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Estimation of Pollution Load and Carrying Capacity in the Tributaries of the Ramganga River in the Moradabad Region of Uttar Pradesh, India: Implications for Environmental Management

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Abstract

Considering the abundance of possible pollutant sources along the Ramganga, i.e., agricultural lands, industrial areas, and population density in Uttar Pradesh, this study aimed to quantitatively assess the pollution load and carrying capacity of the river based on different physio- chemical water quality parameters. Water sampling and primary parameter measurement were conducted monthly by purposively selected four different sites at Moradabad (A district of Indian state Uttar Pradesh) region. Determination of the study area was based on the condition of the drain and its surroundings and assumed there was a decrease in river water quality. Descriptive and graphics analyses for different water quality parameters, i.e., Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Ammoniacal Nitrogen as NH3-N, Nitrate as NO3- and Total Dissolved Solid (TDS), were used for calculating pollution load carrying capacity (PLCC) of the river in the specific region. The result demonstrated that the carrying capacity at almost each sampling point had a negative value for BOD and COD, i.e., -14.7398, -818.4098, -174.1735, and -282.7259 Kg/Day toward the BOD, 80.1845, -1873.9096, -271.2571 and -421.9873 Kg/Day towards the COD for respective sampling sites. This shows the actual pollution load for BOD and COD is higher than the maximum pollution load (Discharge Standard for Surface water as per CPCB). It was noticeable that the drain is polluted towards the BOD and COD and flowing above the maximum pollution load. However, it was not contaminated towards TDS, NO3- and NH3-N as carrying capacity shows a positive value for each sampling site.

Keywords: Carrying Capacity; Pollution Load; Ramganga; Water Quality Parameters; CPCB

Introduction

Since the beginning of time, people have preferred to reside near fertile river alluviums since they are the source of a wide range of commodities and services. Because rivers are the primary source of water for agriculture, industry, and residential usage, their natural conditions have been lost worldwide due to over-exploitation and pollution. With the passage of the Water Act in 1974, river pollution in India gained major attention beginning in the 1980s. Despite the regular water quality monitoring at many locations in the Ganga River, As per The Central Pollution Control Board of India (CPCB) the water quality has not improved noticeably, particularly in the most contaminated section between Kannauj and Varanasi. This stretch is where several small and large tributaries, including the Ramganga, Kali, and Gomati, join the Ganga, carrying a significant pollutant load. The pollution not only affects the river's ecosystem but also the health and livelihoods of the local communities. While there are some reports on the water quality and pollution of the Kali and Gomati Rivers, the absence of such reports for the Ramganga River is a significant gap in our understanding. CPCB has estimated that approximately 235 MLD of untreated industrial wastewater and 227MLD of domestic sewage are discharged into the Ramganga (directly or through tributaries) from the industrial and urban centers of Uttrakhand and Uttar Pradesh states, with an estimated biochemical oxygen demand (BOD) load of 132 TPD [1]. This underscores the urgent need for more research and data collection on the Ramganga River. Additionally, 764 highly polluting industries in Uttarakhand, Uttar Pradesh, Bihar, and West Bengal that discharge wastewater into the main stem of the Ganga River (either directly or through drains) and its two significant tributaries, the Ramganga and Kali-east, have been listed by the CPCB. It was found that 1123 MLD of water is used by severely polluting enterprises. The tannery industry leads in the number of industrial units, whereas the pulp and paper, chemical, and sugar sectors lead in wastewater generation. Additionally, it is noted that, relative to water consumed, Grossly Polluting Industries (GPI) in Uttar Pradesh generates 39% of wastewater, whereas GPI in Uttrakhand generates almost 56.7% of wastewater. [1].To manage this, we need to understand how much pollution these water bodies can handle without becoming unsafe or unusable. This concept is called Pollutant Carrying Capacity (PCC), and it's a crucial part of keeping our water resources healthy and accessible [2]. Moradabad, a renowned city in Uttar Pradesh, India, has been celebrated since ancient times for its exquisite brass metal handicrafts, coveted both within India and internationally. Located in western Uttar Pradesh, it lies between 28°-21´ to 28°-16´ Latitude North and 78°- 4´ to 79° Longitude East. The city is bordered by the Ram Ganga River to the northeast and the Gangan River to the southwest [3]. The Ramganga River Basin spans an area of 22,685 square kilometers, constituting around 8% of the entire catchment area of the Ganga Basin. Serving as a significant tributary to the Ganga River, the Ramganga originates from the Dudhotali range in the Gairsain village of Chamoli district, Uttarakhand. With an average elevation of 1530 meters above mean sea level (MSL), it meanders through the region. The basins geographical coordinates range from 30°06'02.2200"N to 27°10'42.1100"N latitude and 79°16'59.2200"E to 79°50'01.600"E longitude, covering a total length of 642 kilometers. Initially, the river traverses a distance of 158 kilometers from its source within the mountains before emerging onto the expansive plains of the Ganga[4]. The primary sources of water pollution in Moradabad are the brassware industry's industrial discharges, untreated domestic sewage, and agricultural runoff. These pollutants degrade water quality and pose severe risks to both human health and the environment. Addressing these issues requires stringent enforcement of environmental regulations [5]. The main sources of pollution and accurately estimating the amount of pollution entering rivers is crucial for effectively managing water bodies. However, despite various methods available for estimating pollution loads, there are significant challenges in pinpointing the main sources of pollution and determining how much pollution rivers can handle due to the complex and varied nature of pollution discharge and river features. In simpler terms, figuring out where pollution comes from and how much a river can handle is tricky because pollution sources and river conditions can be very different and complicated [6]. Conducting a carrying capacity analysis through this pollution index method is a novel aspect of this study. The findings can greatly benefit government efforts in managing activities such as forest conversion, erosion control, sedimentation, settlements, and waste disposal to ensure the sustainability of the lake ecosystem. In essence, this method provides detailed insights into lake conditions and helps guide sustainable management practices [7]. This study focused on the water pollution of the the Sot River, also known as the Sot Nadi and Aril River, are tributary of the Ramganga River, which holds significant policy implications in India, as it serves as a water source for 43% of the country's population[8].. Essentially, by regularly monitoring water quality, we can better understand and address the negative effects of both natural processes and human interventions on river systems [9]. Over the past forty years, the Ganges River Basin has experienced significant changes due to population growth and economic development. The basin's population has increased by nearly 100 million, leading to expanded agricultural areas to meet food demand. This growth has relied heavily on water resources, particularly groundwater, which has seen a dramatic increase in extraction. However, this has resulted in a rise in over-exploited groundwater blocks from 118 to 680 between 1984 and 2009, highlighting the urgent need for sustainable water management practices in the region[10]. There is limited information available on the water quality of the Ramganga River, as it was not included in the monitoring program of the National River Conservation Program conducted by the Ministry of Environment and Forests, Government of India. However, the Central Water Commission, under the Ministry of Water Resources, Government of India, conducts monthly monitoring of select water quality parameters at three locations along the river. This monitoring primarily focuses on assessing the suitability of water for irrigation purposes. Despite the river's extensive length of over 590 kilometers from its source to its confluence with the Ganga River, only limited water quality data is currently available[11]. Essentially, understanding the pollution load capacity helps in devising an appropriate management plan to mitigate pollution and preserve the health of the Ramganga Sub Watershed ecosystem [12].

Study Area

Moradabad district, once the second most populous in Uttar Pradesh until Sambhal district was carved out in 2011, is the focus area for assessing Pollution Carrying Capacity. Located between 28°21′ to 28°16′ north latitude and 78°4′ to 79° east longitude, it is bordered by the Ramganga River to the east and the Ganga River to the west. The Ramganga River, a significant tributary of the Ganga, originates in the Doodhatoli ranges of Pauri Garhwal, Uttarakhand. It spans 596 kilometers with a catchment area of 32,493 square kilometers, flowing through several districts of Uttarakhand and Uttar Pradesh, including Moradabad. Major tributaries like Khoh, Gagan, Aril, Sot,Kosi, and Deoha (Garra) contribute to its flow, with the Kalagarh dam situated in its basin [13]. The Sot River, also known as the Sot Nadi, originates in the lower Himalayan foothills of the Kumaon region in Uttarakhand, India. Flowing from these foothills into the plains of Uttar Pradesh, it passes through the Moradabad district before merging with the Ramganga River. The river's source is typically near Nainital, Uttarakhand, and its confluence with the Ramganga River is vital for local hydrology and irrigation. The Sot River is primarily used for agricultural irrigation and domestic water needs, and agricultural fields and patches of natural vegetation border it. Key sites along the Sot River include Asmoli Village in the Moradabad Division, with coordinates 28.7327°N, 78.5274°E and 28.710108°N, 78.536733°E (shown in Table 1). Nearby, pollution sources include industrial discharges and domestic wastewater, contributing to water quality issues in this area.

Similarly, the Aril River, originating from the lower Himalayan foothills of the Kumaon region, flows into the plains and merges with the Ramganga River in Moradabad. It is crucial in regional hydrology and irrigation, supporting agricultural and domestic needs. Notable sites along the Aril River include Raja ka Sahaspur and Rasulpur Kaili Village in Moradabad, with coordinates 28.6247999°N, 78.782153°E and 28.52271°N, 78.80787°E, respectively (Figure 1). Both sites face pollution challenges due to nearby industrial activities and domestic waste. The transition from hilly terrains to plains affects the river's flow rate and sediment load, further influencing water quality and ecosystem health.

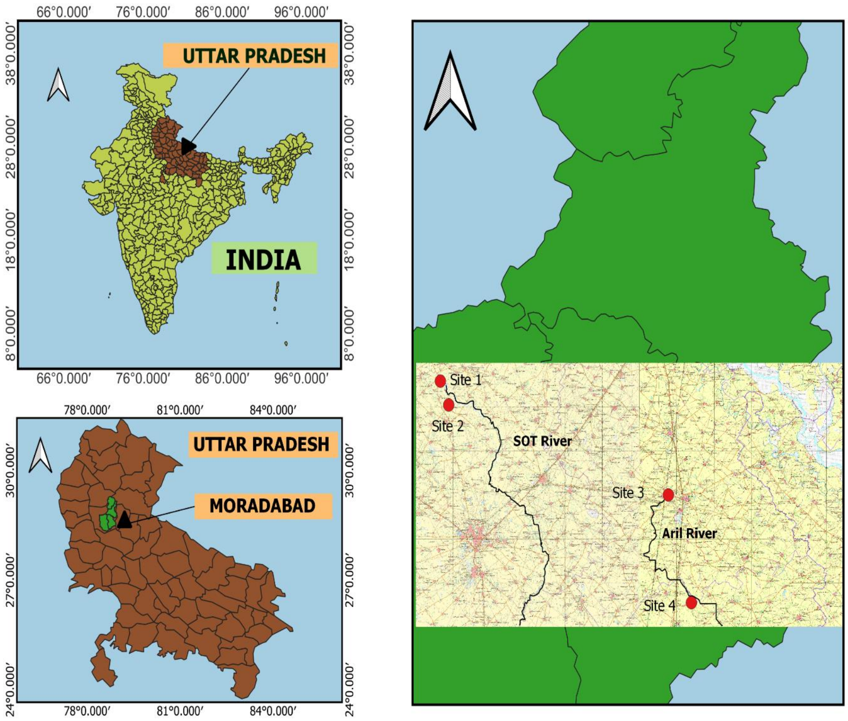

Figure 1: Research location

Table 1: Locations coordinate points with source of pollution

Sr. no	Location	Latitude	Longitude	Place	Drain/River	Source
1	Site 1	28.7327	78.5274	Asmoli Vilage In Moradabad Division	SOT River	Industries & domestic
2	Site 2	28.71011	78.53673	Asmoli Vilage In Moradabad Division	SOT River	Industries & domestic
3	Site 3	28.6248	78.78215	Raja ka Sahaspur in Moradabad	Aril River	Industries & domestic
4	Site 4	28.52271	78.80787	Rasulpur Kaili Village in Moradabad	Aril River	Industries & domestic

Material and Method

The research aimed to assess water quality in compliance and determine the pollution load and carrying capacity of the Ramganga River. The study focused on parameters like Total Dissolved Solid (TDS), Biological Oxygen Demand (BOD_3), Chemical Oxygen Demand (COD), Nitrate, and Ammoniacal nitrate. Sampling was conducted directly from the river at specific locations. Pollution load analysis was performed using following equations. These equations calculate both the actual pollution load (APL) and the maximum pollution load (MPL) based on pollutant levels and flow rates. The pollution load--carrying capacity (PLCC) was then determined by subtracting the measured pollutant load from the maximum allowable load according to quality standards [14].

The study of pollution load was by using the following calculation:

Actual Pollution Load:

$APL = (CA)j \times Qs$

where:

APL = Actual pollution load (kg/day)

$(CA)_j$ = Actual level of pollutant j (mg/l)

Qs= Discharge (ML/day)

Maximum pollution load (MPL):

$$MPL = (CAs)j \times Qs$$

where:

MPL = pollution load according to quality standard (kg/day)

Qs= Discharge (ML/day)

$(CAs)_j$ = maximum level of pollutant j,according to quality standard (mg/l)

Furthermore, the pollution load carrying capacity (PLCC) can be calculated as follow:

Pollution Load Carrying Capacity (PLCC) = Pollution load according to quality standard (MPL) – Actual Pollution load (APL)

Result and Discussion

To ascertain the pollution load carrying capacity (PLCC), it is essential to compute the differential between the maximum allowable pollution load (MPL) and the actual pollution load (APL). This computation necessitates data including river discharge rates and concentrations of various pollutants such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), nitrate, and ammoniacal nitrate, in accordance with established quality standards.[15]

River Carrying Capacity toward BOD

Table 2: BOD Pollution Load and Carrying Capacity Analysis

Sl. No.	Sampling Point	Discharge (MLD)	BOD (mg/l)	Actual Pollution Load for BOD $(APL)_{BOD}$ (Kg/Day)	Discharge Standard for Surface water (mg/l) (CPCB)	Max Pollution Load for BOD $(MPL)_{BOD}$ (Kg/Day)	Carrying Capacity for BOD (MPL-APL) (Kg/Day)
1	Site 1	1.3757	40.7143	56.0112	30	41.2714	-14.7398
2	Site 2	4.8386	199.1429	963.5669	30	145.1571	-818.4098
3	Site 3	1.4429	150.7143	217.4592	30	43.2857	-174.1735
4	Site 4	1.9614	174.1429	341.5688	30	58.8429	-282.7259

The carrying capacity for BOD, calculated as the difference between the maximum allowable pollution load (MPL) and the actual pollution load (APL), indicates that all sites have negative carrying capacities. The carrying capacity of BOD on site 1, site 2, site 3 and site 4 are -14.7398 kg/day, -818.4098 kg/day, -174.1735 kg/day and -282.7259 kg/day respectively as shown in table 1.This implies that the actual BOD pollution load exceeds the permissible limits at all sites. The analysis reveals that the river's carrying capacity for BOD is exceeded at all sampling points, indicating severe pollution levels. The ecological impacts include oxygen depletion, aquatic life mortality, and potential eutrophication, while health impacts range from increased risk of waterborne diseases to long-term exposure to harmful pollutants. Immediate remedial measures are required to mitigate these impacts and restore the river to acceptable quality standards.

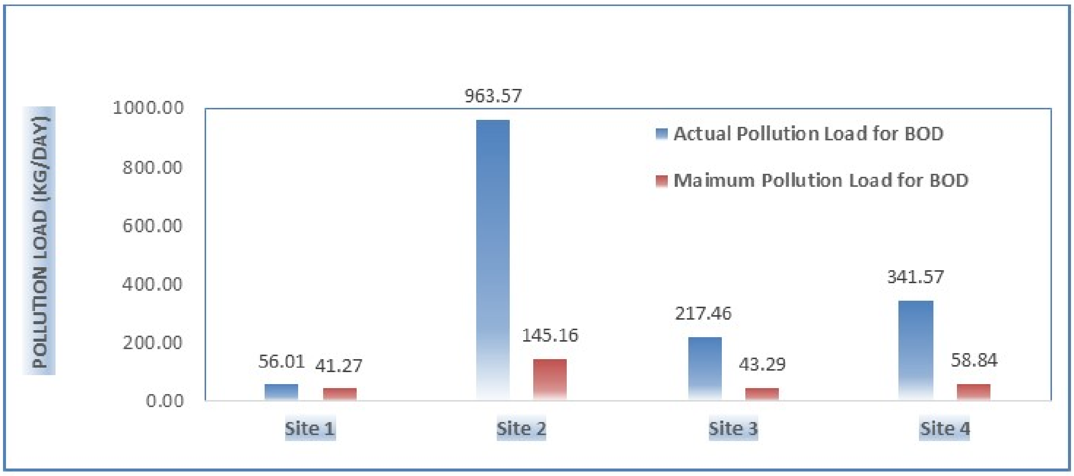

Figure 2: Pollution load towards BOD

As shown in figure 2, the graphic unequivocally demonstrates that the actual pollutant loads at all four sites exceed their corresponding maximum carrying capacities. This emphasizes how important it is to implement efficient pollution control strategies to preserve and improve the Sot and Aril Rivers' overall health.

River Carrying Capacity toward COD

Table 3: COD Pollution Load and Carrying Capacity Analysis

Sl. No.	Sampling Point	Discharge (MLD)	COD (mg/l)	Actual Pollution Load for COD $(APL)_{COD}$ (Kg/Day)	Discharge Standard for Surface water (mg/l) (CPCB)	Max Pollution Load for COD $(MPL)_{COD}$ (Kg/Day)	Carrying Capacity for COD (MPL-APL) (Kg/Day)
1	Site 1	1.3757	191.7143	263.7441	250	343.9286	80.1845
2	Site 2	4.8386	637.2857	3083.5524	250	1209.6429	-1873.9096
3	Site 3	1.4429	438.0000	631.9714	250	360.7143	-271.2571
4	Site 4	1.9614	465.1429	912.3445	250	490.3571	-421.9873

Chemical oxygen demand (COD) serves as a reliable indicator, quantifying the oxygen required for oxidizing organic substances in water. Essentially, it's a dependable measure to assess water pollution levels[17]. Chemical Oxygen Demand (COD) is a measure of the oxygen required for oxidizing pollutants in water[18]. The analysis of pollution load and carrying capacity for COD, at the four sites along the Sot and Aril Rivers highlights critical pollution issues exceeding the rivers' capacities. At Site 1, the discharge is 1.3757 MLD with a COD concentration of 191.7143 mg/l, resulting in an actual pollution load (APL) of 263.7441 kg/day. This is within the maximum pollution load (MPL) of 343.9286 kg/day as shown in Table 3 & Figure , leaving a positive carrying capacity of 80.1845 kg/day. This indicates the river can assimilate some additional pollutants without severe ecological damage.

However, Site 2, Site 3 & Site 4 have APL of 3083.5524 kg/-day, 631.9714 kg/day and 912.3445 kg/day respectively which significantly exceeds the MPL for all Sites. This results in a negative carrying capacity of -1873.9096, -271.2571 and -421.9873 kg/day, showing a severe overburden of pollutants far beyond what the river can handle, indicating high levels of organic and chemical contamination.This substantial exceedance shows that the pollution levels are far beyond what the river can assimilate, leading to severe environmental stress.

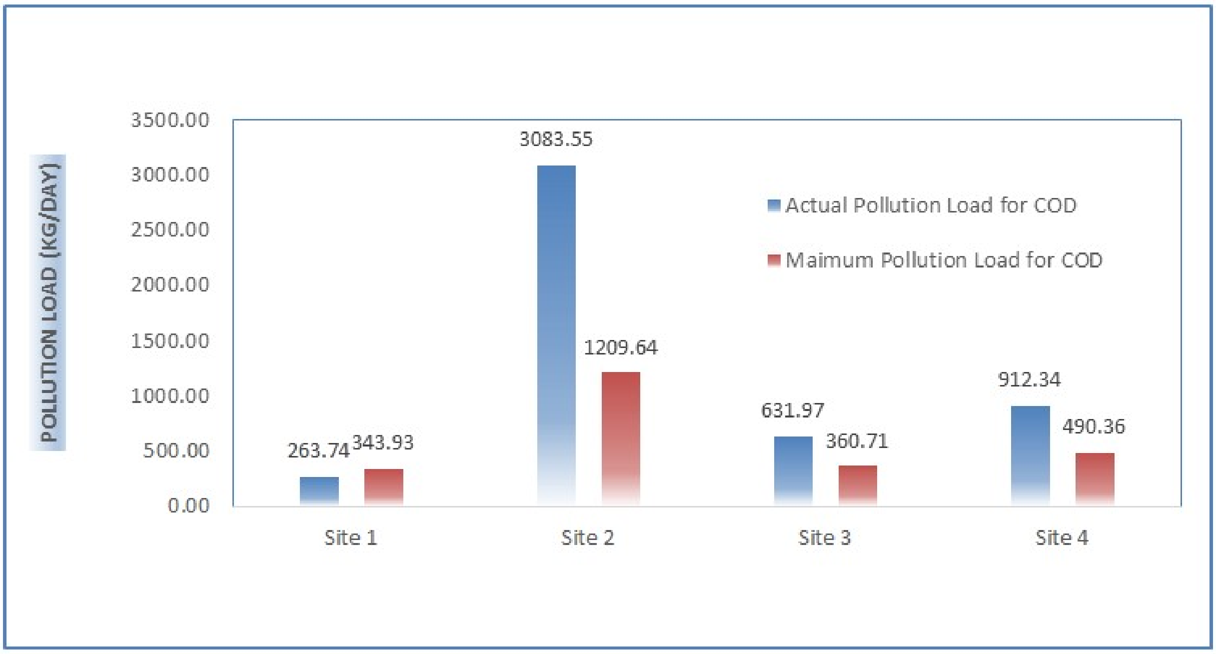

Figure 3: Pollution load towards COD

River Carrying Capacity towards TDS

Table 4: TDS Pollution Load and Carrying Capacity Analysis

Sl. No.	Sampling Point	Discharge (MLD)	TDS (mg/l)	Actual Pollution Load for TDS (APL)TDS (Kg/Day)	Discharge Standard for Surface water (mg/l) (CPCB)	Max Pollution Load for TDS (MPL)TDS (Kg/Day)	Carrying Capacity for TDS (MPL-APL) (Kg/Day)
1	Site 1	1.3757	769.71429	1058.9069	2100	2889.0000	1830.0931
2	Site 2	4.8386	1029.5714	4981.6549	2100	10161.0000	5179.3451
3	Site 3	1.4429	704.14286	1015.9776	2100	3030.0000	2014.0224
4	Site 4	1.9614	891.14286	1747.9131	2100	4119.0000	2371.0869

The composition of substances dissolved and suspended in liquid substances can significantly differ. Total Dissolved Solids (TDS) analysis plays a crucial role in determining the capacity of the Ramganga river to sustain life. TDS encompasses a variety of components including oxygen-demanding waste and disease-causing agents, which pose significant threats to the environment. These substances have the potential to cause extensive harm by depleting oxygen levels in the water and by serving as carriers for diseases that can affect both aquatic life and human health. Therefore, understanding and monitoring TDS levels is essential for safeguarding the health and ecological balance of the Ramganga river ecosystem [16].

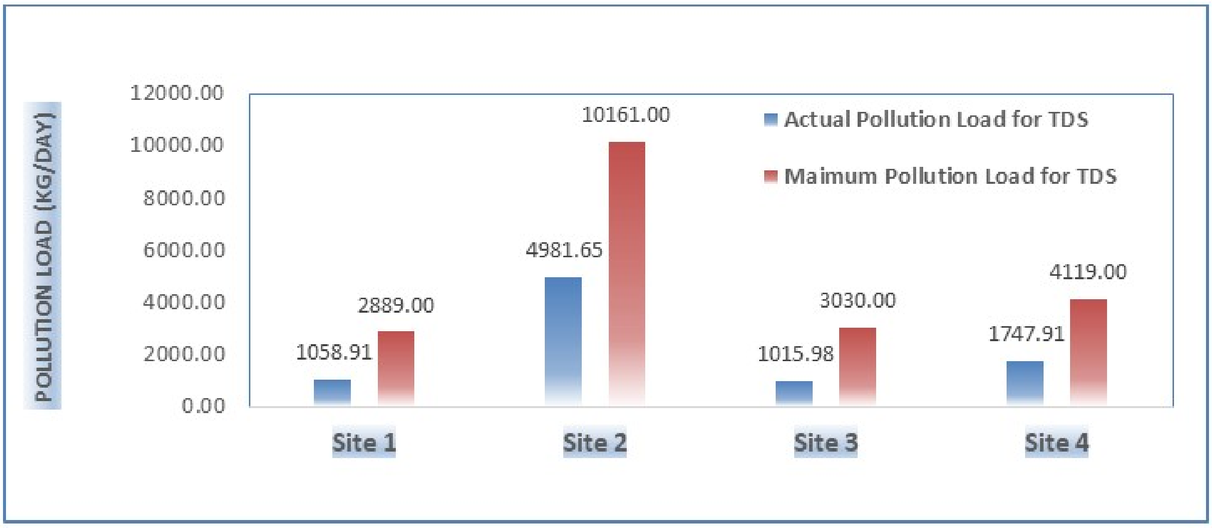

Figure 4: Pollution load towards TDS

The analysis of Total Dissolved Solids (TDS) pollution load and carrying capacity at four sites along the Sot and Aril Rivers shows that all sites have positive carrying capacities, indicating the rivers can currently handle the TDS levels without significant ecological damage. Site 1 has an actual pollution load (APL) of 1058.91 kg/day against a maximum pollution load (MPL) of 2889.00 kg/day, leaving a carrying capacity of 1830.09 kg/day as shown in Table 3 and Figure 3. Site 2 has an APL of 4981.65 kg/day and an MPL of 10161.00 kg/day, with a carrying capacity of 5179.35 kg/day. Site 3 APL is 1015.98 kg/day, within an MPL of 3030.00 kg/day, resulting in a carrying capacity of 2014.02 kg/day. Site 4 has an APL of 1747.91 kg/day and an MPL of 4119.00 kg/day, leaving a carrying capacity of 2371.09 kg/day. While the current TDS levels are manageable, continuous monitoring is essential to prevent future exceedances, which could degrade water quality and affect agricultural productivity.

River Carrying Capacity towards Nitrate

A nitrogen-oxygen combination, nitrate (NO_3^-) is frequently present in sewage and fertilizers. Excess nitrates in river environments can lead to eutrophication, which damages aquatic life by causing dead zones, oxygen depletion, and an overgrowth of algae. High nitrate levels in drinking water have been linked to cancer and other health problems in humans, as well as the birth abnormality methemoglobinemia in newborns.

Table 5: Nitrate Pollution Load and Carrying Capacity Analysis

Sl. No.	Sampling Point	Discharge (MLD)	NO3- (m/l)	Actual Pollution Load for NO3- (APL)NO3- (Kg/Day)	Discharge Standard for Surface water (mg/l) (CPCB)	Max Pollution Load for NO3- (MPL)NO3- (Kg/Day)	Carrying Capacity for NO3- (MPL-APL) (Kg/Day)
1	Site 1	1.3757	2.82	3.8795	10	13.7571	9.8776
2	Site 2	4.8386	3.20	15.5042	10	48.3857	32.8815
3	Site 3	1.4429	1.94	2.7991	10	14.4286	11.6294
4	Site 4	1.9614	2.38	4.6682	10	19.6143	14.9461

The analysis of nitrate (NO_3^-) pollution load and carrying capacity at four sites along the Sot and Aril Rivers reveals that all sites are within acceptable limits as shown in figure 4 and table 4. Site 1 has an actual pollution load (APL) of 3.8795 kg/-

day against a maximum pollution load (MPL) of 13.7571 kg/-day, leaving a carrying capacity of 9.8776 kg/day. Site 2, APL is 15.5042 kg/day, within an MPL of 48.3857 kg/day, resulting in a carrying capacity of 32.8815 kg/day. Site 3 shows an APL of 2.7991 kg/day against an MPL of 14.4286 kg/day, leaving a carrying capacity of 11.6294 kg/day. Site 4, APL is 4.6682 kg/-day, within an MPL of 19.6143 kg/day, leaving a carrying capacity of 14.9461 kg/day. These positive carrying capacities indicate that the rivers can handle nitrate levels without significant ecological or health impacts. However, continuous monitoring is essential to ensure these levels remain within safe limits to prevent future adverse effects.

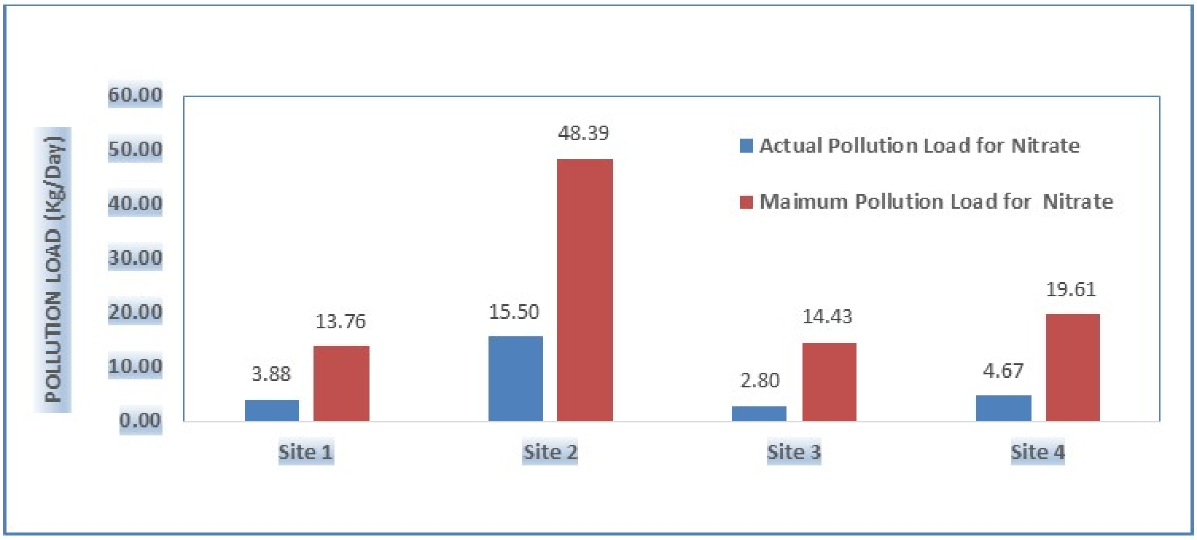

Figure 5: Pollution load towards Nitrate

River Carrying Capacity towards Ammoniacal Nitrogen (NH_3-N)

Ammoniacal nitrogen (NH_3-N), derived from agricultural runoff and wastewater sources, can harm river ecosystems and human health. In rivers, high un-ionized ammonia is toxic to fish and other aquatic life, impairing growth and reproduction and contributing to nutrient overloading and eutrophication. While ammonia poses less direct risk to human health, its presence indicates potential water quality issues. Effective waste management and water quality monitoring are essential to mitigate these impacts.

Table 6: Nitrate Pollution Load and Carrying Capacity Analysis

Sl. No.	Sampling Point	Discharge (MLD)	NH3-N (m/l)	Actual Pollution Load for NH3-N (APL)NH3-N (Kg/Day)	Discharge Standard for Surface water (mg/l) (CPCB)	Max Pollution Load for NH3-N (MPL)NH3-N (Kg/Day)	Carrying Capacity for NH3-N (MPL-APL) (Kg/Day)
1	Site 1	1.3757	13.1	18.0219	50	68.7857	50.7639
2	Site 2	4.8386	28	135.4800	50	241.9286	106.4486
3	Site 3	1.4429	24.757143	35.7210	50	72.1429	36.4218
4	Site 4	1.9614	17.871429	35.0535	50	98.0714	63.0179

As shown in table 6, the positive carrying capacity values for ammonia nitrogen (NH_3-N) at each site in the river illustrate the extent to which each site can accommodate additional pollutants before reaching regulatory limits as having maximum pollution load (MPL) more than actual pollution load (APL) . At Site 1, with a carrying capacity of 50.76 kg/day, the river can absorb this amount of additional NH_3-N without surpassing the maximum permissible load. Site 2 demonstrates the highest carrying capacity of 106.45 kg/day, indicating a robust ability to handle excess ammonia nitrogen compared to other sites. In contrast, Site 3 has a carrying capacity of 36.42 kg/day, reflecting a more constrained ability to absorb additional NH_3-N, nearing its MPL. Site 4, with a carrying capacity of 63.02 kg/day, falls between Sites 1 and 2, indicating a moderate level of tolerance for additional pollution

Conclusion

In the conclusion as BOD is showing negative carrying capacity at all the various sites which means the level of organic pollutants in the water exceeds the capacity of the ecosystem to naturally degrade or assimilate them, leading to environmental degradation and COD is also showing negative carrying capacity at all the sites which means the concentration of pollutants in the water is so high that it overwhelms the natural processes responsible for oxygenating and purifying the water. This leads to a situation where the ecosystem cannot effectively handle or break down the pollutants, resulting in a decline in water quality and ecological health. TDS is showing the positive carrying capacity at all various sites which means they do not pose a significant threat to the environment or aquatic life. A positive carrying capacity associated with TDS indicates that the water quality is within acceptable limits and can support a healthy ecosystem. Nitrate and Ammoniacal Nitrogen are showing the positive carrying capacity at all the various sites which means they do not pose a significant threat to the environment or aquatic life. In addition, this work provides valuable insights into the types and loads of pollutants in a typical river within the Ganga Basin, which can aid policymakers and planners in devising more effective and practical pollution control strategies.

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