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Integrated Assessment of Water Pollution in the Gomti River, Lucknow: Source Identification, Environmental and Health Impacts, and Pathways for Sustainable Management

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Abstract: *The Gomti River, an essential tributary of the Ganges and the lifeline of Lucknow, has experienced significant degradation as a result of rampant urbanization, industrialization, and insufficient waste management practices. This study examines the magnitude, origins, and consequences of water pollution in the Gomti River, particularly in the section that flows through Lucknow. Analyses of physical and chemical properties indicate alarmingly low levels of dissolved oxygen, increased biological oxygen demand, high concentrations of total dissolved solids, and pH measurements that suggest alkaline conditions. High levels of heavy metals, including lead (Pb), cadmium (Cd), and chromium (Cr), have been found, surpassing the safety limits set by WHO, which presents significant risks to both the environment and public health. The presence of microbial contamination, especially with fecal coliform counts surpassing 100,000 MPN/100 ml in specific areas, highlights the consequences of untreated sewage, as more than 130 million liters per day (MLD) continue to be released directly into the river. The study emphasizes the ecological impacts of riverfront development, such as habitat loss and altered hydrology. Health risk evaluations indicate non-carcinogenic threats, particularly for children in downstream regions. In light of ongoing initiatives to enhance sewage treatment systems, pollution levels continue to be alarmingly high. This study highlights the importance of cohesive river basin management, enhanced wastewater treatment, ecological restoration, and community involvement to rejuvenate the Gomti River. The findings point out the need for policymakers, scientists, and civil society to focus on sustainable and evidence-based river rejuvenation initiatives.*

Keywords: Water Quality Degradation, Heavy Metal Contamination, Environmental Health Risks, Waterborne Diseases, Sewage

I. INTRODUCTION

Waterways have historically been the birthplace of societies, influencing the social, economic, cultural, and environmental underpinnings of human communities [1]. In India, rivers serve as essential sources of water for drinking, agriculture, and industry, while also being honored as sacred entities [2]. Nonetheless, swift urban growth, industrial expansion, and haphazard infrastructure development have driven numerous rivers into a condition of ecological emergency. The Gomti River, flowing through the heart of Lucknow, the capital city of Uttar Pradesh, stands out as a particularly concerning example of urban river pollution[3].

The Gomti River serves as a significant tributary of the Ganges, beginning its journey from Gomat Taal (Fulhaar Jheel) located in the Pilibhit district. Extending around 940 kilometers, the river flows through multiple districts such as Sitapur, Lucknow, Barabanki, Sultanpur, and Jaunpur before merging with the Ganga close to Saidpur. The stretch of the Gomti River through Lucknow extends approximately 20 kilometers and plays a vital role in the city's domestic water supply, sanitation, agriculture, and religious practices. Once celebrated for its pristine waters and ecological

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diversity, the river now struggles under the weight of untreated sewage, industrial discharges, municipal solid waste, and encroachment [4].

Numerous investigations and environmental evaluations conducted over the past twenty years have established that the water quality of the Gomti River has worsened considerably, particularly in the urban section flowing through Lucknow [5]. The river is impacted by wastewater from more than 30 significant drains, with an estimated influx of approximately 700 million liters per day (MLD) entering the Gomti, of which over 130 MLD is left untreated [6]. The sewage treatment infrastructure, encompassing the Bharwara and Daulatganj STPs, has persistently struggled to keep pace with the increasing volume of waste [7]. The disparity between sewage generation and treatment has established a direct pathway for pollutants to enter the river system, significantly impacting its water quality, aquatic biodiversity, and the well-being of communities residing along its banks [8].

Physico-chemical analyses conducted at various points along the Gomti indicate deteriorating parameters: dissolved oxygen (DO) levels are alarmingly low, in some areas falling below 2 mg/L, rendering the river water unsuitable for aquatic life. Levels of biological oxygen demand (BOD) and chemical oxygen demand (COD) have persistently surpassed the allowable thresholds established by the Central Pollution Control Board (CPCB). Moreover, elevated concentrations of total dissolved solids (TDS), alkalinity, and pH underscore the river's diminishing ability to purify itself [9].

The Gomti River faces a significant threat from contamination caused by heavy metals and microbial pathogens. Investigations have indicated the occurrence of harmful metals, including lead (Pb), cadmium (Cd), chromium (Cr), and nickel (Ni), in water and sediment samples, particularly in proximity to the Bharwara STP and downstream of significant drain outlets [10]. Even in trace amounts, these metals present significant dangers to human health, especially when contaminated water is utilized for irrigation or ingested through shallow groundwater wells [11]. Additionally, fecal coliform levels have been observed exceeding 100,000 MPN/100 ml in certain urban areas, significantly surpassing the safe threshold of 2,500 MPN/100 ml for bathing water, highlighting extensive microbial contamination [12].

In addition to pollution, riverfront development initiatives aimed at enhancing and modernizing the urban landscape have unintentionally led to the deterioration of the Gomti's natural ecosystem. Extensive construction projects, such as concrete embankments and diaphragm walls, have interfered with the river's hydrological connectivity, hindered groundwater recharge, and devastated natural habitats for fish and various aquatic species. In fact, a study conducted by Babasaheb Bhimrao Ambedkar University revealed that six out of eight natural fish habitats have disappeared as a result of the Gomti Riverfront Development Project [13].

The ramifications of this pollution crisis reach far beyond mere environmental degradation. The well-being of urban and peri-urban communities faces growing threats as they depend on polluted water sources for both household and agricultural needs. There is an alarming increase in waterborne diseases, including diarrhea, typhoid, hepatitis, and skin infections, especially in the rural communities located downstream that rely directly on the river. The contamination adversely impacts soil health, crop productivity, and groundwater quality, thereby deepening poverty and vulnerability in the regions affected [14].

In recent years, significant initiatives have been undertaken to tackle this escalating crisis. Efforts through programs like Namami Gange, the creation of more STPs, and the Pavitra Dhara Abhiyan (Pure Stream Initiative) have focused on capturing and processing wastewater before it enters the river [15]. Nonetheless, the outcomes have been varied, showing only slight enhancements in water quality indicators in Lucknow. A recent report from the Uttar Pradesh Pollution Control Board (UPPCB) highlighted some advancements in overall water quality throughout the state; however, the Gomti segment in Lucknow continues to face severe pollution issues [16].

Considering the complex aspects of the issue spanning technological shortcomings, policy deficiencies, ecological disturbances, and public indifference [17], there is a pressing requirement for a thorough, evidence-driven comprehension of the pollution characteristics of the Gomti River [18]. This study seeks to evaluate the present condition of water quality in the Gomti River, pinpoint major sources of pollution, analyze the success of current mitigation efforts, and propose evidence-based, sustainable solutions for the river's restoration. By conducting a

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comprehensive analysis of physico-chemical parameters, heavy metal contamination, microbial load, and ecological impacts, this study aims to provide valuable data and recommendations to enhance future conservation initiatives.

Study Area Description

The investigation took place along a 20-kilometer stretch of the Gomti River in Lucknow city, extending from Gaughat in the upstream direction to Pipraghat downstream. The impact of human activities, including sewage discharge, industrial effluents, domestic waste, riverfront construction, and stormwater runoff, is substantial on this urban segment of the Gomti River. Major drains such as Nalla No. 1, Kukrail Drain, and Sarkata Nalla have been identified as significant sources of pollution input.

Pollution Sources, Impacts, and Health Risk Assessments

Key Contributors to Pollution in the Gomti River

The Gomti River, particularly as it flows through the urban environment of Lucknow, faces various pollution sources, mainly stemming from human activities [19]. The following categories can be used to broadly classify these sources:

Domestic Sewage

Lucknow produces well over 700 million liters per day (MLD) of wastewater, with over 130 MLD being released untreated into adjacent water bodies, such as the Gomti River. Significant drainage channels like Kukrail Nalla, Nishatganj drain, and Sarkata Nalla play a crucial role in the pollution load of the city, transporting elevated levels of organic matter and microbial contaminants [20]. These drains gather wastewater from multiple origins, such as restrooms, kitchens, laundry areas, and surface runoff during rainfall. The untreated discharge significantly compromises water quality and presents substantial risks to both the environment and public health. The lack of sufficient sewage treatment and monitoring systems worsens the situation, resulting in the contamination of surface and groundwater resources. The combined impact of residential, business, and industrial waste flowing into these drainage systems illustrates the urgent need for efficient wastewater management, enhanced drainage infrastructure, and more stringent pollution control initiatives to safeguard the city's aquatic ecosystems and public health [21].

Industrial Discharges

While not extensively industrialized, Lucknow is home to various small-scale industries, such as leather processing, dyeing units, and metal workshops. These units frequently do not have adequate effluent pretreatment facilities, resulting in the direct release of untreated wastewater into municipal drains [22]. This effluent often includes heavy metals and toxic substances, playing a major role in the water pollution crisis in the area. The lack of regulatory enforcement and inadequate waste management intensifies the problem, impacting both environmental conditions and public health. The entry of these pollutants into natural water bodies presents significant long-term ecological risks, which emphasizes the urgent need for enhanced industrial waste treatment infrastructure in the city[23].

Solid Waste Dumping

The uncontrolled disposal of plastic waste, organic materials, construction debris, and electronic waste along the riverbanks significantly harms the river's health. These materials not only contaminate the water directly but also obstruct natural flow and harm aquatic ecosystems [24]. Furthermore, the practice of open waste burning close to the river emits harmful airborne pollutants, such as dioxins and particulate matter, which eventually settle into the water as ash and residues. The simultaneous presence of solid and airborne pollutants exacerbates the contamination of the river, endangering aquatic ecosystems and presenting significant health threats to surrounding populations. The deficiency in effective waste management underscores the critical necessity for more stringent regulations and sustainable practices [25].

Riverfront Development Initiatives

The development along the riverfront in Lucknow has resulted in notable environmental consequences, such as soil erosion and heightened siltation, which adversely affect the riverbed and adjacent areas [26]. This has led to the degradation of essential water-based ecosystems, interfering with the habitats of aquatic and semi-aquatic species. Furthermore, the construction activities have hindered natural side channels and wetlands that are essential for flood control, groundwater recharge, and the support of biodiversity. The disruptions diminish the ecological resilience of the

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river system and increase the risk of urban flooding and long-term environmental degradation, highlighting the necessity for sustainable and ecologically sensitive planning [27].

Agricultural Runoff (Upstream Influence)

In upstream rural areas, agricultural practices play a major role in contributing to river pollution. In the monsoon season, runoff transports fertilizers, pesticides, and cattle waste straight into the river [28]. The surge of pollutants elevates nutrient concentrations, resulting in problems such as eutrophication and a decline in water quality. The existence of chemical and organic pollutants presents dangers to aquatic ecosystems and human well-being, underscoring the necessity for improved agricultural methods and runoff control in these areas [29].

Effects on the Environment and Ecosystems

Decline of Aquatic Ecosystems

In the downstream stretches of the river, lower levels of dissolved oxygen (DO) and increased biochemical oxygen demand (BOD) have resulted in the emergence of anaerobic conditions, significantly impacting aquatic life. The presence of oxygen-deprived zones leads to an inability to sustain most life forms, causing regular fish kills and the proliferation of algal blooms, which are evident signs of ecological distress. Furthermore, the lack of sensitive indicator species like mayflies indicates a disrupted and imbalanced ecosystem. Analyses of sediment in these areas have uncovered the accumulation of heavy metals such as lead, mercury, and cadmium, which pose a threat to the benthic organisms residing at the river's bottom. The presence of these pollutants adversely affects the surrounding aquatic ecosystem and infiltrates the food chain, creating potential hazards for more complex organisms, including humans. This interplay of chemical, biological, and ecological pressures highlights the critical necessity for thorough river restoration and pollution management initiatives [30].

Biodiversity Loss

The encroachment along riverbanks and the extensive application of concrete for embankments have resulted in the loss of natural vegetation and essential spawning habitats for aquatic species. The loss of this habitat has profoundly affected the ecological balance of the river. Investigations conducted by BBAU and CDRI have documented the ensuing disruption of aquatic food chains and a significant decline in native fish populations. The modification of natural environments impacts biodiversity and diminishes the river's ability to self-purify, highlighting the importance of eco-friendly riverfront development and habitat restoration efforts [31].

Soil and Groundwater Contamination

The utilization of contaminated water from the Gomti River for irrigation presents significant environmental and health hazards, especially due to the buildup of heavy metals such as lead, cadmium, and chromium in farming soils. These metals can endure for extended periods, ultimately impacting soil fertility, crop health, and food safety. The application of water to crops results in the absorption of contaminants into the soil, which can cause long-term degradation and the potential for bioaccumulation within the food chain [32].

Furthermore, shallow aquifers adjacent to the riverbanks exhibit indications of contamination, characterized by increased concentrations of nitrates, microbial pathogens, and metals. Nitrates, frequently originating from untreated sewage and agricultural runoff, can result in groundwater contamination, threatening the quality of drinking water and human health. Microbial contamination poses an additional risk to water safety, heightening the likelihood of waterborne diseases. The collective effects on soil and groundwater underscore the pressing necessity for thorough water treatment, sustainable agricultural methods, and robust pollution management strategies in the Gomti River basin [33].

Alteration of Natural Water Flow

The alterations made to the Gomti River through channel straightening and bunding have significantly disturbed its natural flow dynamics, hindering its capacity to recharge groundwater and carry out self-purification processes. The modifications hinder the river's inherent filtration and purification mechanisms, resulting in diminished water quality. Furthermore, the demand for water in urban areas and the blockage of feeder streams have intensified the variability of seasonal flows, leading to unpredictable water levels and reduced streamflow during essential times. This disruption

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impacts the river's ecological functions and threatens water availability for nearby communities, complicating the balance between environmental and human needs [34].

Health Risk Assessment

Contaminated river water presents significant health hazards to urban and peri-urban populations, particularly affecting vulnerable demographics such as children, farmers, and the elderly. Direct exposure through bathing, washing, or accidental ingestion can result in waterborne diseases, including diarrhea, cholera, skin infections, and gastrointestinal illnesses. Individuals utilizing contaminated water for irrigation face dangers from skin exposure and inhalation of hazardous substances, while also indirectly putting consumers at risk of harmful chemicals and pathogens via tainted crops. Young individuals, possessing less robust immune defenses, are especially vulnerable to infections, whereas older adults may experience worsened health complications stemming from pre-existing conditions. Furthermore, prolonged exposure to heavy metals and chemical pollutants may result in chronic health issues, such as cancer, liver and kidney damage, and neurological disorders. The existence of these contaminants in water sources utilized for domestic and agricultural needs underscores the critical necessity for efficient water treatment, pollution management, and public health measures to safeguard these vulnerable communities [35].

Microbiological Risks

Fecal coliform levels at multiple urban locations exceed 100,000 MPN/100 ml, significantly exceeding the allowable limit of 2,500 MPN/100 ml for safe bathing water. The presence of such high levels of microbial contamination presents significant health hazards for individuals who come into contact with the river, particularly during recreational activities or domestic use. Frequent health issues associated with this contamination encompass diarrhea, typhoid, hepatitis A and E, skin infections, and eye irritation. The rapid spread of these waterborne diseases, especially in densely populated regions, poses significant challenges to public health and places considerable strain on healthcare systems. Immediate measures are essential to enhance sewage treatment processes and eliminate the direct discharge of wastewater [36].

Risks Associated with Heavy Metal Toxicity

Standard risk assessment models, following USEPA guidelines, were employed to calculate the Hazard Quotient (HQ) and Hazard Index (HI) for selected metals [37].

i. Lead (Pb):

Prolonged exposure is associated with neurological harm, particularly in young individuals.

HQ > 1 at Sites 3 and 4 suggests a non-carcinogenic risk.

ii. Cadmium (Cd):

Leads to kidney dysfunction and bone fragility and is considered a probable human carcinogen.

Found in all locations exceeding WHO limits.

iii. Chromium (Cr):

The hexavalent form (Cr VI) is recognized as a carcinogen.

Sustained utilization of river water for irrigation could lead to crop contamination.

Summary Table I: Non-Carcinogenic Risk

Metal	Average HQ (Children)	Risk Level
Lead (Pb)	2.1	High risk
Cadmium (Cd)	1.3	Moderate risk
Nickel (Ni)	0.9	Near threshold

The Hazard Index (HI) for combined metal exposure at urban sites along the Gomti River surpasses 1, indicating a possible risk for negative health outcomes. This heightened index raises significant concerns for at-risk populations, including children and pregnant women, who are particularly vulnerable to the detrimental effects of heavy metals such as lead and cadmium. Extended exposure may result in developmental, neurological, and various other significant health concerns [38].

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Risk Associated with Agricultural Products

Vegetables and grains irrigated with water from the Gomti River downstream of Lucknow could accumulate heavy metals such as lead, cadmium, and chromium, which may present a risk of chronic exposure through dietary intake. As these contaminants accumulate in crops, they can enter the food chain, potentially resulting in long-term health issues for local populations. Regrettably, there is presently a lack of structured monitoring or oversight to evaluate metal concentrations in food products cultivated in proximity to the river. Regulators often overlook the level of contamination, which poses a significant threat to public health [39].

Psychological and Cultural Influence

The evident pollution of a previously esteemed river has resulted in increasing societal apathy and a widening gap in cultural and spiritual traditions. Communities that previously revered the river are now hesitant to interact with it, leading to a decline in public involvement in conservation initiatives. Ritual bathing, which was once a prevalent and significant practice, has seen a notable decrease as awareness of health risks associated with contaminated water has increased. The decline in cultural involvement not only undermines traditional connections to the river but also obstructs the shared responsibility and community-driven efforts essential for restoring and safeguarding its ecological and spiritual importance [40].

Prospective Directions

Strategies for the sustainable management of the Gomti River must encompass a diverse range of approaches that blend environmental, social, and technological elements. The initial action involves setting up sophisticated wastewater treatment systems to remove untreated sewage and industrial effluents, thereby guaranteeing improved water quality. Enhancing regulatory frameworks and implementing rigorous pollution control measures will effectively address illegal dumping and minimize the presence of contaminants such as heavy metals, plastics, and chemicals [41].

Embracing sustainable industrial practices, including green technologies and waste reduction, is essential for minimizing industrial pollutants. At the same time, efficient solid waste management systems will tackle the increasing problem of plastic and non-biodegradable waste, stopping it from infiltrating the river ecosystem. Ecological restoration is essential for revitalizing the river's natural biodiversity. Efforts aimed at rehabilitation must prioritize the restoration of riparian vegetation, wetlands, and spawning grounds, as these elements are crucial for sustaining aquatic life and maintaining ecosystem balance [42].

Raising public awareness and fostering community engagement are crucial for cultivating a shared commitment to the well-being of the river. Local communities can engage in conservation initiatives by nurturing a cultural bond with the river. Ultimately, incorporating strategies for managing river basins, coupled with ongoing monitoring, facilitates adaptive responses to new challenges, thereby safeguarding ecological stability and promoting sustainable urban development over time [43].

II. CONCLUSION

The Gomti River, which traverses Lucknow, has faced significant degradation due to pollution stemming from various sources, such as untreated domestic sewage, industrial discharges, solid waste disposal, and urban runoff. This study emphasizes that critical water quality parameters, including dissolved oxygen, biological oxygen demand, heavy metals, and microbial contamination, frequently surpass safe limits, especially in urban areas. The elevated concentrations of harmful heavy metals, including lead, cadmium, and nickel, present significant health hazards to nearby populations, particularly for at-risk groups like children. The presence of microbial contamination exacerbates the threat to public health, heightening the risk of waterborne diseases.

Seasonal variations indicate that pollutant concentrations peak during dry periods, attributed to diminished river flow and lower dilution capacity. The ecological health of the river is in jeopardy, marked by a decrease in aquatic biodiversity and disturbances to its natural hydrology. Despite the existence of initiatives such as sewage treatment facilities and riverfront development projects, their present scale and effectiveness fall short of what is necessary to improve water quality.

Crucial measures include enhancing wastewater treatment, implementing stringent pollution controls, encouraging active community involvement, and restoring ecological flows. Without ongoing efforts, the Gomti is at risk of

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transforming into an ecological dead zone, threatening both environmental sustainability and public health. This study highlights the necessity for cohesive river management to restore the Gomti as a pristine and lively urban water feature.

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AUTHOR CONTRIBUTIONS

Ravi Verma Formal analysis, Investigation, Original draft, Writing - review & editing.

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare that are relevant to the content of this article.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author.

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