Print ISSN: 0976-2876 Online ISSN: 2250-0138

Available online at: http://www.ijsr.in

INDIAN JOURNAL OF SCIENTIFIC RESEARCH

DOI:10.32606/IJSR.V16.I1.00011

Received: 23-04-2025 Accepted: 21-07-2025 Publication: 31-08-2025

Indian J.Sci.Res. 16 (1): 65-72, 2025 Original Research Article

INVESTIGATION OF ECOLOGICAL ACTIVITIES IN RIVER GANGA FROM PRAYAGRAJ TO VARANASI REGION OF UTTAR PRADESH INDIA

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ABSTRACT

Watersheds and rivers are essential for ecosystem services and preserving ecological integrity. The Ganga River in India, the second biggest river system, has been profoundly affected by heavy metals, pesticides, and religious effluents. Atmospheric deposition in the Ganga River Basin is a considerable concern. This research carried out in the Ganga River from Prayagraj to Varanasi are 25° 14'N to 25° 23.5'N and 82° 56'E to 83° 03'E. The Ganga River runs northward in Varanasi, situated on its left bank. The Ganga River watershed receives almost 15 kg/ha of reactive nitrogen (Nr) yearly from atmospheric deposition. Nitrogenous substances from the atmosphere influence the quantity of carbon dioxide absorbed by ecosystems via photosynthesis. A study revealed that the Ganga River watershed gets more than 15 kg/ha of reactive nitrogen yearly from atmospheric deposition, influencing the carbon dioxide absorption in ecosystems via photosynthesis. The persistent input of phosphorus affects primary productivity and ecosystem composition. The research indicated that the Ganga River is exhibiting declining N:P and Si:N ratios, which impacts the organisation of the phytoplankton population. Monitoring nutrient stoichiometric ratios is essential, since silicon limitation stimulates diatom growth and may lead to dissolved silicon consumption above 90% during diatom proliferation. The shift from phosphorus to nitrogen limitation may result in worse food quality for consumers and insufficient representation of silicon-restricted phytoplankton by diatoms. The water quality index (WQI) of the river signifies substandard to very detrimental conditions in downstream locations, especially in summer.

KEYWORDS: Ecological Activities, Ganga River, Uttar Pradesh, Water Quality, Water Pollution

Water, constituting about 70% of the Earth's surface, is the most accessible natural resource and is essential for sustaining biodiversity and the integrity of ecosystems. It facilitates diversion, transit, storage, and recycling, acting as a conduit for the relocation of nutrients across many domains, whether via precipitation (rain, snow, sleet, etc.), as groundwater, inside lentic systems, or as flowing water in lotic systems, such as rivers. Water is the most reliable factor affecting ecosystem structure and function by controlling nutrient cycle. Freshwater, the essential element for sustaining terrestrial life and freshwater ecosystem habitats, comprises just a little fraction of the biosphere. Rivers have a key role in freshwater resources, transportation, human supply, and terrestrial-oceanic connections. Rivers serve as a longitudinal hydrologic continuum connecting terrestrial and marine systems. The continuum is an essential mechanism in the land-ocean system, including the transport of energy, matter, and organisms facilitated by water, either within or across components of riverine corridors. The modification of this continuum resulting from human activities varies with the kind and magnitude of disturbance and remains a significant worldwide concern (Tyagi *et al.*, 2013). Rivers are swiftly altered by human endeavours including urbanisation, industrialisation, dam construction, and inter-basin transfer. The quality of water is deteriorating rapidly due to human discharges. Approximately 90% of wastewater in underdeveloped nations is discharged straight into rivers without treatment. Like other aquatic ecosystems, rivers are influenced by several stressors that impact their structure and function, which react in distinctly opposing but complementary ways to environmental pressures. The structure of a river ecosystem includes attributes including channel morphology, water quality, and the mix of biological communities, while its functioning is indicated by activities such as metabolism, organic matter breakdown, and secondary production (Al-Obaidy and Al-Khateeb, 2013). The Ganga River in India, together with the Brahmaputra-Meghana River System, is the second biggest river system after the Amazon River System in terms of water flow and has a total drainage area of around 1.75 million km². It serves as a lifeline for approximately 26% of the Indian population. Following the building of the Tehri Dam in 2006, the ecosystem of the Ganga River has undergone significant transformation. The river remained mostly unaffected by human activity until the 1940s. Numerous tanneries, distilleries, chemical factories, textile mills, and slaughterhouses are situated along the river, discharging effluents or dumping rubbish directly or indirectly into the Ganga River. Along the Ganga River, there are 36

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Class I cities and 14 Class II cities producing about 2601.3 and 122 MLD of wastewater, respectively. Of them, only 1192.4 and 16.4 MLD (44% of the total) are processed in treatment facilities (Yadav *et al.*, 2018).

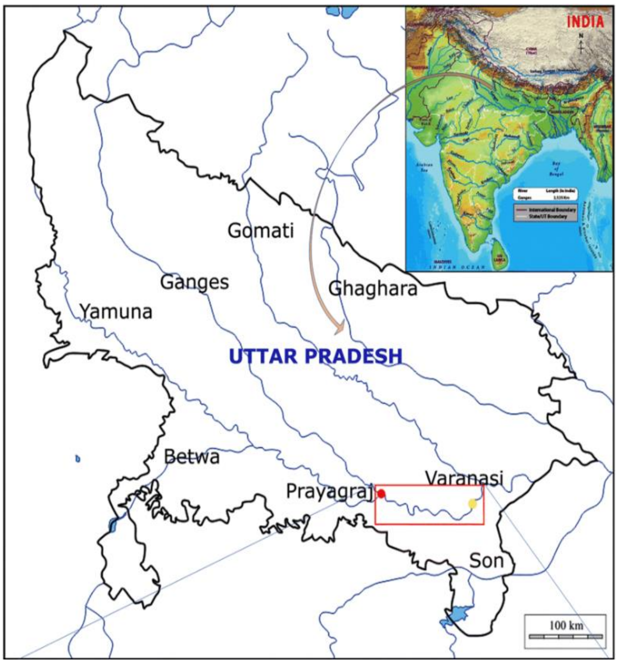

Figure 1: Map view of river Ganga from Prayagraj to Varanasi, Uttar Pradesh

Source:https://www.researchgate.net/figure/Map-of-the-river-Ganga-from-Prayagraj-to-Varanasi-regions-of-Uttar-Pradesh-India_fig1_354870403

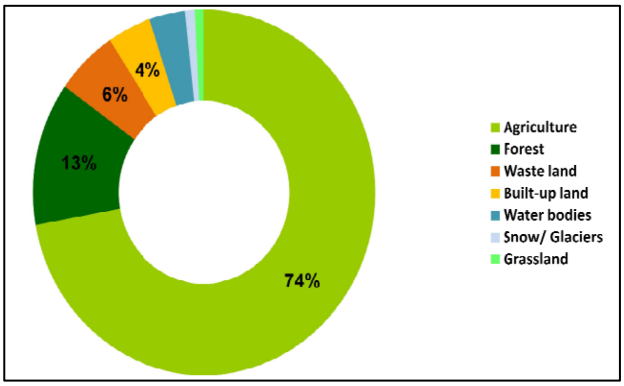

Figure 2: Land % used in the Ganga basin

Additionally, The river, over its whole course, gets substantial influxes of heavy metals, pesticides, and organic waste from religious practices. The land use pattern within the watershed significantly influences regional runoff, discharge dynamics, erosion, and sediment transport in the rivers. The retention and loss of nutrients in a watershed are intricately associated with land use, prevailing vegetation, soil properties, and many weather conditions. This has strong causal relationship with downstream eutrophication. The major portion (over 74%) of the Ganges basin land use Figure 1. constitutes agricultural land. For this reason, the river receives a large input of nutrients from agricultural residues. Annually, about 115,000 tonnes of fertiliser, including 88,600 tonnes of nitrogen, 17,000 tonnes of phosphorus, and 9,200 tonnes of potassium, is transported to the Ganga River by agricultural runoff (Beg and Ali, 2008).

The Ganga basin, mostly an agricultural watershed in India, is experiencing significant repercussions from intensive agriculture, which heightens soil vulnerability to erosional losses of dissolved organic carbon (DOC) and nutrients. Agricultural harvests, irrigation, and grazing act as nitrogen sinks, whilst point and non-point inputs work as nitrogen sources in the watershed's nitrogen budget. The river has seen substantial modifications in sediment transport and deposition, including intense floods and frequent shifts in its trajectory. The ecosystem services of a river include more than just the supply of water and food; they mainly assimilate waste from their watershed, including manmade sources that contribute to reduced water quality and heightened output. The flow of rivers is the principal variable that determines all aspects of the ecosystem, both directly and indirectly, and affects other characteristics, including the biota. The reduction of aquatic species exemplifies the grave repercussions of habitat degradation in the Ganga River. Habitat loss and destruction are also due to the construction of floodplain embankments, which are built to redirect rivers for flood management reasons. The problem is worse by the significant release of liquid waste and the disposal of solid trash, using riverbanks and floodplains as landfill sites for land reclamation for various reasons. Atmospheric deposition in the Ganga River Basin, a vital supply of nutrients for the Indian subcontinent, may affect the structure and functioning of environmentally sensitive ecosystems. The Indo-Pacific archipelago mostly contributes to these loads, with the world's seas receiving an annual influx of 1 Gt of carbon, about 60% of which is inorganic and 40% organic (Figure 2).

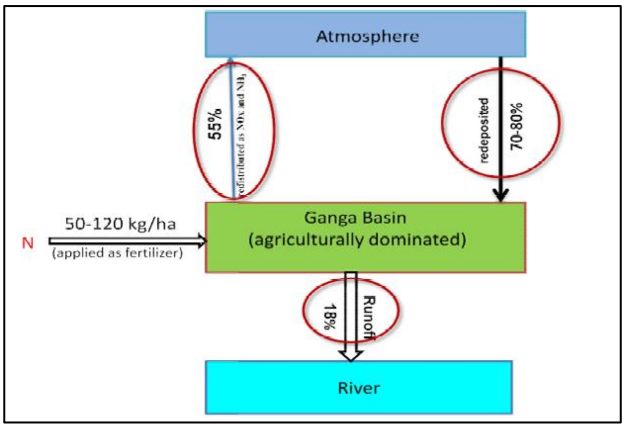

Figure 3: Atmospheric N deposition in Gange basin

Human-induced changes in the nitrogen biogeochemistry of running streams have become a major global issue, affecting both terrestrial and aquatic ecosystems. This is particularly significant in developing countries where anthropogenic nutrients persist. In India, landscape alteration, fertiliser use, and urban-industrial impacts significantly alter aquatic ecosystems. The N:P stoichiometry in global aquatic systems has been altered due to disproportionate nutrient input and management practices. In India, the escalation of nitrogen supply from fertilisers parallels an increase in phosphorus from animal sources and fertiliser application. This challenges the conventional paradigm that freshwater phytoplankton productivity is mostly governed by phosphorus availability. The Ganga River, exposed to urban-industrial discharges, agricultural runoff, and human-induced disruptions, may undergo major changes in N:P:Si stoichiometry, leading to enduring effects on water quality and biological nutrient limitations. This research investigated the ecological activities in the Ganga River from the Prayagraj to Varanasi region including an area of around 100 to 135 km.

METHODOLOGY

The coordinates of the Ganga River from Prayagraj to Varanasi U.P. India are between 25° 14'N – 25° 23.5'N and 82° 56'E – 83° 03'E. The Ganga River flows from south to north in Varanasi, which is located on the left bank of the river.

Sampling of Atmospheric Deposits

The bulk deposition collectors, including a 5L high-density polyethylene bottle connected to a 115 cm^2 Teflon funnel, were used to collect air deposition. To prevent birds from nesting in these collection systems, their tops were equipped with PVC needles. The ideal height for the deposition collectors was about 2.5 to 3 meters above ground level to prevent the mixing of re-suspended roadway particles. Wet deposition was assessed by collecting rainwater samples on an event-specific basis. To mitigate the buildup of resuspended soil particles, these collectors were maintained at an elevation between 2.5 and 3 meters. At the end of each sampling session, the funnels were cleansed with double distilled water to remove particulates adhered to their walls. At the end of each biweekly collection session, the collectors were replaced with new ones. Upon arrival at the laboratory, a 50 ml aliquot of the air deposition sample and a 50 ml aliquot of the rinse water were collected, filtered, and stored in the dark at ambient temperature until analysis.

Nutrients Analysis

Samples of atmospheric deposition were analysed for nutritional ions such as NO_3^- and PO_4^{3-}.. Additionally, ammonia concentration is quantified as ammonium ion using the phenate technique. To 4 ml of the sample, 0.5 ml of reagent A solution and 0.5 ml of reagent B were added. The mixture was incubated at 37 ºC for 20 minutes. The absorbance of the sample was measured at 625 nm using a UV-Visible spectrophotometer. Phosphate - P was assessed using Olsen's sodium bicarbonate technique. This technique employs 0.50 M sodium bicarbonate as the extracting reagent. For analysis, the working solution (a combination of ascorbic acid and sulphuric molybdate) was included into the extractant, well mixed, and the absorbance was measured at 880 nm using a UV-VIS spectrophotometer. The results obtained were converted to µg g-1 using a standard curve.

Sampling to River Water Sample Collection for Physico-Chemical Analysis

The study collected composite water samples from 11 research locations from January 2024 to June 2024. The parameters of temperature, total dissolved solids, salinity, specific conductivity, and pH of the river water were tested on-site. The water temperature was measured using a multi-parameter tester, and the pH was measured using a multi-parameter tester. The specific conductivity of water samples was determined at each location. Total dissolved solids (TDS) were quantified using a multi-parameter tester, and the chloride concentration was determined using Mohr's technique. Total alkalinity was determined using a titrimetric technique. Dissolved oxygen was calculated using Winkler's modified technique. Biochemical oxygen demand (BOD) samples were collected in two 300 ml BOD bottles, and the oxygen concentration was assessed after three days of incubation at 27°C. If the BOD was elevated, distilled water or tap water with low BOD was used to dilute the sample. The chemical oxygen demand (COD) was assessed using a standard technique, which involved adding a sample to a flask and adding sulphuric acid. The flask was exposed to a 2-hour flux and distilled water was added post-reflux. Essential nutrient ions were quantified using a flame photometer, and sulphate concentration was determined using titration. Dissolved organic carbon (DOC) was determined using the KMnO4 digestion technique. Nitrate ion (NO3-) was quantified using the phenol disulphonic acid technique, while ammonium (NH4+) was quantified using the phenate technique. Phosphate-phosphorus was quantified using the stannous chloride technique, and dissolved silica (DSi) was quantified using the molybdate blue technique.

Water discharge statistics were provided from the Central Water Commission (CWC) and the Central Pollution Control Board (CPCB) for the year 2015-16. The results of these tests provide valuable information on the water quality and potential sources of pollution.

Water Quality Index (WQI)

WQI was calculated using 11 parameters such as pH, TDS, conductivity, total alkalinity, DO, BOD, Cl-, NO3-, SO4 2-etc.

RESULTS

The data about atmospheric deposition of nutrients (nitrogen and phosphorus) from eleven research sites throughout three sub-watersheds of the Ganga River is shown in Figure 4. Nutrient atmospheric deposition exhibited variability across different locales and time scales. Among the study locations, Rj in the middle sub-watershed got greatest input of TRN, whilst Ap in the same sub-watershed received the lowest. At Rj, the atmospheric deposition of nitrogen compounds varied from 8.072 to 16.3 kg ha-1 each season. The deposition of NO3- was maximal in Rj, with values between 6.08 and 10.58 kg ha-1 season-1, whereas it was minimal at Ap, with values ranging from 2.61 to 5.75 kg ha-1 season-1. Peak phosphate deposition occurred at Rj, with values fluctuating between 0.56 kg ha-1 season-1 and 0.88 kg ha-1 season-1. Gs in the lower sub-watershed received little AD-P, with values ranging from 0.13 to 0.44 kg ha-1 season-1. The deposition of nutrients steadily increased during the research period. This tendency was prevalent in two types of Nr and AD-P. Nutrient depositions were maximal in winter and minimal in summer. The deposition of NH4 + was recorded at its peak in Rj, with values ranging from 1.99 kg ha-1 season-1 to 5.71 kg ha-1 season-1. The minimal deposition was rarely recorded at Rk (1.14-2.64 kg ha-1 season-1) in the upper sub-watershed and Ap (0.95-1.23 kg ha-1 season-1) in the middle sub-watershed. Gs in the lower sub-watershed received little AD-P, with values ranging from 0.13 to 0.44 kg ha-1 season-1 (Fig. 4). The deposition of nutrients steadily increased during the research period. This tendency was prevalent in two types of Nr and AD-P. Nutrient depositions were maximal in winter and minimal in summer on a seasonal scale (Fig. 5). The deposition of NH4 + was recorded at its peak in Rj, with values ranging from 1.99 kg ha-1 season-1 to 5.71 kg ha-1 season-1. The lowest deposition for the same was reported rarely in Rk (1.14-2.64 kg ha-1 season-1) in the upper sub watershed and Ap (0.95-1.23 kg ha-1 season-1) in the middle sub-watershed. The polar figure 5 illustrates the magnitude of deposition of two types of Nr as phases, with radius as a function of angle. The distance from the centre of the circle denotes the values. Mapping atmospheric deposition of NO3- in the Ganges Basin indicated that all research sites exhibited AD-NO3- levels above 15 kg ha-1 yr-1, but only 45% of the sites recorded AD-NH4+ deposition surpassing 10 kg ha-1 yr-1.

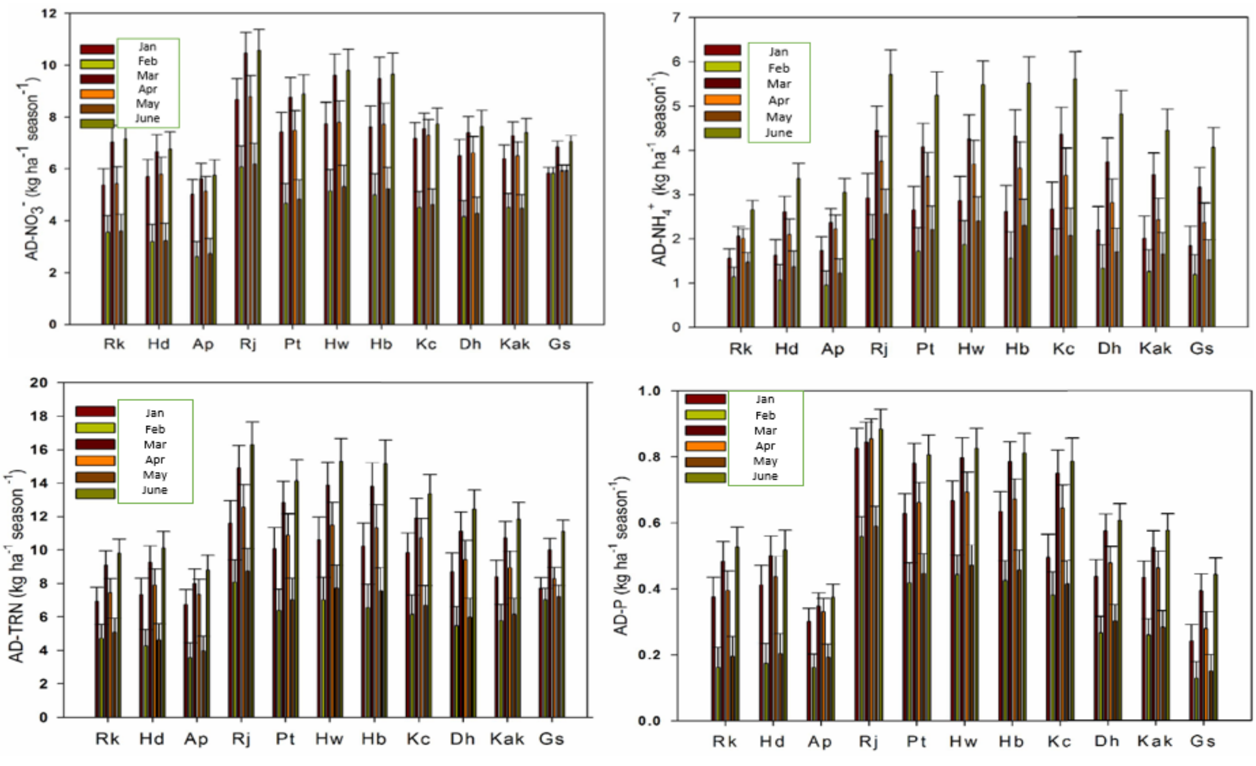

Figure 4: Atmospheric deposition of nutrients in Ganga river

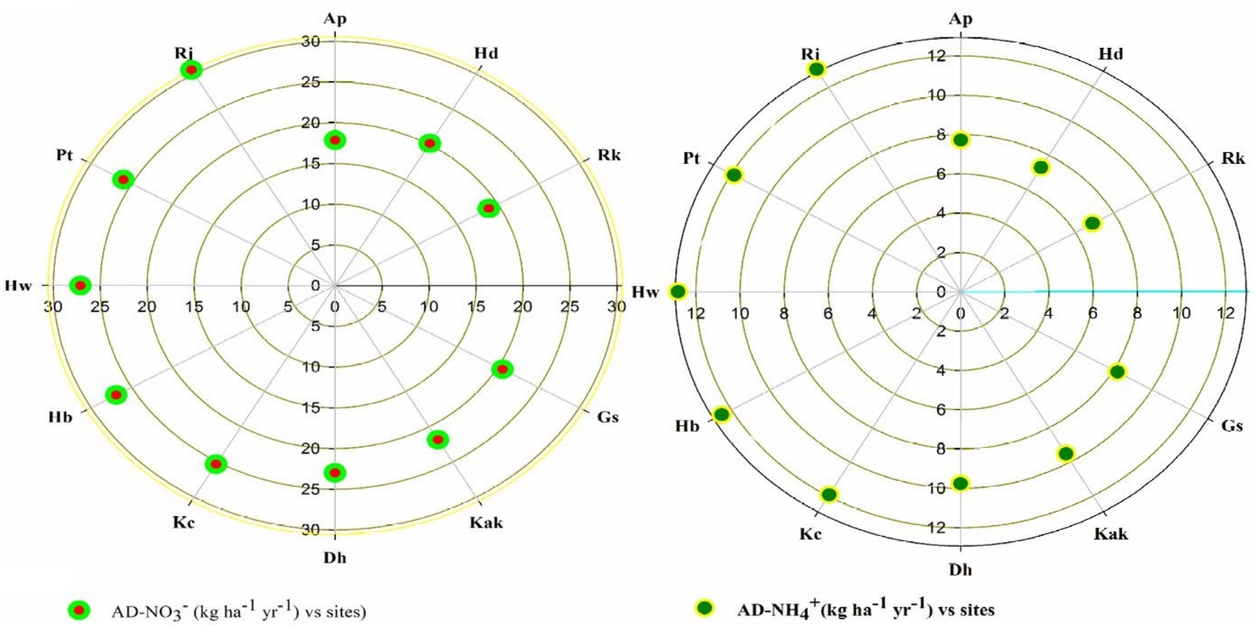

Figure 5: Mapping of atmospheric deposition

Model estimatesthat around 66% of the Western Ghats, 42% of Indo-Burma, and 9% of the Himalayas experience atmospheric nitrogen deposition more than 15 kg ha–1 yr–1. The quantity is adequate to influence land and aquatic ecosystems. Ranking the research sites about air deposition of phosphate in the Ganges Basin, as shown in the pie-chart graphic (Fig. 6), indicated that, with the exception of Gs, 91% of the study sites exhibited AD-P > 1 kg ha-1 yr-1. This signifies a continuous influx of nutrients, rather than an intermittent discharge, in the Ganges Basin. In addition to vigorous agricultural practices and urban development, the basin experiences severe dust storms from the west, accompanied by substantial aerosol buildup. Consequently, the cumulative impact of atmospheric alteration, prevailing westerly winds, and the forest edge effect amplifies AD intake, even in isolated regions. (Figur 7 and 8)

Moreover, the analysis of variance of atmospheric deposition data revealed a significant influence ($p < 0.001$) attributable to location, season, and year (Table 1). Nonetheless, the interactions of these factors were not significant (ns) in some instances. The data underwent principal component analysis (PCA) (Fig. 10) to identify key factors contributing to spatiotemporal variations.

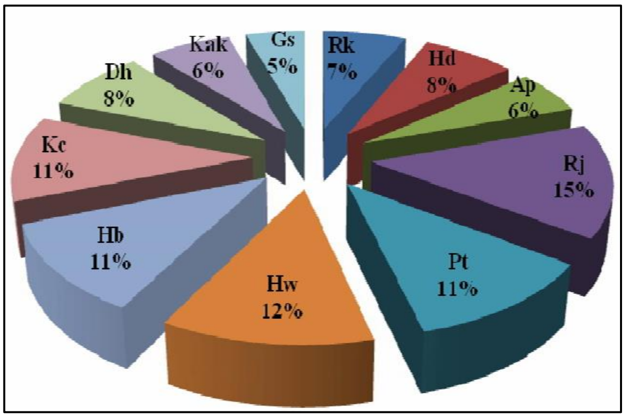

Figure 6: Ranking of sites based on AD-P

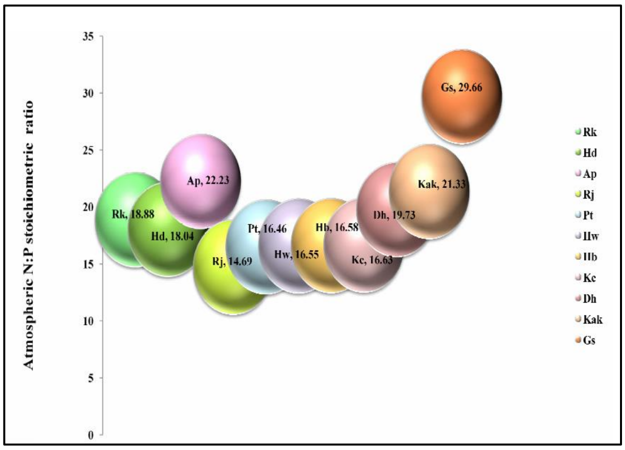

Figure 7: Atmospheric N:P stoichiometric ratio

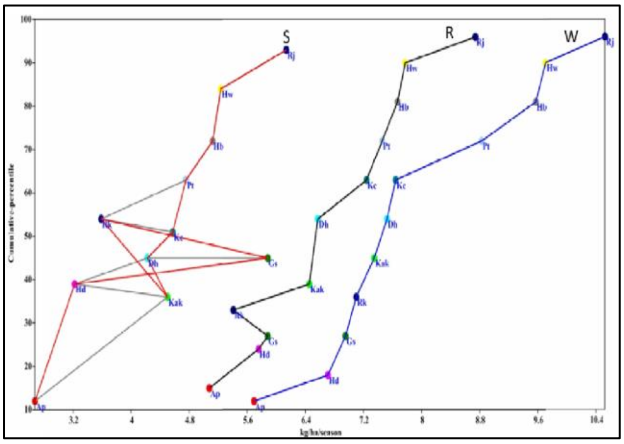

Figure 8: Cumulative frequency for AD- NO3 in ganga

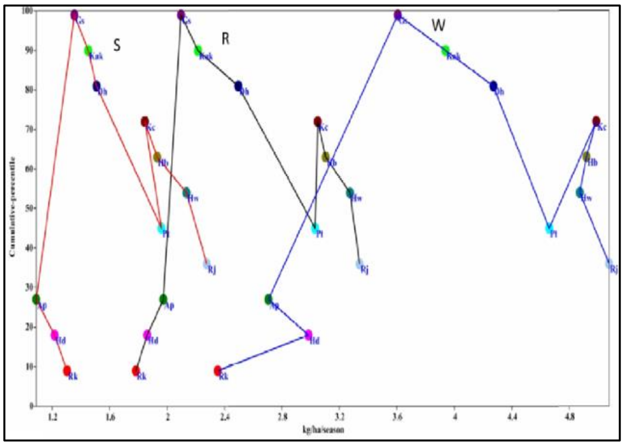

Figure 9: Cumulative frequency for AD- NH4 in ganga

Table 1: F-ratios

Source	Sites (S)	Year (y)	Season (s)	(S x y)	(S x s)	(y x s)	(S x y x s)
AD- Nitrate	2.43E+03	69.571	1.99E+04	0.453^{ns}	1.86E+02	1.82^{ns}	3.64E-01
AD-Ammonia	766.149	2.42E+03	9.60E+03	14.996	69.138	137.378	1.28^{ns}
TRN	5.69E+03	3.31E+03	5.59E+04	1.87+01	3.09E+02	1.66E+02	1.50E+00^{ns}
AD-P	48.848	6.176	1.64E+02	0.076^{ns}	0.73^{ns}	0.061^{ns}	0.072^{ns}

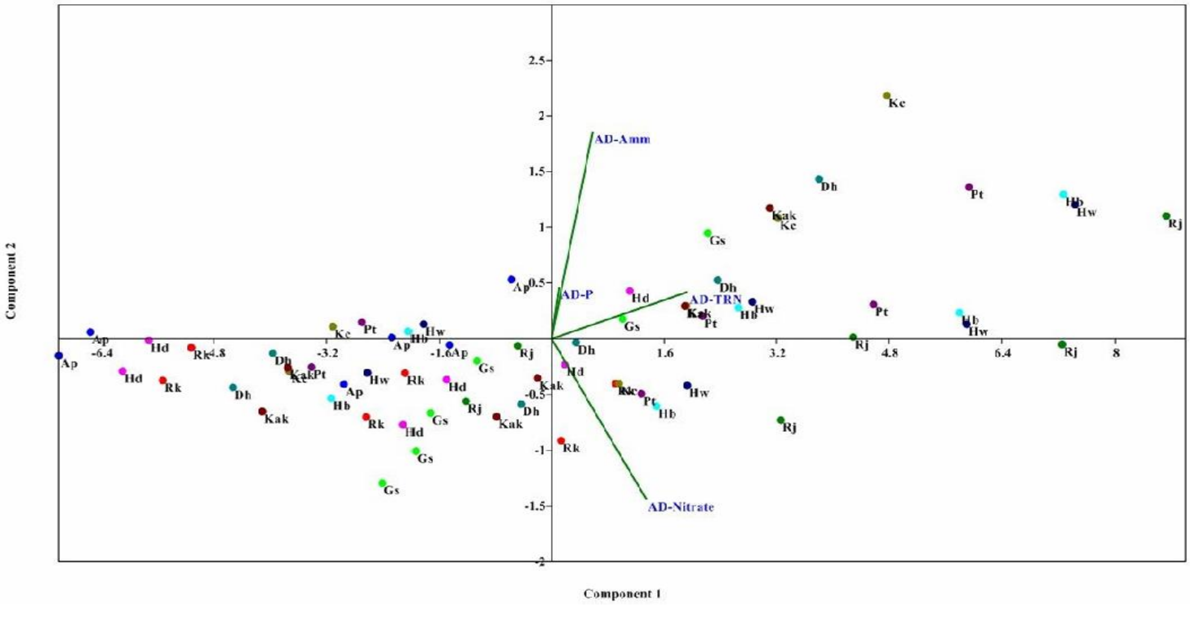

Figure 10: Scatter diagram of PCA for atmospheric deposition attributes measured seasonally during the study period in the Ganges Basin

The area has extensive agricultural activity owing to its location in the most fertile stretch of the Indo-Gangetic plains. The present study emphasised investigating the nutrient influx to the Ganges basin via atmospheric deposition and whether this deposition exhibited significant spatio-temporal trends with sufficient magnitude to impact terrestrial and aquatic ecosystems. This project produces spatio-temporal data at the watershed size on these concerns from January 2024 to June 2024. The data on air deposition in this investigation unequivocally indicated an upward tendency during the six-month period. This tendency was prevalent at all locations, regardless of nutrient levels, likely attributable to an increase in sources of air pollution.”

CONCLUSION

The Ganga River in India, the second largest river system after the Amazon River System, has been significantly impacted by heavy metals, pesticides, and organic waste from religious practices. Land use patterns within the watershed significantly influence regional runoff, discharge dynamics, erosion, and sediment transport. The majority of the Ganges basin land use is agricultural, increasing soil susceptibility to erosional losses of dissolved organic carbon and nutrients. Atmospheric deposition in the Ganga River Basin plays a significant role in altering the structure and functioning of ecologically sensitive ecosystems. The Ganga River watershed receives over 15 kg/ha of reactive nitrogen annually via atmospheric deposition, which affects terrestrial and aquatic ecosystems. The anthropogenic supply of reactive nitrogen has increased from 15 Tg in 1860 to 187 Tg by 2005, and is expected to quadruple by 2050. Recent research indicates that atmospheric deposition in the Ganges Basin provides 1.31-7.75 µmol P m–2 d–1, with AD-P being 1.20–2.0 times more in the middle watershed (SW II). The study also found that the Ganga River is trending towards reduced N:P and Si:N ratios, which has implications for long-term compositional alteration in phytoplankton community structure. Future research should focus on various aspects to improve ecological activities in the Ganga River, such as understanding the river's hydrogeochemical dynamics, ecology, climate change and land use change, seasonality and extreme high flow events, riparian vegetation and floodplain ecology, functional attributes, and river regulation. This will help other developing nations enhance their water bodies and aquatic life.

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