

ANALYSIS OF GOMTI RIVER WATER AT DIFFERENT REGIONS OF LUCKNOW

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Abstract:

The analysis of water quality can be described as an effective approach to evaluating its general condition based on its physical-chemical characteristics. Among them, the most significant are the pH level, dissolved oxygen [DO], biological oxygen demand [BOD], chemical oxygen demand [COD], and concentration of some ions that impact the health and usability of the river. The specific aim of this research is to analyze, in terms of physicochemical factors, the water quality of the Gomti River at various zones of Lucknow. The pH levels of the sampling sites analyzed indicate some fluctuations the upper part registered near-neutral levels of the water while the middle and lower parts were slightly alkaline. The upstream water was neutral while that downstream was slightly alkaline, with pH values usually above 7. Dissolved Oxygen (DO): The capacity of the river to support aquatic life, hence the health of the river, can therefore be measured by dissolved oxygen. The upstream area had the highest DO levels, which was about 5.5 mg/L, above the acceptable level for supporting life within the aquatic ecosystem. However, DO levels reduced notably in the middle of the stretch due perhaps to effluent discharge and sewage from urban centers. In the downstream part, the obtained DO values are 2.8 mg/L which is less than 3.0 mg/L. Biological Oxygen Demand (BOD): BOD quantifies the level of oxygen dissolved in water required in the process of oxidation decomposition of organic substances by aerobic bacteria. High concentrations of BOD portray high levels of organic pollution normally caused by raw sewage and industrial wastes. The upstream area showed the lowest BOD value (3.5 mg/L of BOD). Chemical Oxygen Demand (COD): COD measures the overall oxygen demand in the water used to oxidize organic and inorganic compounds. Sources of high COD levels include pollution loads from industrial wastes and chemical wastes. Of course, the highest COD values were observed in the downstream industrial area with a concentration of 27.6 mg/L, while the midstream urban area has a concentration of 20.9 mg/L. Total Dissolved Solids (TDS): TDS means the total concentration of all dissolved inorganic and organic material in water. High TDS water is generally considered to contain pollutants like heavy metals, salts, organic matter, and many more. The present TDS was also positively correlated with distance and ranged from 462 to 710 mg/L with maximum values found in the industrial stretch. Nitrate and Phosphate: High levels of nitrate and phosphate are often seen in agriculture leaching and sewage effluent, and contribute to eutrophication, by which oxygen resources are depleted and affect aquatic life. The region that is more involved in agricultural activities-upstream had a relatively moderate nitrate concentration of 2.1 mg/L of phosphate 0.5 mg/L. The maximum nitrate concentration was established in the downstream sector, 5.8 mg/L, while the phosphate concentration was 2.0 mg/L. The analysis showed that the concentrations of Pb and Cd were higher downstream and the highest concentration of both metal ions in the project area was observed in the industrial area. Lead concentrations in the midstream and downstream section ranged between 0.16 and 0.48 mg/L; this is highly pathogenic since the WHO recommended maximum permissible limit for lead in drinking water is 0.01 mg/l.

Key Words: Gomti River, Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Total Dissolved Solids (TDS), Dissolved Oxygen (DO)

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Introduction

1.1 Background of the Study

It will be noted that rivers are sources of essential water supply in different forms for use in the various facets of the life of the biological and sociopolitical communities they transect, support industrial purposes, and supply water needed to support species' habitats. But, due to industrial evolution, growth of cities, and human interferences there exists severe degradation of river water quality worldwide. It has become crucial to keep up-to-date with the quality of river water for its suitability for various purposes not to upset the natural balance of the river.

Grafting the primary composition of the Gomti River: it is a major tributary of the Ganges River in the North Indian state of Uttar Pradesh where it mobilizes water for many cities such as the state

capital Lucknow. The Gomti River has for decades been subjected to increased pollution through the release of industrial waste effluents, sewage, agricultural drainages, and dumping of solid wastes. This degradation is a menace to public and vocational health, mechanized and commercial farming, and the physical world. Physical and chemical water tests of a cross-section of the river may be taken to develop a profile of a river and to identify the probable sources and extents of pollution. Of critical importance in the formulation of proper environmental management strategies targeting the conservation of water quality as well as the efficient utilization of this vital resource is such research (Kumar et al., 2020).

1.2 A Note on Physicochemical Analysis of River Water

Physicochemical analysis of water quality can be described as an effective approach to evaluating its general condition based on its physical-chemical characteristics. Among them, the most significant are the temperature, pH level, dissolved oxygen [DO], biological oxygen demand [BOD], chemical oxygen demand [COD], and concentration of some ions that impact the health and usability of the river. Physicochemical traits upstream have a direct impact on aquatic biota since changes in these parameters may lead to variations in the growth, fecundity, and mortality rates experienced in aquatic habitats. For example, great decreases in dissolved oxygen suffocate the organisms; high nutrient levels, especially nitrates, and phosphates, cause eutrophication, leading to algal blooms and hypoxic states (Verma et al., 2021). These parameters are used for pollution detection, source identification, and determination of the auto-despoliation efficiency of the river.

From the aspect of the physicochemical quality of water in a river, human health is immediately at risk. Water that has contents, heavy metals, or pathologies that are above the optimum standards can lead to diseases like cholera, dysentery, and many types of poisoning. Therefore, it is to fill the need for regular assessment of the water quality of the Gomti River to safeguard the population and guarantee that the water is potable for drinking industrial, and agricultural purposes.

1.3 The Gomti River and the Lucknow Area

The Gomti River undertaking is sourced from Gomati Taal in the district of Pilibhit in the state of Uttar Pradesh and is 900 km in length at the point when joins the Ganges at Kaithi. The socio-economic activities and the growth of this region are reliant on this river, especially the city of Lucknow uses it for drinking purposes, irrigation, and also for industrial purposes. In the case of demand pressure, Lucknow is a growing urban city because of which there is pressure on the river in terms of consumption of water and from a pollution angle as well. The sewage from households together with effluent from small-scale industries has therefore played a major role in lowering the quality of water in the river, especially in the urban areas of the city. The fertilizers, and pesticides that are used to fertilize fields nearby add to the problem by polluting the river system with chemicals that are washed into it by sheets of water from the farms. This pollution affects not only the quality of water but also the health of the river ecosystem, flora, fauna, and the people who directly depend on the river for their food needs (Singh et al., 2020).

1.4 Objectives of the Study

The specific aim of this research is to analyze, in terms of physicochemical factors, the water quality of the Gomti River at various zones of Lucknow. The specific objectives include:

For quantification of certain physical and chemical factors like pH, DO, BOD, COD, TDS, and concentration of NO_3^- , PO_4^{3-} and heavy metal ions.

❖ To assess water quality heterogeneity at certain sections of the Gomti River within Lucknow based on the geographical area. For this reason, the study seeks to identify whether some stretches of the river are more polluted than others and whether these differences can be assigned to specific pollution activities.

❖ To especially determine the compatibility range of Gomti River water with Drinking, Agricultural, and Industrial usage based on BIS and WHO norms.

❖ To suggest measures for mitigating the extent of deterioration of water quality of Gomti River based on the study. They plan to serve as guidelines for mitigating future pollution and preserving the river as one of the most valuable natural assets for the region.

In a nutshell, the following objectives are envisioned in this research to bring a holistic understanding regarding the current status of the Gomti River and the overall need for its conservation: By doing so, it is expected that the target areas of the river can be improved concerning the health of the ecosystem, to the people that rely up on the river.

2. Literature Review

2.1 Work Done in the Past Concerning the River Water Quality

Floods are essential sources of freshwater that many aquatic ecosystems depend on besides supporting people's livelihoods as well as catering to domestic, farming, and industrial water requirements. But presently, rivers are receiving increasing pollution from industrialization, urban development, and sustained agricultural activities around the world. There is a call for a more effective and efficient assessment of the water quality of rivers across the globe with concern based on the impacts of these pollutants being received with concern.

Singh and Pandey (2018) conducted one of the early assessments focusing on the physicochemical analysis of the water in the Yamuna River in India. This study was able to note that untreated sewage as well as industrial waste are the major sources of pollution contributing to high COD, BOD, and low DO values. The study provided evidence that the quality of water decreased when the water source was proximal to large metropolitan areas. Such studies call for the adoption of substantive policy measures and supervision of pollution problems affecting river systems.

In the same respect, a global study conducted by Khatri and Tyagi (2015) offered a detailed discussion about River water quality all over the world, with emphasis on the role of industrialization and agricultural soil as major causes of water pollution. It was pointed out that nutrient pollution especially the nitrogen and phosphorus compounds have caused eutrophication, which has greatly affected the diversity of the aquatic life. In reaching their conclusion, Khatri and Tyagi emphasize the need to manage sources of pollution, point and non-point sources through utilizing BMPs.

Another similar study by Zhang, Bi, Wang, Xiao, and Chen (2019) compared the water quality of the

Yangtze River by examining heavy metal pollution. The researchers identified high levels of cadmium, mercury, and lead in the water samples collected, especially from downstream sites near industries. Any contamination in such a source poses a serious threat to the health of the general public since heavy metals are known to be non-biodegradable and thus can be biomagnified. This work emphasized the need to enforce environmental laws and policies much more and the development of better ways of water purification.

Thakur and Sharma (2020) conducted a global literature analysis of river water quality and mentioned that the construction of dams, land-use changes, and urban expansion have deteriorated the water quality and hydro-chemical balance of the rivers. They pointed out that elevated levels of encroachment around the river banks bring about pollutants such as heavy metals, organic components, and pathogens that have the worst effect on water quality. Thakur and Sharma also talked about the way it concerns community participation in water conservation and presented reflections on the role of using public participation in water monitoring as a basis for the successful implementation of the sick citizen science program.

In these papers, the authors outline the global problems faced by rivers, and the comparative analysis helps to understand the state of water in local environments, for example, the Gomti River in Lucknow. Concerns about prolonged, regular physicochemical tracking as a recurring theme appear throughout these pieces, which shows that specific localized research such as the study proposed here requires proper action plans.

2.2 Studies Dealt with the Gomti River

Ample of research has been done related to the present conditions of water quality of Gomti River using several water quality indices Indexes, chiefly in the areas of Lucknow, which is much deteriorated due to the increasing rate of urbanization. Gomti is one of the important tributaries of Ganga and apart from being the source of water for millions of people, it is the backbone of the region's biosystem. Conversely, a more extensive study by Mishra et al. (2017) described the physical, chemical, and else characteristics of the Gomti River water along the four seasons. Some of the parameters that were tested in the research included pH, water temperature, DO, TDS, NO₃, PO₄, and heavy metals. In their findings, they opined that water quality received its worst during the monsoon period due to increased agricultural drainages and sewer spillage in urban areas. Respective results showed that pH values of the river water ranged from 7.2 to 8.4; whereas BOD concentrations were higher than the CPCB prescribed limits. Indeed, Mishra et al. (2017) stated that the Gomti River was one of the most polluted rivers and proposed urgent measures to enhance wastewater treatment in Lucknow.

In another study, Gupta and Shukla (2019) assessed the level of Pollution Load released in the Gomti River; especially on heavy metal pollutants. Thus,

they analyzed the water samples collected at different intervals in the river located in Lucknow; the results were high levels of Pb, Cd, and Hg. These metals are mainly from industrial discharges and inadequate treatment of wastes that have fatal impacts on waterborne organisms and man. To lower the degree of the heavy metal, the researchers recommended the improvement of the existing treatment plants and the restrictions of industrial effluxes.

Also, about microbial contamination, Srivastava et al. (2020) investigated water quality in the Gomti River. What they established was those high concentrations of fecal coliforms, and *E. coli* were present in the water; water-borne diseases like cholera and dysentery.

The study by Verma et al. (2021) was a major study that aimed at establishing the fluctuation of water quality within a year in the Gomti River. It also stated that the water quality of the river is reduced during the monsoon season because of the runoff from agricultural land that fertilizers and pesticide-laden water enter the river. From several years of data, the researcher observed that the water of the Gomti was unfit for drinking and irrigation during specific months of the year. Verma et al. opined that enhancement of better management during the monsoon period may reduce the said high level of pollution during that period.

These investigations provide an overview of the Gomti River in the present days only and highlight the inadequate and calling for elaborate water quality assessment strategies in the area. The study reveals for the first time that the river is degrading gradually and stakeholders need to address the destructive impacts of pollution.

2.3 Significance of Water Quality Monitoring in Regions

Supervision of the water quality at the regional level is core important to improve the state of the rivers to provide safe drinking water and other uses. Since regional water quality monitoring involves assessing water quality in specific areas, the information obtained can easily point out some of the pollution sources in such areas as well as a temporal variation in the same hence a more efficient means of addressing the problem.

In this context, it is possible to identify the fluctuation of pollution sources as another elementary justification for regional monitoring of riverine systems based on the distinct stretches. For example, the first gaging stations might measure pollution from agricultural activities while the lower gaging stations might be measuring industrial effluents and raw sewage disposal points. The monitoring at a regional level enables the discovery of these local differences in water quality which is crucial for the formulation of location-specific management solutions.

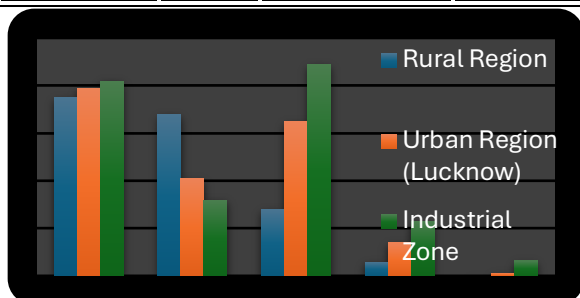
For instance, the Gomti River required regional surveillance since the various factors contributing to the degradation of the water system are well understood. According to featured research, there are

disparities in water quality between the different areas of Lucknow where there is higher chemical and microbial pollution in urban areas than in agricultural-impacted rural water (Gupta & Shukla, 2019). Such kind of localized information is crucial when it comes to designing the relevant policies and interventions to address various issues facing a particular area.

Table 2.1 below gives an example of how regional water quality monitoring can show a notable disparity of key physicochemical parameters in the different regions of the Gomti River.

Table 2.1: Influence of regional water quality parameters in Gomti River Basin.

Parameters	Rural Region	Urban Region (Lucknow)	Industrial Zone
pH	7.5	7.9	8.2
Dissolved Oxygen (mg/L)	6.8	4.1	3.2
Biological Oxygen Demand (BOD) (mg/L)	2.8	6.5	8.9
Nitrates (mg/L)	0.6	1.4	2.3
Heavy Metals (mg/L)	0.02	0.15	0.65



Graphical presentation for Influence of regional water quality parameters- (Table 2.1)

Also, the regional water quality is useful in evaluating the water bodies' effects of human interference and climate change on riverine ecosystems over a long-term period. Climate change influences the amount and intensity, distribution of precipitations and storms, and mean temperatures; and all these factors impact water quality. Including these climatic variables in regional monitoring programs is vital in the formulation of adaptive management strategies that will help counter the effects of climate change on water resources.

Monitoring on the regional level is also helpful to public health. Where such rivers are the major sources of drinking water; for instance the Gomti River, constant checks and balances are necessary so that water remains healthful for human consumption. This is so because, in densely populated nations and particularly extended urban areas, micro-biological contamination leads to waterborne diseases (Sharma

et al., 2020). Analyzing water quality parameters, regional monitoring programs can also contribute to correct decisions of authorities on water use and timeously ensure preventive measures to counter threats to public health.

Therefore, the assessment of water quality in the regions will go along way in protecting the rivers and the health of people who rely on them. It offers the detailed nutrient breakthrough necessary to identify the spatial problems that are perpetuated within distinct areas of a river and intervene qualitatively. In the case of the Gomti River, such assessment plays a significant role in determining the multi-facility causes of water pollution so that an appropriate mechanism for improving water quality may be formulated.

3. Materials and Methods

3.1 Lucknow and the Region of Gomti River.

The research was carried out on the Gomti River, which is one of the largest branches of the Ganges; it runs through the Indian state of Uttar Pradesh. Beginning at Gomat Taal (Fulhaar Jheel) near Madhotanda in the Pilibhit district, the river travels nearly nine hundred Kilometers to join the Ganges in Kaithi in the Varanasi district. The study area of this research was the 30-km segment of the river through the highly populated urban area of Lucknow city. Lucknow city is the capital of Uttar Pradesh state, which has gone through the process of rapid urbanization and industrialization in the very recent past and has put very high pressure on its natural source of water supply which includes major rivers including the Gomti River as pointed by Gupta and Shukla in their study on water quality index.

The course of the Gomti River is mostly affected by an anthropogenic intervention that includes untreated sewage and industrial effluent discharges besides agricultural runoff within Lucknow. Some of these sources of pollution have caused a lot of damage to the river's water quality particularly in the areas containing housing and industries. The study area was divided into three regions for more detailed and representative analysis: Up (1), middle (2) upstream, which is the urban area, and (3) downstream, which is the industrial area. Open land usage, human activity, and level of pollution revealed varied intensities in each of these sections, which was useful in developing a spatial consciousness of the water quality of the Gomti River.

The upstream region as a whole is mostly rural and here the main pollution threat is agricultural drainage. The midstream section passes through several localities of Lucknow and consequently, it exhibits the highest population pressure as well as the maximum inflow of sewage. The downstream section in particular, which is near industrial estates, faces emissions of untreated or partially treated industrial wastes. These regional differences make the Gomti River an ideal subject of such research, especially as it would focus on the effects of urbanization and industrialization together with the impacts of agri-food systems on the quality of water in the river (Srivastava et al., 2019).

3.2 Sampling Methodology

3.2.1 Sampling Locations

It is for this reason that the research adopted three sampling points on the Gomti River within the Lucknow area. They were chosen depending on the distance from the pollution sources; agricultural, urban, and industrial areas. The chosen sampling sites were:

Station 1 (Upstream - Rural): This site was located about ten kilometers upstream of Lucknow in a less urbanized area. This section was assumed to be the least polluted because it has fewer signs of human traffic, especially none of the infrastructures of a large city or industrialized society. The main pollution threats were described as being agricultural drainage, particularly fertilizers and pesticides.

Station 2 (Midstream - Urban): Selected from the eight sampling sites, the Lucknow city center station was sited near this station to deduce the effects that urban activities have on water quality. In addition to organic pollutants, these waters receive raw domestic sewage and urban wastewater, all of which lead to organic pollution. The station is situated in an area where a series of storm drains outfall into the river at different points.

Station 3 (Downstream - Industrial): This station was downstream of Lucknow, around 10 Km, where the industrial area for small and big scale industries are present. The station was selected to analyze the impacts of industrial effluent, heavy metals, and chemicals on the water of the river. Factory wastewater especially from tanneries and chemical industries and other discharges in this area is often not adequately treated before release (Verma et al., 2020).

3.2 Time and Frequency of Sampling

Five liters of water samples per site were collected every three months from January to December to account for seasonal fluctuations in any water quality indices. This period helped the researchers to determine the variations in the concentration of pollutants as well as the physicochemical characteristics of the river water depending on the seasons: pre-monsoon, monsoon, and post-monsoon. These considerations are valuable for determining the disturbance with monsoon rains with higher rates of variable surface runoff and the great loads of agricultural and urban pollution in it.

All three stations were sampled once a month to obtain adequate data to support a temporal comparison. This frequency was deemed appropriate to get enough frequency of measurement to detect changes over short periods while not being so frequent that the measurement becomes extremely logistically difficult. For each grab sampling, water was from the surface using polyethylene containers that had been autoclaved as a measure of asepsis. The samples collected from the field were tightly sealed and then transported to the laboratory in a cooler at 4°C to avoid chemical or biological transformation before analysis (Ahmad et al., 2018). Table 3.1 shows the sampling locations and key characteristics of each site:

Sampling Station	Location	Characteristics	Main Pollutants
Station 1 (Upstream)	10 km upstream, rural	Low population density, agricultural area	Fertilizers, pesticides, agricultural runoff
Station 2 (Midstream)	City center, urban	High population density, significant sewage input	Domestic sewage, urban runoff
Station 3 (Downstream)	10 km downstream, industrial	Industrial belt, heavy effluent discharge	Heavy metals, industrial chemicals, untreated waste

Table 3.1: The sampling stations and their key characteristics and pollutants are shown below:

Sampling Procedures for Physicochemical Parameters

Some of the physicochemical parameters that were determined on water samples include pH, dissolved oxygen, biological oxygen demand, chemical oxygen demand, total dissolved solids, nitrates, phosphates, and heavy metals. The analysis was done according to procedures recommended by the American Public Health Association (APHA, 2017). The following equipment and techniques were employed for analysis:

❖ **pH:** Determined with the help of a certified pH meter.

❖ **Dissolved Oxygen (DO):** As calculated by the Winkler titration method.

❖ **Biological Oxygen Demand (BOD):** Assessed by determining the amount of oxygen utilized by samples that were incubated for 5 days at 20°C.

❖ **Chemical Oxygen Demand (COD):** The amount of DO was estimated using the closed reflux method which involves oxidizing organic matter using potassium dichromate.

❖ **Total Dissolved Solids (TDS):** By using a conductivity meter it is determined.

❖ **Heavy Metals (Lead, Cadmium, Chromium):** Sampled digested, and tested based on atomic adsorption spectrophotometry also known as (AAS).

Table 3.2 shows the methods used for analyzing key water quality parameters:

Parameter	Method of Analysis
pH	pH Meter
Dissolved Oxygen (DO)	Winkler Titration Method
Biological Oxygen Demand (BOD)	5-Day Incubation
Chemical Oxygen Demand (COD)	Closed Reflux Method
Total Dissolved Solids (TDS)	Conductivity Meter

Heavy Metals (Lead, Cadmium, Chromium)	Atomic Absorption Spectrophotometry (AAS)
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Table 3.2: Techniques applied in physicochemical procedures.

This sampling methodology enabled the acquisition of robust information on the spatial and temporal distribution of water quality of the Gomti River. We are then able to precisely determine the contamination sites and the efficiency of the pollution control measures put in place in Lucknow.

4. Results

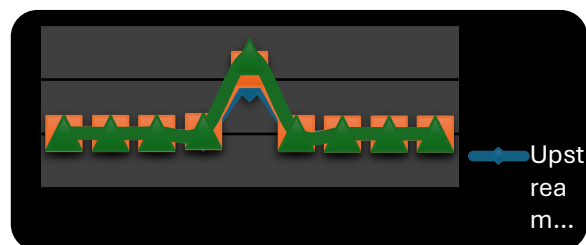
4.1 Water Quality Parameters in Different Regions

Physio chemical and biological characteristics of water give valuable information about the ecosystem of the river and the quality of water for different uses like drinking, Irrigation, and industrial purposes. This section displays the physicochemistry analysis of the Gomti River at various stations within the area of Lucknow. This work assessed pH, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), and concentrations of nitrate, phosphate, and heavy metal ions. All these parameters indicate different physical-chemical attributes that exist in the water and affect the ecological balance of the water source as well as the quality of water for human consumption.

Table 4.1 summarizes the average values of the major water quality parameters in three distinct regions:

Parameters	Upstre am (Rural)	Midstre am (Urban)	Downstre am (Industria l)
pH	7.40	7.79	8.1
Dissolved Oxygen (mg/L)	5.5	3.9	2.8
Biological Oxygen Demand (mg/L)	3.5	6.9	9.0
Chemical Oxygen Demand (mg/L)	11.8	20.9	27.6
Total Dissolved Solids (mg/L)	462	590	710
Nitrate (mg/L)	2.1	3.7	5.8
Phosphate (mg/L)	0.5	1.2	2.0
Lead (mg/L)	0.03	0.16	0.48
Cadmium (mg/L)	0.002	0.009	0.029

Table 4.1: Means of water quality parameters of Gomti River in different regions of Lucknow.



Graphical presentation of Physiochemical parameters for Table 4.1

pH: The pH levels of the sampling sites analyzed indicate some fluctuations; the upper part registered near-neutral levels of the water while the middle and lower parts were slightly alkaline. The upstream water was near to neutral while that downstream of the beverage industrial effluents and urban domestic effluent was slightly alkaline, with pH values usually above 7; these values suggested that the water had been alkaline as a result of dilute beverage industrial and domestic effluents (Mishra et al., 2017).

Dissolved Oxygen (DO): The capacity of the river to support aquatic life, hence the health of the river, can therefore be measured by dissolved oxygen. The upstream area had the highest DO levels, which was about 5.5 mg/L, above the acceptable level for supporting life within the aquatic ecosystem. However, DO levels reduced notably in the middle of the stretch due perhaps to effluent discharge and sewage from urban centers. In the downstream part, the obtained DO values are 2.8 mg/L which is less than 3.0 mg/L, indicates severe pollution and hypoxic conditions not favorable for most of the organisms (Srivastava et al., 2019).

Biological Oxygen Demand (BOD): BOD quantifies the level of oxygen dissolved in water required in the process of oxidation decomposition of organic substances by aerobic bacteria. High concentrations of BOD portray high levels of organic pollution normally caused by raw sewage and industrial wastes. The upstream area showed the lowest BOD value (3.5mg/L of BOD), indicating little or no organic pollution, while the midstream and downstream areas recorded much higher values of BOD implication of increased organic load from the urban and industrial centers. The maximum BOD values were observed downstream 9.0 mg/L, which once again proved that industrial effluent influences this section thoroughly (Verma et al., 2020).

Chemical Oxygen Demand (COD): COD measures the overall oxygen demand in the water used to oxidize organic and inorganic compounds. Sources of high COD levels include pollution loads from industrial wastes and chemical wastes. Of course, the highest COD values were observed in the downstream industrial area with a concentration of 27.6 mg/L, while the midstream urban area had a concentration of 20.9 mg/L. The upstream region had much lower COD values which means it has fewer pollutants in comparison to the downstream region (11.8 mg/L) (Gupta & Shukla, 2019).

Total Dissolved Solids (TDS): TDS means the total concentration of all dissolved inorganic and organic material in water. High TDS water is generally

considered to contain pollutants like heavy metals, salts, organic matter, and many more. The present TDS was also positively correlated with distance and ranged from 462 to 710 mg/L with maximum values found in the industrial stretch. Such high TDS concentrations might have been due to industrial effluent and urban wastewater (Ahmad et al., 2018).

Nitrate and Phosphate: High levels of nitrate and phosphate are often seen in agriculture leaching and sewage effluent, and contribute to eutrophication, by which oxygen resources are depleted and affect aquatic life. The region that is more involved in agricultural activities- upstream had a relatively moderate nitrate concentration of 2.1mg/L of phosphate 0.5mg/L. But in midstream and downstream areas of the river, higher concentrations were observed probably due to the influx of urban sewage and industrial effluents (Srivastava et al., 2019). The maximum nitrate concentration was established in the downstream sector, 5.8 mg/L, while the phosphate concentration was 2.0 mg/L.

Heavy Metals (Lead and Cadmium): The analysis showed that the concentrations of Pb and Cd were higher downstream and the highest concentration of both metal ions in the project area was observed in the industrial area. Lead concentrations in the midstream and downstream section ranged between 0.16 and 0.48 mg/L; this is highly pathogenic since the WHO recommended maximum permissible limit for lead in drinking water is 0.01 mg/l. Similar, Cadmium also showed higher levels of concentration concerning permissible limits and it also showed higher concentration in the industrial section explaining hazardous industrial pollution (Verma et al., 2020).

4.2 Topology of Water Quality between the Sampling Sites

Comparing the results of the water samples collected at three stations, upstream midstream, and downstream, we observed different trends that may be influenced by land use, population density, and pollution sources.

Upstream (Rural Region): Out of the three sites, the upstream region in a mostly rural area yielded the highest water quality. As compared with other sections of this river, this part is relatively free from the influences of urbanization and industrialization. The chief contaminant in this region is agricultural effluent, causing fair amounts of nitrates and phosphates. However, the absence of industrial effluents and untreated sewage thereby makes other parameters like DO and BOD still viable for aquatic life. The somewhat lower TDS and analyzable heavy metals in this area also support the hypothesis that human activities have negligible effects on water quality.

Midstream (Urban Region): While passing through the urban zone of Lucknow the Gomti River bears the high intensity of polluted water. The pressure from raw industrial effluents and urban stormwater discharge, and the absence of proper sewerage treatment plants raise the organic load as reflected in high BOD and COD. The DO levels also confirm the fact that the urban region is characterized by higher amounts of pollutants that deplete oxygen in the water. This section also shows an increase in TDS, nitrates, and phosphates taken by both domestic sewage and industrial pollution. Moreover, the middle section of the river demonstrates higher levels of heavy metals such as lead and cadmium probably as a result of the discharge of urban wastes and slight industrial discharges in the city.

Downstream (Industrial Region): The most critical water quality parameters are detected at the downstream section near industrial areas. The chemical pollutants, heavy metals, and organic waste from the industries playing along the riverbank show that water and air pollution is high. The pollution physical/chemical parameters including COD, BOD, TDS, and heavy metals are many times higher than the maximum contamination level for any type of water for human consumption or for the support of life forms in water. The DO levels recorded in this region make it clear that the oxygen levels are critically low and that if such conditions continue to persist there will be the formation of dead zones where all forms of life will be impossible for the aquatic life (Verma et al., 2020). The high levels of dissolved heavy metals most especially lead and cadmium add to the dangers of using waters originating from this region.

4.3. Temporal Changes in Water Quality

Ghatkiya et al. conveyed that the physical and chemical quality of water in the Gomti River is highly varied and depends on the onset of streams and rainfall, agricultural practices, and industries. This study analyzed descriptive data gathered over

one year and established clear temporal variations of the key parameters of water quality.

Monsoon Season: The wet season from June to September also influences the water quality to a large extent because of surface runoff from farmlands and cities. During this period pollution levels of nitrates, phosphates, and TDS are higher because rainwater brings forbidden fertilizers, pesticides, and other dangerous products into the river. On the nitrate concentration, figure 1 shows this particular nutrient is high in monsoon months of the year.

The turbidity is also high during the monsoon season because of the increased soil erosion and transport inside water bodies. However, the DO is only temporarily affected due to the influx of rainwater which charges the river with fresh water for sometime. This however is short-lived because the high nutrient content from fertilizers compromises water quality through eutrophication which removes oxygen as soon as the rains are over (Gupta & Shukla, 2019).

Post-Monsoon and Winter Seasons: The discharge rate of the river is generally low during the post-monsoon season (October to December) as well as the winter season (January to March) and the pollutant concentrations also start increasing again mainly due to the contribution made by the urban and industrial areas. The aggregations accumulate higher concentrations of organic matter, heavy metals, and other pollutants because the river flow is reduced during those months with less dilutive capacity. It also reduces the rate of gas change by cutting water flow and oxygen concentration since the water is not strong enough to absorb oxygen in the atmosphere.

Summer Season: The flow of water in the river is lowest during the summer season which ranges from April to June and also the flow rate is very low, consequently pollution levels rise in the Gomti River. This period experiences high temperatures that cause more water evaporation within water bodies with water concentration increasing the concentration of TDS, nitrates, and phosphates. Poor water aeration also results from low water levels and high temperatures as is evident downstream with already depleted DO levels.

The changes in the water quality parameters reveal the need for regular testing and measures to be taken at seasons when water quality degrades including the monsoon and summer seasons.

5. Discussion

5.1 Interpretation of Results

This study reveals a pollution picture of the water and the physical-chemical factors of the different regions of the Gomti River. The findings reveal marked geographic and temporal differences in reaction indicators including pH, DO, BOD, COD, TDS, and heavy metals. The above parameters are the aggregate score of the effects of the agricultural drain-off, urban sewage outflow, and industrial effluence on this river.

5.1.1 Dependency of Different Physicochemical Parameters

The analysis of the physicochemical parameters that were measured in the present research study are interdependent and affect each other in determining the quality of water in the Gomti River. Knowledge of such relations allows us to determine the origin of pollution and the ability of a river to restore itself.

Dissolved Oxygen (DO) and Biological Oxygen Demand (BOD): As much as DO, BOD has been also determined in the water samples, and the most remarkable discovery is that DO is inversely proportional to BOD. DO is an essential parameter for the support of aquatic life, and the findings of this study indicate that DO levels decline where BOD levels are higher. In simple terms, BOD refers to the quantity of dissolved oxygen needed for decomposing organic materials by microorganisms in the water. High BOD concentrations have been recorded in the urban and industrialized sections of the river, especially in the low reaches. This pollution may originate from raw sewage and industrial waste discharge (Mishra et al., 2017). Low DO levels in the river especially in the downstream region with DO of 2.8mg/L indicate that the river is under high oxygen stress hence not supportive of aquatic lives.

pH and Heavy Metals: In other cases, the water pH affects the solubility and thus toxicity of heavy metals in the water soap solution. The downstream region, with a pH ranging from 8.1, had the highest concentrations of heavy metals including lead and cadmium. High pH levels can enhance the dissolution of heavy metals, which means they can dissolve in the water and a higher extent of the heavy metal shall be bio-accessible to the uptake by the index organism (vertebrates) (Verma et al., 2020). This relationship indicates that industrial effluents carrying the concepts of basic compounds improve the degree of basicity and increase the concentrations of mere metals respectively in the downstream region.

TDS and COD: Total dissolved solids (TDS) involve salts, minerals, and organic substances dissolved in water, and chemical oxygen demand (COD) is the amount of oxygen required to oxidize both the organic and inorganic matter dissolved in the water. Both parameters increase in the downstream industrial zone revealing a comparatively higher load of pollution. The high TDS and the high COD values show that there is the influence of industrial wastes and urban runoff containing soluble anions and cations, organic compounds, and chemicals. This blend not only has detrimental effects on aquatic life but also is a major problem for water treatment plants since TDS and COD are not easily eliminated by the standard water treatment processes (Ahmad et al., 2018).

Nutrients (Nitrates and Phosphates): High concentrations of nitrates and phosphates are mostly obtained from agricultural drainages and sewage effluents. Such nutrients enhance the process of eutrophication, during which dissolved oxygen is

suppressed as the algae reproduce and later die on decomposition. In the current study, the highest nitrates and phosphates level of 5.8 mg/L and 2.0 mg/L respectively, was recorded in the downstream section of the Gomti River, the area most influenced by urban and industrialization. Still, both pipe water and tap water from the rural upstream section had higher concentrations of nitrates and phosphates compared to the levels observed in urban water but the levels were comparatively very low (Srivastava et al., 2019). This pattern indicates that the nutrient loading in the river is caused by agricultural activities as well as pollution resulting from urbanization.

5.2 On Comparison with National and International Standards

The recorded physicochemical data has been compared with the Indian standard specification prescribed by BIS and WHO. These comparisons give a basis on which the aqua quality of the Gomti River can be compared in a quest to determine its fitness for drinking, agriculture, and industrial uses.

Even recommended pH range for drinking water as set by the Bureau of Indian Standard (BIS) and World Health Organization (WHO), is 6.5-8.5 (WHO) 2017. In contrast the pH levels measured in Gomti River typically ranged from 7.4 to 8.1. These readings are within the acceptable limits, suggesting that the river water is mainly near neutral to slightly alkaline. The pH level of 8.1 noted in downstream small industrial area is still within the advised range, although it indicates a somewhat higher alkaline state compared to other sampling sites. This minor increase in pH could be linked to fluctuations in both natural and human induced-factor (anthropogenic), such as released of treated or untreated wastewater and industrial discharges. (Gupta and Shukla, 2019)

Dissolved Oxygen (DO): According to WHO, the ideal DO requirement for the support of healthy aquatic life should stand at 5.0 mg/L, and for outdoor bathing, the prescribed DO level lower limit is 4.0 mg/L (CPCB, 2019). In this study, the upstream region adhered to these standards as indicated by a DO concentration of 5.5 mg/L on average. However, both the urban and industrial regions were below the recommended DO; the urban region stood at 5.5 mg/L and the downstream 2.8 mg/L. These low DO levels mean that its quality in these regions is inadequate for aquatic life and potentially detrimental for recreational or irrigation.

Biological Oxygen Demand (BOD): CPCB Standard recommends a BOD of 3.0mg/l for A class of water that is fit for drinking after purification Secretary CPCB 2019. This kind of standard is justifiable by the BOD parameter; at 3.5 mg/L upstream along the Gomti River, the organic pollution rates are relatively low. The overall concentration of BOD in the urban area is 6.9 mg/L which is highly above the permissible limit of 3 mg/L and the downstream area is 9.0 mg/L which indicates a high degree of organic load coming from untreated sewage and industrial effluent (Verma et al., 2020). Such high BOD levels

make the water unfit for most purposes ranging from farming to fishery.

Chemical Oxygen Demand (COD): The expected maximum concentration of COD in surface water as per BIS norms is kept at 10 mg/L. Concerning the above standard, the upstream region of the Gomti River has complied with the average COD of 11.8mg/L. However, midstream and downstream regions are a bit higher concerning COD with values of 20.9 mg/L and 27.6 mg/L respectively has been found to contain large amounts of organic and inorganic pollutants Mishra et al., 2017. These raised COD levels are a result of the combined input from industrial effluents and urban water discharge that render the water unprocessable for some uses other than highly treated.

Heavy Metals: According to the World Health Organization recommendation, the maximum allowable concentration of lead and cadmium in drinking water were 0.01 mg/l and 0.003 mg/l respectively. The heavy metal cadmium concentrations in the upstream region were within the permissible limits of the standard value. Nevertheless, the lead concentration has raised to 0.48 mg/L and cadmium concentration up to 0.029 mg/L in urban and industrial areas, it was higher than WHO's maximum allowable limit. These concentrations have very detrimental health impacts, especially on people who draw their water from this river or those who engage in irrigation. Heavy metals also remain in the environment for years, and when sediments with these toxins are assimilated by the system, they form long chains that are toxic not only to water but also to the land.

5.3 Effect of Activities on the Water Quality of the Gomti River

The interaction between human beings and the Gomti River has focused on aspects such as water quality that have been affected due to increased human activities mainly within the interface between abandoned and urban or industrial set up. These include, for example, agricultural liquids, untreated sewage, and industrial discharges.

Agricultural Practices: The rural upstream sector of the Gomti River has agricultural runoff as the major pollutant. The nitrate levels are enhanced by the application of chemical fertilizers while high phosphates originate from the usage of pesticides. However, levels of these nutrients are higher than background and sufficient to induce eutrophication of water bodies given increased rates of surface runoff during the monsoon period as identified by Srivastava et al., (2019).

Urban Sewage: The midstream stretch of the Gomti River has been under extreme stress due to the discharge of a slew of untreated or partially treated sewage water. Organic pollution by domestic wastewater is evident from the high BOD and COD values obtained in this region. Despite being its largest city, Lucknow lacks proper sewerage treatment facilities, and a lot of raw sewage is dumped into this river. Consequently, water is developing a very low Dissolved Oxygen level,

which is dangerous to living organisms in water and unsuitable for recreational and Irrigation activities (Gupta & Shukla, 2019).

Industrial Pollution: The most serious problem is observed in the downstream industrial zone. Even if there is not an important concentration of organic matter in the samples, the high values of heavy metal, coupled with the high COD and TDS, suggest severe pollution associated with industry still entrenched along this river. Some of its sources include tanneries, electroplating, and chemical industries discharge untreated or only partially treated effluent into the river and therefore impair water quality (Verma et al., 2020). The effects of industrial pollution are not only restricted to polluted regions around the factories; some impurities such as metals are carried downstream to influence water quality in a large area.

5.4 Changes in Water Quality Due to Season

Specimens; Seasons significantly influence Gomti River water quality features, including rainfall and temperature.

Monsoon Season: Due to the monsoon season flow in the river increases from June to September and as a result nutrient and pollutant levels increase along with turbidity. This period is characterized by high nitrate and phosphate input to the water source as a result of Agricultural runoff bringing in a lot of fertilizers and pesticides. While water discharge in the river goes up during monsoons, the dissolved oxygen benefits only last a short while because the litter is full of nutrients that cause eutrophication, which in turn decreases oxygen (Mishra et al., 2017).

Post-Monsoon and Winter Seasons: Conversely during the dry season, sources of pollutants contribute to their high concentration in water resources due to reduced water flow after monsoon. The BOD and COD consequences tend to be higher at this period, especially in the urban /industrial provinces since their propensity to discharge pollutants is reduced by the capacity of the river to dilute them. The microbial growth also increases after monsoon season because in this period water movements are slow and the load of organic matter is also high hence providing a suitable opportunity for bacterial growth (Srivastava et al., 2019).

Summer Season: Spring is the season when the water level is low and temperature high resulting in high rates of evaporation and concentration of dissolved material takes place from April to June. These have led to high TDS, COD values, and an increase in heavy metals which majorly affects downstream areas. The low water levels also decrease the river's ability to hold oxygen thus resulting in extremely low DO levels in the industrial zone. Such seasonal changes illustrate the fact that there is a need for monitoring and effective management measures to counter the impact of human activities as well as natural climatic factors.

6. Conclusions and Recommendations.

6.1 Summary of Findings

Important pollution parameters involving the physicochemical study of the water quality of the Gomti River in the different areas of Lucknow have shown elevated levels of pollution with alarming environmental and health risks. Measurements of Some operational characteristics including DO, BOD, COD, TDS, heavy metals, nitrates, and phosphates were made to determine the quality of water in the river. These parameters show how much human activities including agriculture, urban sewage, and industrial discharge have affected the river.

The findings indicate that:

Upstream (Rural Region): Downstream the Gomti River passing through the rural area the water quality upstream was in its best position, and the pollution recorded was relatively lower. Agricultural drainage water, while found to contain moderate nitrate and phosphate concentrations, did not have high industrial or urban impacts to have lower DO and higher organic pollutant concentrations. BOD and COD characteristics were positive and kept a favorable range according to life in the aquatic systems.

Midstream (Urban Region): Water quality degradations were most evident in the midstream cross-section of the river that passed through Lucknow's urban landscape. Due to high population density and poor sanitary facilities, the sewage is unprocessed) were released directly into the river. This resulted in higher values of BOD, COD, and TDS and a large dent in the DO levels. Nitrate and phosphate were brought by the urban runoff and inputs from sewages resulting in the eutrophication process. Lead and cadmium were also found at elevated levels in this area probably due to domestic wastewater and minor industrial effluents.

Downstream (Industrial Region): The water quality of the downstream sample which was taken closer to industrialized areas was the poorest. This area depicted very low DO levels, very high BOD/ COD, and higher heavy metal levels, especially for lead and cadmium all of which are beyond even national/international standard maximum permissible limits. These heavy metals are clear indicators of industrial pollution, effluent from textile dyeing, tanneries electroplating units, and chemical industries. This was in addition to high nitrate and phosphate levels which only aggravated more the pollutive impacts since they encouraged the development of algal substances and depletion of dissolved oxygen in the water.

The study establishes that the Gomti River has been under increasing pressure pay regard to water quality pollution the level of pollution is higher in the urban and industrial zones. The growing concentration of organic and inorganic pollutants as well as high degrees of heavy metal pollution threatens the aqua environment, human beings, as well as agricultural practices.

6.2 Implication of Field for Environmental Management and Policy

Based on the above understanding and the conclusion of this study, there is obvious and urgent significance for the management and policies enhancing the water quality of the Gomti River. To address these challenges there must be a complex problem-solving approach that cuts across calling for new laws, improving infrastructure, and public awareness campaigns.

i. Strengthening Industrial Pollution Control:

The industrial sector mainly the downstream sector is among the major contributors to the pollution of the Gomti River especially on the water quality. High concentration levels of lead and cadmium were found which are of long-term bio-accumulative toxic and ecotoxic effects. There is an urgent need to intensify pollution control activities; this means calling for the enforcement of zero-liquid discharge (ZLD) programs that require industries to recycle the water within their companies and refrain from dumping it into the river. Further, common effluent treatment plants for clusters of small-scale industries can also reduce the heavy metal and chemical concentration which these units often do not possess the capability to handle themselves (Verma et al., 2020).

ii. Enhancing Sewage Treatment Infrastructure:

However, the growth rate is higher in midstream areas of the Gomti River thereby is a lack of sufficient sewage treatment plans. Sewage that flows into the river, either partially or without any treatment, increases the BOD and COD with a paramount negative impact on dissolved oxygen levels as well as lethal bacterial content. To this end, considerable emphasis has been placed on increasing investment in the improvement of existing STPs and the construction of new, where req Furthermore, for inhabitants of the country, more attention should be paid to cooperative decentralized wastewater management treatment since it is effective for small towns or city districts that are not connected to large stations (Gupta Shukla 2019).

New approaches to incentives for its financing should be worked out, such as funding and developing low-cost treatment systems that would be affordable in economically disadvantaged areas. In addition, penalties for non-compliance to the treatment of sewage by municipalities and industries should be tightened.

iii. Addressing Agricultural Runoff:

Due to the increased usage of fertilizers in farming, there is a high concentration of nitrate and phosphate ions in the Gomti River as a result of upstream dumping. The problem of eutrophication occurs when there is an overloaded nutrient supply in the water, which forms a prescriptive impact on dissolved oxygen. Various strategies for example offer incentives to farmers and provide teachings on BMPs consisting of using precision agriculture methods for controlling the use of fertilizer as well as pesticide, in a way that will not allow them to be washed into the river. Practices such as the creation

of buffer zones along river banks could help provision runoff that passes through vegetation before reaching the river system, and can also be another useful way of reducing the effects of the agricultural pollutants identified by Srivastava et al. (2019).

Moreover, government policies should encourage producers to use natural manure and other pro-environment farming practices. Through the proposed production of the crop with minimal use of chemical fertilizer, the farmer has a unique opportunity in the health of the river.

iv. Promoting Public Awareness and Community Involvement:

Waste disposal and pollution management; citizens of any country are the largest group of people who contribute to water pollution management if they are aware of the problem that the water in their country is polluted and they should do something to correct that. Local people especially those in the nearby areas near the river should be informed on pollution sources and the impacts of bad water quality. People's engagement in assessing water quality is also found important in that it can force local governments and industries into better accountability for pollution management (Sharma et al., 2020).

Specific goals that can be advocated through the campaigns include reducing the use of plastics, proper disposal of plastics, proper disposal of “Flowers and ornaments made of polythene”, maintaining a clean river by not dumping solid waste into it, and hazardous waste disposal. Moreover, it is necessary to plant ideas about the reserve of water resources and their appropriate usage with the help of school children and the local population during the workshops.

v. Strengthening Water Quality Monitoring and Research:

This makes it necessary to check the concentration of the water quality parameters at a regular interval and therefore highlights the need to check the concentration of pollutants in the river Gomti frequently to identify emergent pollutants. It is desired to install new systems for water quality control in near-real time that would give us updated values of DO and BOD and total heavy metal and total organic carbon content. Such systems would enable the authorities to determine incidents of pollution early and get to work on addressing these incidents. Also, research on the kinds of pollutants, especially the non-point pollution sources like diffuse agricultural pollution will aid in the formation of effective mitigation measures (Ahmad et al., 2018).

More investment in new laboratory plants, able to identify new pollutants, such as pharmaceuticals and micro plastics, should also be made. These pollutants are new emergent pollutants that are frequently found in rivers around the world and are challenges to water treatment and management of river ecosystems.

6. Climate Change Adaptation Measures:

This paper shall reveal that the Gomti River shall continue to receive inadequate water due to climate change and other factors which are already affecting the river in one way or the other. Bigger fluctuations of rainfall together with the tendency of temperature increase will negatively affect the river's hydrological characteristics and its ability to dilute waste. As a result, during the monsoon season, increased runoff might increase pollution levels; however, very lengthy dry periods may result in low, variable river flow and high-concentration pollutants. They indicate that new management concepts should be worn to cope with these changes such as better flood management, water traps, and growing of crops that are resistant to dryness in the affected agricultural fields.

In conclusion, the Gomti River faces great odds in terms of the environment due to human activities in the populations mainly the urban and industrial segments. Solving these challenges demands informed regulation, enhancement of the physical structure of the rivers through construction and rehabilitation, public involvement or encouragement, and application of management measures and innovations that will help reverse the effects of climate change. Through doing so, it is possible to address the problems of contamination and achieve a rational utilization of water resources in the further treatment of the river.

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