoca* (Roxb.) Willd.	+	+

Species such as *Ficus racemosa*, *Ficus religiosa*, *Ficus benghalensis*, *Mangifera indica*, *Psidium guajava*, *Azadirachta indica*, *Bergera koenigii*, *Acacia mangium*, *Aegle marmelos*, and *Saraca asoca* were found in both ecosystems, indicating their adaptability to varied environmental conditions. Conversely, species including *Tamarindus indica*, *Emblica officinalis*, *Moringa oleifera*, *Musa paradisiaca*, and *Artocarpus heterophyllus* were restricted to village areas, suggesting their sensitivity to industrial stress factors. Industrial sites were predominantly occupied by stress-tolerant species such as *Cassia siamea*, *Eucalyptus globulus*, *Prosopis juliflora*, and *Grevillea robusta*.

Comparative Estimation of Chlorophyll Content

The chlorophyll analysis revealed significant variation in pigment concentration between industrial and village samples. Overall, plants collected from village areas exhibited higher chlorophyll content than those from industrial sites, indicating healthier physiological conditions under lower pollution stress.

Table 2. Chlorophyll content of selected plant species in industrial and village areas (mg/g tissue).

Sample	Species	Industrial Chl a	Industrial Chl b	Industrial Total Chlorophyll	Village Chl a	Village Chl b	Village Total Chlorophyll
S1	*Ficus racemosa* L.	8.43 ± 0.54	26.21± .46	110.49 ± 1.13	9.53±0.19	28.10±0.32	119.77 ± 1.93
S2	*Ficus religiosa* L.	18.27±0.63	1.93 ± 0.65	96.30 ± 1.13	36.18±0.17	4.55 ± 0.16	105.93 ± 1.25
S3	*Ficus benghalensis* L.	11.94± 0.17	13.13±0.21	92.21 ± 1.54	13.60±0.04	14.49±0.18	103.19 ± 1.95
S4	*Mangifera*	8.77 ± 0.22	13.13± 0.13	76.59 ± 1.08	24.28± .21	14.34± .63	84.93 ± 1.98

Sample	Species	Industrial Chl a	Industrial Chl b	Industrial Total Chlorophyll	Village Chl a	Village Chl b	Village Total Chlorophyll
	indica L.						
S5	*Psidium guajava* L.	5.44 ± 0.31	2.81 ± 0.24	56.78 ± 1.17	14.86±0.14	7.42 ± 0.03	91.67 ± 2.03
S6	*Azadirachta indica* A. Juss.	16.13± 0.73	1.14 ± 0.17	83.68 ± 1.28	17.49± .46	1.50 ± 0.13	95.23 ± 1.70
S7	*Bergera koenigii* L.	3.77 ± 0.21	11.37± 0.21	47.94 ± 0.99	5.49 ± 0.07	11.91± .36	59.63 ± 2.02
S8	*Acacia mangium* Willd.	6.33 ± 0.21	9.66 ± 0.18	57.54 ± 1.61	1.84 ± 3.50	15.40± .24	83.75 ± 1.78
S9	*Aegle marmelos* (L.) Corrêa	3.68 ± 0.11	17.33± 0.68	65.12 ± 1.88	11.49±0.26	18.71± .28	101.97 ± 1.45
S10	*Saraca asoca* (Roxb.) Willd.	10.43± 0.27	9.49 ± 0.26	62.84 ± 1.78	13.81± .07	10.33±0.15	92.93 ± 1.89

The highest total chlorophyll content in industrial samples was observed in *Ficus racemosa* (110.49 ± 1.13 mg/g), while the lowest was recorded in *Bergera koenigii* (47.94 ± 0.99 mg/g). In village samples, *Ficus racemosa* also showed the maximum total chlorophyll content (119.77 ± 1.93 mg/g). The overall increase in chlorophyll concentration in village plants suggests improved photosynthetic efficiency under cleaner environmental conditions.

Carotenoid Content

The carotenoid content varied considerably among plant species and between study sites. Plants from village areas generally exhibited higher carotenoid concentration than industrial samples.

Table 3. Total carotenoid content of selected plant species in industrial and village areas.

Sample No.	Species Name	Industrial Area	Village Area
S1	*Ficus racemosa* L.	0.23 ± 0.09	2.67 ± 0.19
S2	*Ficus religiosa* L.	0.52 ± 0.02	2.62 ± 0.14
S3	*Ficus benghalensis* L.	0.86 ± 0.47	3.64 ± 0.40
S4	*Mangifera indica* L.	0.82 ± 0.03	2.46 ± 0.26
S5	*Psidium guajava* L.	0.44 ± 0.01	2.00 ± 0.14
S6	*Azadirachta indica* A. Juss.	1.02 ± 0.02	1.23 ± 0.30
S7	*Bergera koenigii* L.	0.40 ± 0.03	1.21 ± 0.37
S8	*Acacia mangium* Willd.	0.80 ± 0.02	1.43 ± 0.07
S9	*Aegle marmelos* (L.) Corrêa	0.31 ± 0.02	1.33 ± 0.15
S10	*Saraca asoca* (Roxb.) Willd.	1.42 ± 0.10	1.34 ± 0.29

The maximum carotenoid concentration in industrial samples was recorded in *Saraca asoca* (1.42 ± 0.10), whereas *Ficus benghalensis* showed the highest value in village samples (3.64 ± 0.40). Lower carotenoid concentration in industrial plants indicates pigment degradation caused by environmental pollution stress.

Dust Content Analysis

Dust accumulation varied among plant species, reflecting differences in leaf morphology and environmental exposure.

Table 4. Dust content of selected plant species in industrial and village areas.

Sample No.	Species Name	Industrial Area	Village Area
S1	*Ficus racemosa* L.	0.49 ± 0.16	0.49 ± 0.16
S2	*Ficus religiosa* L.	0.55 ± 0.07	0.55 ± 0.07
S3	*Ficus benghalensis* L.	0.53 ± 0.01	0.53 ± 0.01
S4	*Mangifera indica* L.	0.48 ± 0.10	0.48 ± 0.10
S5	*Psidium guajava* L.	0.49 ± 0.17	0.49 ± 0.17

S6	*Azadirachta indica* A. Juss.	0.48 ± 0.27	0.48 ± 0.27
S7	*Bergera koenigii* L.	0.24 ± 0.13	0.24 ± 0.13
S8	*Acacia mangium* Willd.	0.56 ± 0.20	0.56 ± 0.20
S9	*Aegle marmelos* (L.) Corrêa	0.47 ± 0.31	0.47 ± 0.31
S10	*Saraca asoca* (Roxb.) Willd.	0.49 ± 0.23	0.49 ± 0.23

The highest dust accumulation was observed in *Acacia mangium* (0.56 ± 0.20), whereas the lowest was recorded in *Bergera koenigii* (0.24 ± 0.13). The results indicated similar dust deposition in both study sites during the study period.

Ascorbic Acid Content

Ascorbic acid content differed significantly between industrial and village samples, indicating differences in antioxidant activity.

Table 5. Ascorbic acid content of selected plant species in industrial and village areas.

Sample No.	Species Name	Industrial Area	Village Area
S1	*Ficus racemosa* L.	8.66 ± 6.03	18.00 ± 0.26
S2	*Ficus religiosa* L.	10.5 ± 0.30	12.06 ± 0.25
S3	*Ficus benghalensis* L.	10.9 ± 0.25	15.5 ± 0.40
S4	*Mangifera indica* L.	9.43 ± 0.15	14.03 ± 0.15
S5	*Psidium guajava* L.	12.8 ± 0.30	15.1 ± 0.30
S6	*Azadirachta indica* A. Juss.	11.4 ± 0.35	16.5 ± 0.20
S7	*Bergera koenigii* L.	9.63 ± 0.30	11.1 ± 0.30
S8	*Acacia mangium* Willd.	11.8 ± 0.32	18.9 ± 0.79
S9	*Aegle marmelos* (L.) Corrêa	9.73 ± 0.32	10.3 ± 0.64
S10	*Saraca asoca* (Roxb.) Willd.	8.0 ± 0.45	16.4 ± 0.41

Village plants showed comparatively higher ascorbic acid concentration than industrial plants. The maximum ascorbic acid content was observed in *Acacia mangium* from village areas (18.9 ± 0.79), while the minimum was recorded in *Saraca asoca* from industrial areas (8.0 ± 0.45).

pH Analysis

The pH values of leaf extracts showed distinct differences between industrial and village ecosystems. Industrial samples generally exhibited acidic pH, whereas village samples showed neutral to alkaline conditions.

Table 6. Leaf extract pH of selected plant species in industrial and village areas.

Sample No.	Species Name	Industrial Area	Village Area
S1	*Ficus racemosa* L.	3.46 ± 0.25	9.63 ± 0.30
S2	*Ficus religiosa* L.	3.80 ± 0.30	10.26 ± 0.15
S3	*Ficus benghalensis* L.	3.63 ± 0.30	10.9 ± 0.40
S4	*Mangifera indica* L.	4.6 ± 0.36	10.23 ± 0.75
S5	*Psidium guajava* L.	2.9 ± 0.20	7.53 ± 0.32
S6	*Azadirachta indica* A. Juss.	5.33 ± 0.15	8.86 ± 0.25
S7	*Bergera koenigii* L.	3.56 ± 0.35	7.43 ± 0.20
S8	*Acacia mangium* Willd.	3.4 ± 0.50	7.7 ± 0.20
S9	*Aegle marmelos* (L.) Corrêa	5.2 ± 0.10	8.23 ± 0.15
S10	*Saraca asoca* (Roxb.) Willd.	3.46 ± 0.45	8.76 ± 0.30

The highest pH in industrial samples was observed in *Azadirachta indica* (5.33 ± 0.15), whereas *Ficus benghalensis* exhibited the maximum pH in village samples (10.9 ± 0.40). The acidic nature of industrial samples may be associated with deposition of acidic pollutants and particulate matter.

Fluoride Concentration in Water Sources

The fluoride concentration varied among different water sources of Chakulia and Kuanpur. Groundwater samples showed the highest fluoride concentration, with 1.7 mg/L in Chakulia and 1.4 mg/L in Kuanpur, indicating dissolution of fluoride-bearing minerals from geological formations. Pond water showed higher fluoride levels than river water in both areas due to stagnation and evaporation effects. Wastewater samples also exhibited comparatively elevated fluoride concentration. Overall, groundwater and wastewater sources were more affected by fluoride contamination than surface water sources, indicating the necessity of regular monitoring and treatment of drinking water.

Major industries of Balasore district contribute to environmental pollution

Major industries in the Balasore district that contribute significantly to environmental pollution include paper mills, ferroalloy industries, tyre manufacturing units, plastic industries, stone crushers, and wastewater-generating industrial units. These industries mainly contribute to air pollution, water pollution, soil contamination, noise pollution, and dust accumulation.

Table 7. Major Pollution-Contributing Industries in Balasore District.

Sl. No.	Industry Name	Type of Industry	Major Pollutants Released	Environmental Impact
1	Emami Paper Mills	Paper and pulp industry	Suspended particulate matter (SPM), wastewater, chlorine compounds	Air and water pollution
2	Balasore Alloys Limited	Ferroalloy and metal industry	Smoke, SO_2, NO_x, metallic dust	Air pollution and soil contamination
3	Birla Tyres	Tyre manufacturing	Carbon black dust, volatile gases, particulate matter	Air pollution and respiratory hazards
4	Oriplast Limited	Plastic manufacturing	Plastic waste, chemical fumes	Soil and water pollution
5	Stone crusher units of Balgopalpur and Mitrapur	Stone crushing industry	Dust particles, silica dust, noise	Severe dust and noise pollution
6	Fish processing and wastewater discharge units	Marine processing industry	Organic waste, untreated effluents	Water pollution and foul odour
7	Small-scale chemical	Engineering and	Industrial effluents, fumes,	Water and soil

Sl. No.	Industry Name	Type of Industry	Major Pollutants Released	Environmental Impact
	and fabrication units	chemical industries	oils	contamination

Research studies conducted in industrial areas of Balasore identified major pollution sources including industrial emissions, vehicular emissions, unpaved roads, and stone crusher activities. Industrial regions such as Balgopalpur Industrial Estate were reported to experience high atmospheric dust and particulate pollution due to industries like Emami Paper Mills and Ispat/Alloy industries.

Effect of Smoke and Metallic Dust Released from Balasore Alloys Ltd. on Similipal Biosphere Reserve and Kuldiha Wildlife Sanctuary

Balasore Alloys Limited is one of the major ferroalloy industries located in the Balasore region of Odisha. The industry releases smoke, suspended particulate matter, metallic dust, furnace emissions, and hazardous residues during ferrochrome and ferroalloy production processes. Industrial emissions from such units generally contain particulate matter, sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide, and traces of heavy metals including chromium-bearing dust. Environmental reports associated with the industry also mention generation of flue dust and ferrochrome slag, which require proper management and disposal.

The continuous release of smoke and metallic dust may adversely affect nearby forest ecosystems including the Similipal Biosphere Reserve and Kuldiha Wildlife Sanctuary. These protected forest areas are ecologically sensitive zones rich in biodiversity and support numerous species of flora and fauna including elephants, tigers, leopards, gaurs, hornbills, orchids, and endemic plant species. Kuldiha Wildlife Sanctuary is ecologically connected with Similipal through forest corridors and elephant migration routes, making the region highly vulnerable to industrial pollution and habitat degradation.

Smoke and dust particles released from ferroalloy industries can settle on forest vegetation and leaf surfaces, reducing chlorophyll content, photosynthetic efficiency, and overall plant productivity. Metallic dust deposition blocks stomatal openings, interferes with gaseous exchange, and may lead to premature leaf senescence and decline in forest health. Long-term accumulation of chromium-containing particulate matter may also alter soil chemistry and microbial activity, thereby affecting nutrient cycling within forest ecosystems. Environmental clearance proceedings related to ferrochrome activities in Odisha have highlighted concerns regarding hexavalent chromium contamination in nearby water bodies and groundwater systems.

Wildlife populations within Similipal and Kuldiha may also experience indirect ecological stress due to habitat degradation, air pollution, and contamination of water sources. Herbivorous animals may ingest contaminated vegetation and water, leading to bioaccumulation of toxic metals through the food chain. Dust pollution and industrial noise may disturb animal movement, breeding behaviour, and migratory routes, especially within the Mayurbhanj Elephant Reserve landscape that includes Similipal, Kuldiha, and Hadgarh forests.

The ecological significance of Similipal Biosphere Reserve and Kuldiha Wildlife Sanctuary demands strict environmental monitoring and pollution control measures around industrial regions. Proper management of flue dust, hazardous waste, gaseous emissions, wastewater discharge, and greenbelt development around industrial zones is essential to minimize environmental impacts. Continuous assessment of air quality, heavy metal deposition, vegetation health, and wildlife habitat conditions is necessary for conserving the biodiversity and ecological stability of these forest ecosystems.

Effect of Smoke, Open Wastewater Discharge, and Metallic Dust on Tribal Communities of Balasore District

The tribal communities residing near industrial regions of Balasore district are increasingly exposed to environmental pollution caused by industrial smoke, open wastewater discharge, and metallic dust deposition. Industrial activities associated with ferroalloy industries, paper mills, tyre manufacturing units, stone crushers, and wastewater discharge systems contribute significantly to environmental degradation in surrounding rural and tribal areas. These pollutants adversely affect air quality, water resources, agricultural productivity, and public health, thereby influencing the socio-economic conditions of local tribal populations.

Smoke emissions from industrial units release suspended particulate matter (SPM), sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide, and fine dust particles into the atmosphere. Continuous exposure to polluted air may lead to respiratory disorders such as asthma, chronic cough, bronchitis, eye irritation, skin allergies, and reduced lung function among tribal populations living near industrial belts. Elderly people, women, and children are particularly vulnerable to long-term exposure to smoke and airborne pollutants. Dust and smoke also reduce visibility and create unhealthy living conditions in nearby villages.

Metallic dust released from ferroalloy industries and stone crushing units contains fine particles of heavy metals and mineral residues that settle on houses, vegetation, agricultural fields, and water bodies.

Continuous dust deposition on crop plants interferes with photosynthesis, reduces agricultural productivity, and damages leaf surfaces. Tribal communities, which largely depend on subsistence agriculture and forest resources, may experience economic losses due to reduced crop yield and declining soil fertility. Long-term exposure to metallic dust may also contribute to skin diseases, irritation, and possible toxic effects due to heavy metal accumulation.

Open wastewater discharge from industries and domestic drains contaminates ponds, rivers, agricultural lands, and groundwater sources used by tribal communities for drinking, cooking, bathing, irrigation, and livestock. Untreated wastewater often contains organic pollutants, suspended solids, chemicals, fluoride, oils, and metal residues that deteriorate water quality. Consumption of contaminated water may lead to gastrointestinal disorders, fluorosis, waterborne diseases, kidney-related problems, and other health complications. Polluted water bodies also affect fish populations and aquatic biodiversity, thereby impacting local livelihoods dependent on fisheries and wetland resources.

Environmental pollution also creates indirect social and economic impacts on tribal communities. Declining environmental quality reduces forest productivity, medicinal plant availability, fuelwood resources, and traditional livelihood opportunities. Pollution-induced health problems increase medical expenses and reduce work efficiency among economically weaker populations. In many industrially affected regions, tribal people face displacement, loss of agricultural land, and environmental insecurity due to expanding industrial infrastructure and improper waste management practices.

The ecological and public health impacts of industrial pollution in Balasore district highlight the need for sustainable industrial practices, strict environmental regulations, and continuous pollution monitoring. Proper treatment of industrial wastewater, control of smoke emissions, dust suppression measures, greenbelt development, and regular health assessments in tribal villages are essential for minimizing environmental risks. Protection of tribal communities requires integrated efforts involving environmental authorities, public health agencies, industries, and local governance systems to ensure environmental justice and sustainable development in the region.

Effect of Smoke, Open Wastewater Discharge, and Metallic Dust on Schools, Colleges, and Fakir Mohan University

Industrial pollution in Balasore district, particularly from smoke emissions, open wastewater discharge, and metallic dust released by industries and vehicular activities, may adversely affect the health and academic environment of students studying in schools, colleges, and educational institutions including

Fakir Mohan University. Continuous exposure to polluted air and contaminated surroundings creates both physical and psychological stress among students and staff members.

Smoke emitted from industrial units and heavy traffic releases suspended particulate matter (SPM), sulfur dioxide (SO_2), nitrogen oxides (NO_x), and other harmful gases into the atmosphere. These pollutants reduce ambient air quality and may lead to respiratory problems such as asthma, coughing, throat irritation, breathing difficulty, headaches, and allergic reactions among students. Children and young adults are particularly sensitive to air pollution because their respiratory systems are still developing. Prolonged exposure to polluted air can reduce concentration, physical activity, and overall learning efficiency in classrooms.

Metallic dust generated from ferroalloy industries, construction activities, and stone crushing units may settle on school buildings, classrooms, playgrounds, laboratory equipment, books, and vegetation around campuses. Dust accumulation reduces environmental hygiene and may create eye irritation, skin allergies, and respiratory discomfort among students and teaching staff. Fine particulate matter can remain suspended in the air for long periods and enter classrooms through open windows and ventilation systems, thereby affecting indoor air quality. Educational institutions located near roadsides or industrial corridors are generally more vulnerable to such pollution.

Open wastewater discharge from industrial and domestic drainage systems also poses significant health risks to students. Stagnant wastewater near educational campuses can produce foul odour, encourage mosquito breeding, and increase the risk of waterborne and vector-borne diseases such as diarrhoea, dengue, malaria, and skin infections. Contaminated water bodies and drains surrounding educational institutions may further deteriorate sanitation and environmental quality, especially during the monsoon season.

At Fakir Mohan University, environmental pollution may indirectly affect academic activities, field research, biodiversity studies, and the overall campus ecosystem. Dust deposition on campus vegetation can reduce plant growth and photosynthetic activity, while air pollution may affect the ecological health of botanical gardens and green spaces used for research and educational purposes. Students engaged in outdoor activities, sports, environmental surveys, and laboratory fieldwork may face greater exposure to pollutants.

Environmental stress caused by industrial pollution can also influence students psychologically by creating discomfort, reduced outdoor participation, fatigue, and anxiety regarding health and environmental safety. Poor environmental conditions may decrease the quality of the educational atmosphere and reduce overall well-being and productivity among students and faculty members.

Therefore, regular environmental monitoring around educational institutions, proper industrial emission control, wastewater treatment, plantation programmes, greenbelt development, and awareness campaigns are necessary to safeguard the health of students and maintain a clean and healthy academic environment in Balasore district.

Diseases and Health Problems Reported in Villages such as Remuna, Nuapadhi, Mardarajpur, and Adjoining Areas of Balasore District

Villages located near industrial belts, stone crusher zones, brick kilns, wastewater discharge channels, and polluted road corridors in Balasore district, including areas such as Nuapadhi, Mardarajpur, and surrounding settlements, are increasingly vulnerable to environmental and public health problems. Continuous exposure to smoke, dust, industrial emissions, contaminated water, and poor sanitation may contribute to the occurrence of several respiratory, waterborne, dermatological, and pollution-related diseases among rural populations.

One of the most common health problems observed in these villages is respiratory disease. Smoke emitted from industries, brick kilns, vehicular traffic, and stone crusher units releases particulate matter, sulfur dioxide (SO_2), and nitrogen oxides (NO_x), which may cause asthma, chronic cough, bronchitis, breathing difficulty, throat irritation, chest pain, and allergic respiratory disorders. Children, elderly individuals, and people with pre-existing respiratory conditions are particularly vulnerable to long-term air pollution exposure. Reports from Balasore indicate deteriorating air quality and increasing concern regarding respiratory ailments linked to pollution exposure.

Dust pollution is another major environmental issue in adjoining villages. Metallic dust, silica dust from crusher units, and fly ash-like particulate deposition may lead to eye irritation, skin allergies, headaches, nasal irritation, and reduced lung function. Long-term exposure to fine dust particles can contribute to chronic respiratory disorders and reduced work efficiency among agricultural workers and daily labourers.

Open wastewater discharge and contamination of ponds, drains, and groundwater sources increase the risk of waterborne diseases in rural communities. Common diseases associated with contaminated water include diarrhoea, dysentery, gastroenteritis, typhoid, cholera-like infections, and stomach disorders. Poor sanitation, stagnant wastewater, and microbial contamination further aggravate public health conditions during monsoon seasons. Outbreaks of diarrhoeal diseases in rural villages of Odisha demonstrate the vulnerability of village populations to unsafe drinking water and inadequate sanitation systems.

Fluoride-contaminated groundwater may also create long-term health risks in certain rural areas of Balasore district. Continuous consumption of high-fluoride water may lead to dental fluorosis, joint pain, skeletal fluorosis, and bone-related disorders. People depending on untreated tube-well water are generally more susceptible to such conditions.

Environmental pollution also indirectly affects nutrition, agriculture, and mental well-being. Dust deposition on crop plants reduces agricultural productivity and damages vegetable crops, fruit trees, and paddy cultivation. Reduced crop yield and declining environmental quality may create economic stress among rural and tribal families dependent on agriculture and forest resources. Continuous exposure to polluted surroundings may further contribute to fatigue, reduced immunity, stress, and poor quality of life among villagers.

Assessment of fluoride concentration in different water sources of Kuanpur and Chakulia Villages of Balasore district, Odisha

The fluoride content in different water sources of Chakulia and Kuanpur shows clear variation according to source type. In both locations, groundwater from tube wells recorded the highest fluoride concentration, with 1.7 mg/L in Chakulia and 1.4 mg/L in Kuanpur. This suggests that fluoride enters groundwater through the dissolution of fluoride-bearing minerals present in rocks and soil. Because groundwater remains in contact with geological materials for a longer time, the fluoride concentration becomes higher than in surface water. Among surface water sources, pond water showed higher fluoride levels than river water in both areas. Chakulia pond water contained 0.45 mg/L, while river water had 0.35 mg/L. In Kuanpur, pond water had 0.7 mg/L and river water had 0.5 mg/L. This difference may be due to stagnation, evaporation, and accumulation of dissolved substances in ponds, whereas rivers are continuously diluted by flowing water. Domestic water supply sources had moderate fluoride concentrations, such as 0.75 mg/L in Chakulia tap water and 0.8 mg/L in Kuanpur. Wastewater also showed comparatively high values, with 1.1 mg/L in Chakulia and 1.2 mg/L in Kuanpur.

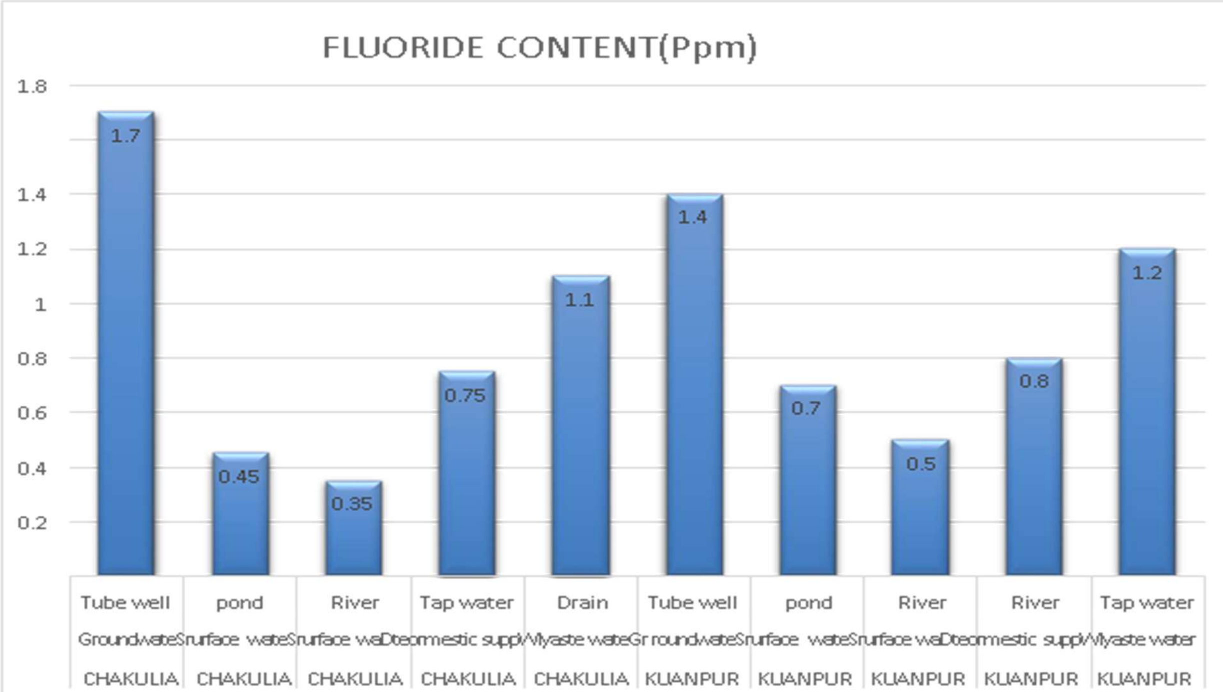

Fig. 1 Graphical representation of Fluoride content in different water sources of Chakulia and Kuanpur area.

Fig. 2. Different water sources across Kuanpur and Chakulia areas of Balasore district, Odisha.

Table 8. Fluoride concentration in different water sources across Kuanpur and Chakulia areas of Balasore district, Odisha.

Study location	Source category	Type of water	Fluoride content
Chakulia	Groundwater	Tube well	1.7±0.1
	Surface water	pond	0.4±0.26
	Surface water	River	0.3±0.20
	Domestic supply	Tap water	0.7±0.45
	Waste water	Drain	1.1±O.1
Kuanpur	Groundwater	Tube well	1.4 ±0.1
	Surface water	Pond	0.6± 0.1
	Surface water	River	0.5± 0.1
	Domestic supply	Tap water	0.9 ±0.1
	Waste water	Drain water	1.1±O.1

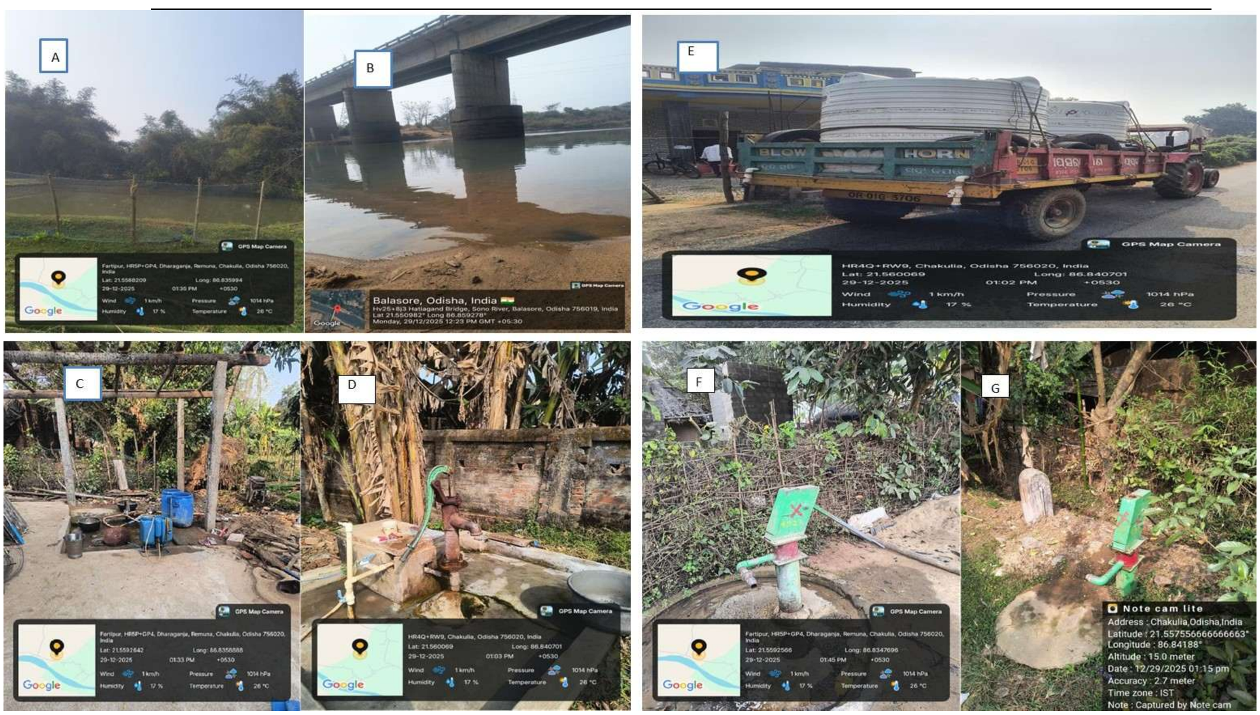

Fig. 3. Open waste water discharge and their effect on ponds, river and ground water in villages of Balasore district, Odisha.

DISCUSSION

The present study demonstrates that industrial pollution significantly influences environmental quality, vegetation characteristics, and public health conditions in different regions of Balasore district, Odisha. Comparative analysis between industrial and village ecosystems revealed marked variations in plant diversity, chlorophyll concentration, carotenoid content, ascorbic acid levels, pH values, dust accumulation, and water quality parameters. These observations indicate that industrial emissions, metallic dust deposition, smoke release, and wastewater discharge exert substantial ecological stress on plants, water resources, and human populations residing near polluted areas.

The distribution of plant species clearly reflected the impact of industrial disturbance on biodiversity composition. Village ecosystems supported greater diversity of fruit-bearing and environmentally sensitive species such as *Tamarindus indica*, *Emblica officinalis*, *Moringa oleifera*, and *Artocarpus heterophyllus*, whereas industrial areas were dominated by stress-tolerant and pollution-resistant species including *Cassia siamea*, *Prosopis juliflora*, *Eucalyptus globulus*, and *Grevillea robusta*. Such changes in vegetation composition are commonly associated with industrial pollution, dust deposition, soil degradation, and altered microclimatic conditions. Species capable of tolerating harsh environmental conditions often survive better in industrial zones due to physiological and structural adaptations against pollutants.

Chlorophyll estimation revealed that plants growing in village areas maintained comparatively higher chlorophyll a, chlorophyll b, and total chlorophyll contents than those growing in industrial environments. Reduction in chlorophyll concentration in industrial plants may be associated with atmospheric pollutants and dust particles that interfere with photosynthesis. Smoke and particulate deposition on leaf surfaces can block stomatal openings, reduce light penetration, and impair chloroplast function, ultimately decreasing pigment synthesis and photosynthetic efficiency. Similar reductions in chlorophyll content under polluted conditions have been reported in several urban and industrial ecosystems where plants experience continuous exposure to sulfur dioxide, nitrogen oxides, and heavy metal particulates.

Carotenoid content also showed noticeable variation between the two ecosystems. Village plants exhibited higher carotenoid concentrations compared to industrial plants, indicating healthier physiological status under less polluted conditions. Carotenoids play an important protective role by scavenging reactive oxygen species and protecting chlorophyll pigments against oxidative damage. Lower carotenoid levels in industrial samples suggest oxidative stress caused by environmental pollutants and dust deposition. Industrial emissions containing metallic particles and gaseous pollutants may enhance oxidative damage in plant tissues, thereby reducing pigment stability and photosynthetic performance.

Dust accumulation on leaf surfaces is another important indicator of environmental pollution. The present investigation recorded moderate to high dust deposition among selected plant species, especially in species with broad and rough leaf surfaces such as *Acacia mangium* and *Ficus religiosa*. Dust particles interfere with gaseous exchange and transpiration by blocking stomata and forming a physical barrier on leaf surfaces. Long-term particulate deposition can reduce plant growth, photosynthetic efficiency, and productivity. Although similar dust values were observed in both ecosystems during the study period, industrial regions generally remain more vulnerable to particulate pollution due to industrial emissions, vehicular activities, road dust, and stone crusher operations.

Ascorbic acid content was comparatively higher in village plants than industrial plants. Ascorbic acid acts as a major antioxidant compound that protects plant cells from oxidative stress caused by pollutants and environmental stressors. Elevated ascorbic acid levels in healthier plants indicate better metabolic activity and stronger antioxidant defense mechanisms. Lower concentrations observed in industrial samples may reflect stress-induced metabolic disturbances caused by pollutants such as sulfur dioxide, nitrogen oxides, and heavy metal dust. Therefore, ascorbic acid serves as a useful biochemical indicator for evaluating pollution tolerance and environmental stress in plants.

Leaf extract pH analysis further supported the influence of industrial pollution on plant physiology. Industrial samples exhibited acidic pH values, whereas village samples remained neutral to alkaline. Acidic pH in industrial plants may result from deposition of acidic pollutants such as sulfur dioxide and nitrogen oxides released from industrial combustion processes. Acidification of leaf tissues may alter enzymatic activities, nutrient absorption, and cellular metabolism, thereby affecting plant growth and physiological performance. Water quality assessment demonstrated significant variation in fluoride concentration among different water sources. Groundwater samples showed higher fluoride levels than surface water, indicating prolonged interaction between groundwater and fluoride-bearing geological materials. Open wastewater discharge and industrial contamination may further aggravate water pollution in nearby villages and agricultural areas. Consumption of fluoride-contaminated water may lead to dental fluorosis, skeletal disorders, gastrointestinal complications, and long-term public health concerns among rural populations. The environmental impacts observed in the present study also extend to surrounding tribal communities, schools, colleges, and educational institutions including Fakir Mohan University.

Smoke emissions, metallic dust, and untreated wastewater may adversely affect respiratory health, sanitation, agricultural productivity, and overall quality of life in nearby villages such as Nuapadhi, Mardarajpur, and adjoining areas. Exposure to polluted air and contaminated water may contribute to respiratory disorders, skin diseases, waterborne infections, fluorosis, and allergic reactions among local inhabitants. Educational institutions located near polluted regions may also experience deteriorating environmental quality, affecting student health, academic activities, and campus vegetation.

Industrial pollution may additionally threaten ecologically sensitive areas such as the Similipal Biosphere Reserve and Kuldiha Wildlife Sanctuary through atmospheric transport of smoke and metallic dust. Continuous deposition of pollutants on forest vegetation may alter biodiversity composition, reduce forest productivity, and disturb wildlife habitats. Since these protected regions support diverse flora and fauna, strict environmental management around industrial zones is essential to minimize ecological degradation.

Overall, the study highlights the strong relationship between industrial activities and environmental deterioration in Balasore district. The observed reduction in plant pigments, alteration of biochemical parameters, water contamination, and associated public health risks emphasize the need for sustainable industrial practices, pollution control strategies, greenbelt development, wastewater treatment, and regular environmental monitoring. Conservation of native biodiversity, protection of public health, and restoration of ecological balance are essential for achieving sustainable environmental management in industrially affected regions of Odisha.

CONCLUSION

The present study clearly demonstrates that industrial activities in Balasore district significantly influence environmental quality, plant physiology, water resources, and public health conditions. Comparative analysis between industrial and village ecosystems revealed considerable variations in plant diversity, chlorophyll content, carotenoid concentration, ascorbic acid level, pH, dust accumulation, and fluoride concentration in water sources. Plants growing in village areas exhibited comparatively higher chlorophyll, carotenoid, and ascorbic acid contents, indicating healthier physiological status and lower environmental stress than plants growing in industrial regions. In contrast, industrial plants showed reduced pigment concentration, acidic pH, and signs of physiological stress due to continuous exposure to smoke, metallic dust, and atmospheric pollutants. The study also revealed that industrial ecosystems support mainly pollution-tolerant and stress-resistant plant species, whereas village ecosystems maintain greater diversity of sensitive and economically important species. Dust deposition and industrial emissions adversely affect photosynthesis, plant metabolism, and overall ecological balance. Water quality assessment further indicated higher fluoride concentration in groundwater and wastewater sources, emphasizing the potential risk of water contamination in nearby rural communities. Environmental pollution generated from industrial smoke, metallic dust, and untreated wastewater was also found to affect tribal populations, schools, colleges, and educational institutions including Fakir Mohan University. Respiratory disorders, waterborne diseases, skin irritation, and environmental stress may increase among populations residing near polluted industrial zones. Furthermore, ecologically sensitive regions such as the Similipal Biosphere Reserve and Kuldiha Wildlife Sanctuary may also experience long-term ecological impacts due to atmospheric transport of industrial pollutants and metallic particulates. The findings of the present investigation emphasize the urgent need for effective pollution control measures, proper industrial waste management, treatment of wastewater, dust suppression strategies, and continuous environmental monitoring in industrial regions of Balasore district. Plantation programmes, greenbelt development, biodiversity conservation, and public health awareness initiatives are essential for reducing environmental degradation and protecting ecosystem health. Sustainable industrial development combined with strict environmental regulation will be necessary to maintain ecological stability, public well-being, and long-term environmental sustainability in the region.

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