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Water Pollution in a Densely Populated Megapolis, Dhaka

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Abstract: Rapid urbanization has been a boon for industrial growth in Bangladesh, leading the Dhaka megapolis to become one of the least livable places in the world. These circumstances, however, have received little attention by policy makers and in academic research. Using mainly secondary data, this article explores the water quality of the river Buriganga that flows across Dhaka and identifies major sources of pollutants. While much of the article analyzes the sources and extent of pollution, it also points toward a great threat to public health from the presence of high levels of heavy metals, such as chromium, lead, and iron, as well as chemicals, including ammonia and phosphate. Moreover, the article recommends some policy changes that could potentially reduce pollution levels and boost water sustainability not only in Dhaka but also in other fast-growing cities in the least developed countries (LDCs).

Keywords: urbanization; water pollution; environmental sustainability; megapolis; Dhaka; LDCs

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1. Introduction

Dhaka, the capital of Bangladesh, is predicted to be the sixth-largest megapolis by 2030 [1]. Coupled with this rapid growth, it is the most densely populated and least habitable city in the world, which poses safe water challenges. Dhaka is not a planned city and much of its urbanization is linked to its industrial development, which over time has resulted in decreased water quality [1,2]. Inadequate sewage and inefficient waste management contribute to the water pollution, resulting in water quality in the river to parameters far below the critical limit [3]. Moreover, untreated industrial waste and household sewage are discharged into the river system, leading to the extinction of aquatic life and the failure of ecosystems. Furthermore, industrial effluents have damaged land fertility around Buriganga and affected the agriculture. The accumulation of waste has also reduced the navigability of the river, adversely affecting the water transportation system [4].

Both industrial and human waste have increased the level of biochemical substances and heavy metals in water, posing a great threat to the aquatic system and public health [5]. Chemical substances, such as biodegradable oxygen demand (BOD) and chemical oxygen demand (COD), have increased the acidity levels in water and destroyed the underwater microorganisms while heavy metals caused a threat to human organs. The use of fertilizers and pesticides in agriculture likewise contributes to the deterioration of surface water quality and contaminates groundwater aquifers [6].

The Buriganga is a major source of water for domestic and industrial use, as well as a means of transportation; it also helps dilute the non-degradable pollutants. However, a high concentration of pollutants degrades its purification capacity. The dilution and reoxygenation capacity is particularly reduced significantly during the dry season, resulting in a high presence of BOD and COD, and a low presence of dissolved oxygen (DO). Untreated municipal sewer and industrial effluents result in water being highly contaminated by eutrophication. During flooding, such polluted water comes in human contact and adversely affects the public health of the megapolis [7].

A few studies have explored the presence of heavy metals in the aquatic system in the Buriganga, but the effects of acute toxicity and genotoxicity on the fish and human population have hardly been addressed [8,9]. Some have studied water pollution in relation to climate change and negative consequences on urban poverty, mortality, and morbidity [10–12]. However, the study of water pollution management at different urban levels is scant, especially in the context of LDCs [13]. This article explores the sources of pollution and analyzes the nature and extent of pollution that negatively impacts public health, while offering some management strategies of reducing the pollution. Such strategies address both wastewater management (% of compliant discharges) and waste management (waste and waste production), which have implications for water sustainability in cities [14].

The succeeding section is set to present a discussion on the methodology. Section 3 discusses sources of pollution, leading into Section 4, which analyzes the categories of pollution. Section 5 focuses on the extent of pollution, followed by the discussion section highlighting the potential consequences. Section 7 offers some policy strategies to control pollution at sources. The final section draws conclusions, while making recommendations for future research and pointing to limitations.

2. Methodology

The study follows a mixed method strategy to analyze the data, collected from both secondary and primary sources. Primary data were collected from both point and non-point sources that contribute to water pollution of the river, while visiting physically alongside the river. The study identifies both point and non-point sources of pollution, as well as the source at the Sewerage Treatment Plant at Pagla (PSTP). The point sources are grouped into three: Sluice gates alongside the Dhaka Integrated Flood Protection (DIFP); city drains along the Buriganga; and outfall from the PSTP. The non-point sources include domestic and industrial waste. We clustered the industries on the basis of type, and measured the pollution discharge in (m^3/day) at 6 points. Domestic wastewater was observed from Lalbagh throughout the Babubazar area, and industrial wastewater was observed from Zinzira to Keraniganj. We looked into industrial pollutants, domestic sewers, clinical waste, and physical encroachment, which contribute to major pollution of the Buriganga.

Secondary data were collected from institutions, such as Institute of Water Modelling (IWM), Water & Sanitation Program (WSP), and Dhaka Water Supply & Sanitation Authority (DWASA). We explored a range of pollutants and their extent, including BOD_5, COD, ammonia (NH_3-N), ammonium (NH_4-N), nitrate ion (NO_3-N), phosphate ion (PO_4), chromium (Cr), and lead (Pb) between 2005 and 2018 (measured in kg/day) as well as the "coliform" measure (per 100 mL). We also looked into the BOD_5 presence in wastewater (ml/L), flowrate (m^3/day), and BOD_5 level at PSTP. Pollution was measured using the 'wet method' at four seasons. The waste-water flow was counted for 12 h in a day, taking into account the tidal influence and water consumption practices [15]. Pollution load = Concentration (mg/L) × Flow (m^3/s) × Flow time [= Conc. (mg/L) × Q (m^3/s) × 12.0 h = Conc. (gm/m^3)/(1000 gm/kg) × Q (m^3/s) × (3600 s/h) ×12.0 (h/day) = Load (kg/day)].

We analyzed both primary and secondary data and explored the nature and extent of pollutants in water.

3. Point and Non-Point Sources

Due to poor revenue sources of the city governments, the sewerage network is absent in some locations, so sewage is connected with the storm water lines there. The disposal of untreated industrial and chemical waste into storm sewer lines ultimately contaminates the river water. Other causes of pollution include the solid waste dumping points besides the river, lack of sanitary latrine facilities for the poor living nearby, obstruction of the natural flow of water due to engrossments, pollutants at the PSTP, and absence of a sanitary sewage system alongside the Buriganga river.

Industrial and household waste cause damage to the physical, chemical, and biological properties of water. High temperature and turbidity, and unbalanced hydrogen (pH) and DO damage algae and the water ecosystem. There are mainly two categories of pollution sources—point sources and non-point source—that contribute to water pollution of the Buriganga and the connecting Turag River. Pollution loads from various point and non-point sources are tabulated in the tables in Appendix A. Figure 1 below presents the Buriganga in the southwest of Dhaka, which is connected with the Turag in the northwest, and Balu and Shitalakhya in the east.

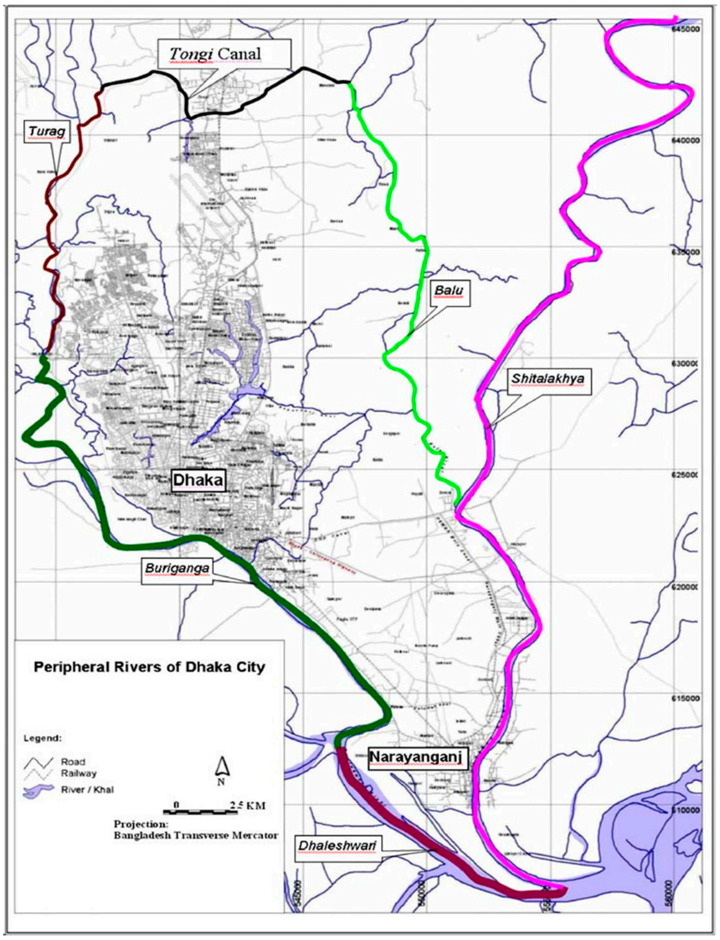

Figure 1. The Buriganga crossing Dhaka and its connection with other rivers.

3.1. Point Sources

In reference to map 1, the point sources of pollution of the Buriganga are identified as: Group 1: Sluice gates alongside the Dhaka Integrated Flood Protection (DIFP); Group 2: City drains along the Buriganga, including the Dholai Khal; and Group 3: Outfall from the PSTP. These sources largely make the river water contaminated and the worst quality for human usage and underwater microorganisms.

3.1.1. Group 1

The sluice gate along the DIFP Embankment: Eleven sluice gates are found alongside the DIFP embankment. Sluice gate S-6 mainly drains out storm water and sewage from Mohammadpur, Kallyanpur, and adjoining areas through Kallyanpur Khal and part of Ramchandrapur Khal. During high-flow seasons, it washes all small-industrial waste and household waste into the Buriganga, while S-7 drains out the toxic ternary waste from Hazaribagh, which largely contributes to the pollution of the Buriganga. Along with the tannery waste, it discharges household waste from the neighboring areas through Kantasur Khal.

A part of Ramchandrapur Khal drains out dark and toxic wastewater through S-7. Household waste from Rayerbazar, Nimtala, Sultanganj, Zigatala, Nawabgonj, Gajmahal, Kantasur, and West Dhanmondi is discharged to Buriganga through S-7, which also carries the tannery waste from Nimtala Beel to Buriganga. S-8 also carries tannery waste from Borhanpur, Kanipara, and Battola areas, which is later discharged into the Buriganga river. Both sources pollute the water of the Buriganga, while S-9 drains out wastewater from Pilkhana, Enayetgonj, Ganaktuly, Azimpur, Bhagalpur, and Nawabgonj, and S-10 drains out wastewater from Shahidnagar, Balughat, and Amligola into the Buriganga.

3.1.2. Group 2

Municipal drains: 41 drains in Dholai Khal area carry municipal wastewater into Buriganga. Mostly earthen canals pass over Postagola-Shashan Ghat to Balubazar. In the Dholai Khal area, one of the major channels of water pollution of the river Buriganga, 40% of the total pollutants is discharged at these points (Bhuiyan, Rakib, Dampare, Ganyaglo, & Suzuki, 2011). Gerani Khal, connected with Dholai Khal, discharges wastewater from part of Narinda, Saidabad, Farashganj, and the adjoining area of Hrishikesh-Dash Road. Untreated wastewater through these channels directly flows into the Buriganga river and deteriorates its water quality.

3.1.3. Group 3

The Pagla Sewerage Treatment Plant (PSTP): The PSTP is the only point where municipal wastewater is treated before falling into the Buriganga. This plant is located at S-7 and Dholai Khal, which controls the pollution level of wastewater at that point. As such, the level of pollution is less at S-7 and Dholai Khal, compared to that of other sluice gates alongside the Buriganga river. However, the PSTP treats a lower volume of wastewater than its capacity due to the low flow of wastewater during dry seasons (approximately 48,000 m^3/day), and such plants are absent at points of other sluice gates alongside the Buriganga river. The following Figure 2 demonstrates the dark wastewater, which directly falls into the Buriganga in the absence of the Sewerage Treatment Plant at the points of all sluice gates except S-7 and pollutes the river water.

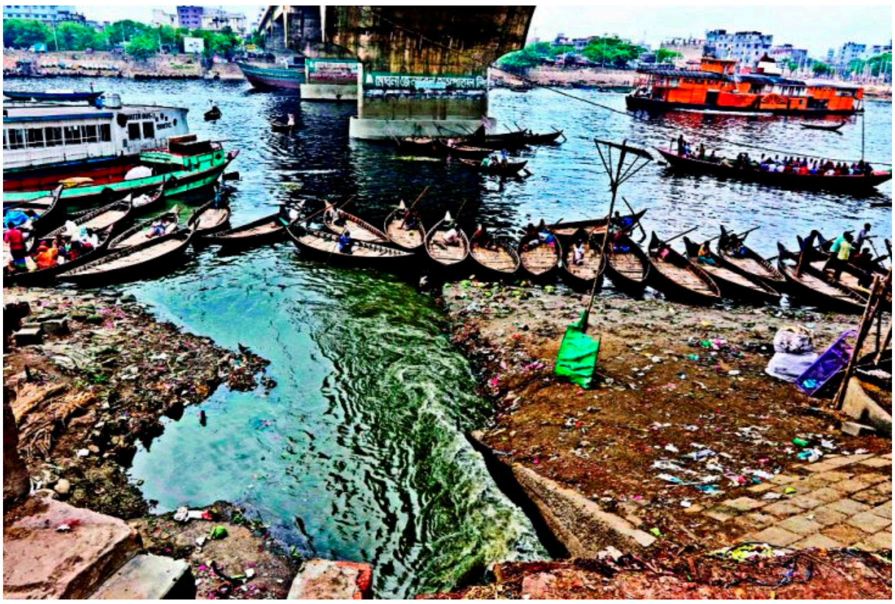

Figure 2. The usual quality of wastewater falling through the sluice gates.

3.2. Non-Point Sources

Numerous non-point sources of domestic and industrial waste also contribute to water pollution of the Buriganga. Significant domestic wastewater is discharged into the Buriganga water from the Lalbagh area throughout the Babubazar area. The indiscriminate release of wastewater deteriorates the quality of water, particularly in the dry season when the volume of water is lower, resulting in the river water becoming more dark with a pungent smell. Moreover, industrial wastewater from the densely populated Zinzira to Keraniganj significantly contaminates the Buriganga water.

Both point and non-point sources of pollution ultimately transform the water into the condition that is visible in Figure 2.

4. Categories of Pollution

Industrial pollutants, domestic sewage, and clinical waste largely contribute to the water pollution of the Buriganga river. The untreated sewage and industrial waste pollute the water. As a result, the water looks dark at some points, and a greasy film on the surface is visible in a vast area of the river. The concentration of pollutants at different points of the river is, however, due to the adjacent source and type of pollutants being discharged into the river.

4.1. Industrial Pollutants

Both light and heavy industries that contribute to pollution of the river water include textiles, polythene, rubber, dry cell, cosmetics, paint, soap, plastics, and chemicals. Leather and textile industries channel toxic wastewater into the Buriganga (and Turag) and contribute much to river pollution. Approximately 15,800 m^3 of wastewater are discharged per day from the sole leather industries in Hazaribagh area, and 3400 m^3 of wastewater from the textile industries in Fatullah, which contributes to 17,600 and 3850 kg/day, respectively, of BOD. The pollution contributors to Dhaka's rivers and its location are presented in Table 1. The total BOD load at several points of the Buriganga near these industries is much higher than tolerable levels, making river water highly contaminated and toxic for human use and the water ecosystem.

Table 1. Industries in and around Dhaka.

Cluster Name	Type of Industry	Number of Industries	Total Waste Water Discharged (m^3/Day)	Total BOD Load (kg/Day)	Discharged into River
Hazaribag	Leather	136	15,800	17,600	Turag
Tongi BSCIC	Textile	13	4300	4400	Tongi Khal
Fatulla	Textile	6	3400	3850	Buriganga
Kanchpur	Textile	9	4300	3480	Lakhaya
Tejgaon	Textile, Chemical	43	3885	2435	Begunbari Kkal

Source: [16].

Some pollutants are biodegradable and transformed through a particular biochemical process. Other non-biodegradable pollutants, such as heavy metals, including lead and chromium, and chemical substances deteriorate the water quality of the river, and reduce the anchorage capacity of the Buriganga. Heavy metals are harmful for the functioning of the human brain, kidney, lungs, liver, and blood circulation, and long-term exposure to heavy metals may cause cancer [17,18].

4.2. Domestic Pollutants

Domestic sewage also contributes to water pollution of the Buriganga river. Household waste and sewers that run through either drainage or earthen channels ultimately fall into the river and contaminate water. Such contamination contains dissolved and suspended pollutant particles, which are sources of disease-causing bacteria. Various chemical substances that are used for keeping households clean contribute to river water pollution. Non-sanitary toilets, particularly in the low-income areas and slum neighborhoods, contribute much to water pollution as they contain both viral and bacterial diseases. These pathogens can be a serious threat to public health if they are transmitted into drinking water [19].

4.3. Clinical Waste

Except the International Centre for Diarrheal Disease Research, Bangladesh (ICDDRB), more than 500 hospitals/clinics across Dhaka generate 20 t of hazardous and toxic medical waste per day; a quarter of such waste constitutes infectious substances that can potentially cause diseases. This huge amount of untreated medical substances is mostly dumped into the Buriganga rivers, which causes serious public health concern. Moreover, improper disposal and management of medical waste causes adverse effects as the infectious pollutants leach into the ground water and heavy metals in the leachate contaminate the underground water [20].

4.4. Encroachment

The river flowing by the western flank of Dhaka encounters 244 establishments, including makeshift homes, small factories, dockyards, and boat-making workshops [21]. Approximately 50 acres of land around the Buriganga is seen to be encroached, of which 38.7 acres are in Kotwali and 4.3 acres are in the Keraniganj area. The encroachment usually takes place during the dry season by influential quarters, all the way down the flood protection embankment, making the Buriganga a narrow channel in some parts. Structures are built on the encroached land along the Buriganga, and garbage is indiscriminately dumped for landfill, particularly in Kamrangir Char, Kamalbagh, and Islampur. Despite the government's interventions to protect the river channel, the encroachment continues, damaging the river's capacity to be navigable as well as bearing the brunt of a huge volume of pollutants.

5. Pollution Parameters and Loads

A high level of biochemical and chemical organic substances is observed in the Buriganga river water. According to Table 2, all parameters exceed the standard critical levels for both drinking and fishing, particular in the upper Buriganga water. For example, the DO level in water is less than 1 mg/L, whereas the standard minimum requirement is 4 for drinking and 5 for fishing. Similarly, the BOD presence is as high as 12–55 mg/L against the standard maximum level of 3–6 mg/L. Other parameters in water are far above the corresponding standard levels for human use and underwater organisms.

Table 2. Water quality standard of the Buriganga river.

Parameter	Standard Value		Observed Value	
	Drinking	Fishing	Upper Buriganga	Lower Buriganga
DO mg/L	4	5	0	<1.0
BOD mg/L	3	6	35–55	12
COD mg/L	-	-	60–90	20
NH_3 mg/L	2	0.02	8–10	0.4–0.5
NH_4^+ mg/L	2	1.2	16–17	7–10
NO_3^- mg/L	10	40	1.5–1.8	2–3
PO_4^- mg/L	6	-	0.4	0.4
Cr mg/L	0.05	0.02	0.006–0.27	0.002–0.004
Pb mg/L	0.10	0.10	0.001	0.001
Zn mg/L	5	0.10	1–4	1–4
Hg mg/L	0.001	0.0001	<0.001	<0.001
Cl mg/L	600	600	40–80	40–80
SS mg/L	-	25	60–100	60–100
Alkalinity mg/L	-	70–100	150–175	150–175
Coliform 1000/100 mL	0	-	8–160	8–160

Source: [22]. Notes: The standard DO represents the minimum required value, while others represent the maximum levels of concentration. The upper Buriganga water flows between Hazaribagh and Kamrangir Char and the lower Buriganga between Chadnighat and Nabinagar.

According to Tables 3 and 4, the BOD levels at points S-7, S-9, and S-10 are high enough to suggest that both domestic and industrial pollutants are major contributors of pollution of the Buriganga river. A high concentration of COD, NH_3-N, NH_4-N, NO_3-N, and PO_4 in water at all points, which is remarkably high at point S-7, indicates the presence of eutrophication. High levels of COD and chemicals, such as nitrogen, ammonia and ammonium, nitrate, and phosphate, demonstrate the worst quality river water. Such a high concentration of chemicals and heavy metals adversely affects both the human and fish population who rely heavily on the Buriganga water.

Table 3. Sampling sites of Institute of Water Modelling for the Buriganga River.

Waste Water Outlet Drain for Monitoring	Water Quality Monitoring Station
Sluice No. 7 (Katasur)	Buri—1 (Mirpur Bridge)
Sluice No. 8 (Hazaribagh)	Buri—2 (Basila)
Sluice No. 9 (Islampur)	Buri—3 (Islampur)
Sluice No. 10 (lalbagh)	Buri—4 (Islampur)
Dholai Khal	Buri—5 (Chadnighat)
PSTP (Pagla)	Buri—6 (Pagla)
-	Buri—7 (Fatulla)
-	Buri—8(Hariharpara)
-	Buri—9 (Nabinagar)

Source: [22].

Table 4. Wastewater pollutant in four outlets.

Sample Location	Flow Rate (m^3/s)	Parameter Tested (mg/L)							
		BOD	COD	NH_3-N	NH_4-N	NO_3-N	PO_4	Cr	Pb
S-7	0.82	425	2134	1.40	84.10	8.9	6.25	1.75	<0.001
S-8	0.3	60	205	0.30	20.96	1.2	1.55	0.05	<0.001
S-9	0.32	150	585	0.16	27.34	5.0	9.45	0.01	<0.001
S-10	1.2	140	565	0.09	25.66	5.7	7.65	0.01	<0.001

Source: [22].

Furthermore, the level of pollution deteriorates or remains almost unchanged. For instance, the BOD_5 parameter increased two-fold between 2005 and 2014, while other parameters still remain above the critical levels, which illustrates the low-quality water of Buriganga. Over the period, the BOD_5 level increased two-fold, from 45,388 to 90,176 kg/day, demonstrating the continuous deterioration (Table 5). Though the NO_3N level decreased from 5762 kg/day in 2008 to 1038 kg/day in 2013, it increased at slower rates. Presumably, this happened due to relocation of the leather processing industries from Dhaka to Savar. This particular industry contributed to a high level of Cr and Pb in the Buriganga water, which is evident at points S-7 through S-10, all of which exceed the toxic levels.

Table 5. Pollution loads in water.

River	Observation Period	Pollution Load (kg/Day)				
		BOD_5	NH_3-N	PO_4	Cr	Pb
Buriganga	5 April	45,388	-	-	-	-
	8 February	58,000	5762	2333	17	18
	13 April	37,547	1038	-	15	50
	13 December	106,225	1078	-	84	-
	14 March	78,033	1111	-	490	8
	14 April	90,176	1137	1582	12	-

Source: [22].

6. Discussion

The "Coliform" in the Buriganga water gradually increased, though it increased in the connected Turag, Balu, and Lakhya rivers during the period between 1990 and 2018 [23]. Additionally, the DO levels varied between 0 and 2.0 mg/L at several points (between Mirpur Bridge and Pagla), which is far below the standard level for human use and to support the aquatic life in the Buriganga. The maximum BOD_5 level (240 mg/L) was observed in the dry seasons (e.g., December, which is far above the critical levels for drinking and fishing at Hazaribagh through Keranigang (IWM 2018). COD was also as high as 60–90 mg/L in the dry season. The underwater aquifer is polluted by the seepage of heavy metals, such as chromium, which reached a level that has long-term effects on human health [24].

The Buriganga water contains a huge amount of toxic substances, such as pathogenic organisms, oxygen-demanding waste, plant nutrients, synthetic organic chemicals, inorganic chemicals, radioactive substances, oil, and heat, all of which have negative consequences on water sustainability and public health. In particular, untreated waste from tanneries—approximately 95,000 L per day—continues to contribute to water pollution of the Buriganga, which is harmful [25]. Though some of the tannery industries have moved to Savar, the relocation of tanneries from Dhaka to Savar has largely been unsuccessful, resulting in sustained contamination of the Buriganga water [26,27]. A high level of organic and bacterial pollutants is still evident, concerning biological pollution of the Buriganga [28].

Oxygen-demanding substances, in addition to decomposing material, which makes use of oxygen during the process of decay, reduce the amount of oxygen in the environment. Sediments and suspended solids consist of mostly inorganic material washed into rivers. Nutrients, mainly nitrogen and phosphorus, can accelerate eutrophication, or the rapid biological "aging". Industrial and municipal wastewater contains high concentrations of organic carbon, phosphorus, and nitrogen, while also possibly containing pesticides, toxic chemicals, salts, inorganic solids (e.g., silt), as well as pathogenic bacteria and viruses that pose a great threat to cities' populations [29,30].

Water contamination incurs costs to public health through the transmission of bacterial and viral waterborne diseases. A high level of pollution causes diarrhea, typhoid, and malaria/dengue, which is common in cities, which may turn into an epidemic as cities are densely populated. Moreover, the presence of excessive heavy metals in water, such as Cr, Pb, and iron (Fe), as well as chemicals, such as ammonia and phosphate, can pose serious threats to public health. Copper (Cu), Pb, and cadmium (Cd) can cause dysfunctions of human organs, and harm the human brain, kidney, lungs, liver, and blood circulation; a longer exposure may even cause cancer.

Furthermore, chemical substances can affect aquatic life and destroy the habitat of flora and fauna as high acid levels kill the microorganisms in water and prevent them from reproducing. Moreover, using polluted water for irrigation can contaminate underground aquifers and the human food chain, while also posing risks of bioaccumulation for future generations [31]. Agricultural wastes contain high levels of phosphorus and nitrogen, organic carbon, pesticide, and fecal coliform bacteria. Moreover, mercury is methylated by aquatic organisms, before being transmitted into food.

The biodegradation process breaks down the pollutants as microorganisms use organic substances as a source of carbon and energy. Many organic materials, however, enter into the watercourses at a high enough level so that they are also responsible for water pollution. Again, anaerobic decomposition is usually performed by a completely different set of microorganisms, to which oxygen may even be toxic.

7. Policy Responses

The pollution of the Buriganga exceeds the tolerable levels of human consumption and the aquatic ecosystem, posing a great threat to the urban livelihood and underwater organisms. Sustainable water policy will need to address the issue urgently to avoid a potential epidemic. Such policy will include both short-term and long-term management strategies that have potential implications for reducing the water pollution levels.

7.1. Sewage and Effluents Control

Firstly, compulsory waste treatment can be enforced in industrial policy. Such enforcement will reduce the volume of industrial effluents, as well as sewage and wastes. The industry can install separate treatment plants for sewage and effluents so that the harmful substances are properly treated. Moreover, the policy must speed up the relocation of tannery industries from Dhaka, which will substantially reduce the toxic substances in water of the Buriganga and connecting rivers.

Effective policy must also include strategies for controlling the indiscriminate disposal of sewage into water that contains organic pollutants. Such policy must enforce strategies for the treatment of medical waste, and might involve introducing the Plasma Arc System, which is common in many countries in the world [32]. The policy must also take necessary steps to stop connections between sanitary sewage and storm sewer, as well as the dumping of garbage in nearby rivers. Public awareness can also reduce the amount of garbage into sewage lines. An introduction of pricing on effluent volume could significantly reduce the water pollution.

7.2. Regulatory Measures

Secondly, planning and land-zoning policy can control the water pollution of the Buriganga. Such policies include building an embankment on the south, and demarcating the river bank and wetland from other areas. Installation of treatment plants at Keraniganj and Kamrangir Char and setting up public toilets in the adjacent slum areas will reduce the water pollution of the rivers. Relocating the industrial zone to outside could significantly reduce the pollution levels. Policies must introduce regulations for preserving depression areas to reduce surface run-off into the river, and for setting up community-based plants for composting the domestic waste. Moreover, a public campaign to save Buriganga would have potential implications, yet it should be participatory and involve elected representatives. Moreover, public sector involvement and regulatory instruments could tackle illegal encroachment. Such a policy would incorporate strategies to dredge the riverbed and enhance navigability, and adequate plants and maintenance of the riverbank will improve the surrounding environment and appearance of the river.

7.3. Institutional Enforcement

Finally, policy must enforce the legal measures to control pollution of the Buriganga and other connected rivers. To this end, it must include periodical Environmental Impact Assessments (EIAs). The Department of Environment must actively monitor the pollution levels and take necessary measures to maintain the water quality for human consumption and aquatic ecosystems, until a separate authority to save the Buriganga and other rivers is formed. Toxic chemicals and organic substances must be controlled through regulatory measures under the Environmental Protection Act 1995, with updated regulations and guidelines to keep the surface and underground water safe. Appropriate laws of penalties must also be enforced to control pollution and improve the water quality.

An autonomous authority could carry out the strategies for controlling pollution at sources. Such an authority might monitor the presence and level of various polluting substances in water and carry out investigations into the biodiversity and water ecosystems. The authority may also encourage the involvement of other relevant government agencies, including Department of Environment, Industry, Environment and Forest, Water Resources and Land, as well as non-governmental organizations in such efforts.

8. Conclusions

The study carried out an investigation into the water pollution in the Buriganga by exploring the sources and pollution that pose a great threat to public health and the water sustainability of the megapolis. Such a threat is inflicted from waterborne diseases that can spread rapidly, and their high potential for contagion into epidemic levels, particularly in the densely populated city. Such a threat is amplified as pollution levels far exceed the tolerable limits of human use and underwater microorganisms. Moreover, the contaminated groundwater and the presence of toxic substances in water have adverse effects on the human food chain, causing generational health impacts, specifically for the poorest segments of society [33]. Such concerns demonstrate that a policy response is urgent, in order to contain water pollution at a level to avoid the looming catastrophe in fast-growing cities in LDCs [34]. This study presented some policy measures that have been deemed effective for controlling the river water pollution in fast growing cities in LDCs. The magnitude of the threat from each of the polluting substances, however, demands further investigation under a highly technical team. This is so that appropriate pollution-controlling measures specific to each of these pollutants are in place to inform the policy. Nevertheless, the study has been able to clarify issues of the water pollution of the river that contribute to the literature of water sustainability of cities in LDCs.

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Appendix A

Table A1. BOD load discharged into the Buriganga from PSTP treatment plant.

Date	BOD_5 (mg/L)	Flow Rate (m^3/Day) Max.	Flow Rate (m^3/Day) Min.	Average Flow (m^3/Day)	BOD_5 Load (kg/Day)
8 March	240	46,440	38,700	42,570	10,216.80
8 April	240	52,200	39,960	46,080	11,059.20
8 May	60	56,520	41,328	48,924	2935.44
8 June	20	49,680	40,860	45,270	905.40
13 April	150	31,000	15,000	26,000	3450.00
13 December	170	29,952	15,000	22,476	3820.92
14 February	240	27,360	16,338	21,849	5243.76
14 March	200	29,016	14,028	21,522	4304.40
14 April	200	39,780	19,278	29,529	5905.80
15 March	190	42,980	21,250	27,870	-
17 March	175	40,600	20,500	22,500	5500.20

Source: [22].

- Observations at S4, S5, and S6 points were not available during April 2013 and December 2013. Therefore, values from measurements taken in March 2014 were used to calculate pollution loads of the Turag River.
- Observations of S11 were not available during April 2013 and April 2014.
- Values from measurements taken in March 2014 were taken to compute loads for the Buriganga River. The load contributed by the PSTP into the Buriganga is not included in the table.
- The load contributed by non-point sources is not included in the table.
- Values in shaded areas are provisional and the authority of the data is therefore limited.
- Measurements of NH_3, PO_4, Cr, and Pb were not available at the PSTP outfall so these were calculated using the level of BOD observed during 2008.

Table A2. Pollution load into the peripheral Buriganga through different point sources, e.g., wastewater drains.

Point Sources	Time	Load (kg/Day)							
		BOD_5	COD	NH_3-N	NH4-N	NO_3-N	PO_4	Cr	Pb
S8, S9, S10, S11, Dholai Khal	8 February	41,100	-	4500	-	-	1430	8.3	12.8
	13 April	26,097	136,819	35	9285	-	-	8.7	45.9
	13 December	94,404	167,631	57	12,002	351	-	77.7	-
	14 March	65,729	155,030	67.5	7689	213.2	-	483.2	3.4
	14 April	76,270	153,511	18	4060	1317.6	905	4.19	-
	15 April	76,650	160,500	19	4560	1422	1230	8.9	6.3
	16 April	55,730	155,000	21	5560	1162	920	12.0	9.2

Source: [22] (Estimation is based on a single measurement in a day).

Table A3. Pollution loads contributed by non-point sources estimated using the dry method.

Discharge into	Non-Point Sources	Load (kg/Day)							
		BOD_5	COD	NH_3-N	NH_4-N	NO_3-N	PO_4	Cr	Pb
Buriganga	City drains	8000	NA	840	NA	NA	250	5.0	3.5
Lakhya	Lakhya	4150	NA	430	NA	NA	140	1.0	1.5
Tongi Khal	Tongi	5160	NA	540	NA	NA	170	1.5	2.0
Dhaleswari	Dhaleswari	2800	NA	290	NA	NA	100	0.5	0.90

Source: [15].

Table A4. Pollution loads of other wastewater outlets.

Station	Date of Collection	Pollution Load (kg/Day)							
		BOD_5	COD	NH_3-N	NH_4-N	NO_3-N	PO_4	Cr	Pb
S-4	14 March 2018	6718	11,073	75.3	3284	211.5	NA	27.12	2.74
S-5	14 March 2018	225	372	1.4	177	3.5	NA	0.80	0.46
S-5	27 April 2018	130	298	1.1	66	7.3	22.25	0.00	-
S-6	15 March 2018	10,584	17,600	7.3	1595	96.8	NA	0.27	0.29
S-6	27 April 2018	2722	8346	17.3	1344	127.0	568.51	0.03	-
S-7	27 April 2017	25,834	49,758	66.8	3359	N.A.	NA	83.68	8.03
S-7	31 December 2017	24,116	39,950	425.8	1861	41.6	NA	372.89	80.33
S-7	15 March 2018	90,685	150,906	132.8	4012	410.9	NA	515.77	0.40
S-7	27 April 2018	15,055	75,595	49.5	2979	315.3	221.40	61.85	-
S-8	27 April 2017	544	2,994	8.9	725	N.A.	NA	0.82	2.55
S-8	31 December 2017	1913	3732	5.8	815	15.6	NA	2.64	-
S-8	15 March 2018	25,855	43,074	45.0	1298	50.8	NA	479.91	0.18
S-8	27 April 2018	778	2657	3.7	272	15.6	20.09	0.62	-
S-9	27 April 2017	5616	18,101	1.7	646	N.A.	NA	1.64	6.31
S-9	31 December 2017	3672	8208	6.0	924	36.7	NA	1.62	-
S-9	14 March 2018	16,200	27,009	1.4	413	7.8	NA	2.20	2.90
S-9	27 March 2018	2074	8087	2.2	378	69.1	130.64	0.19	-
S-10	27 April 2017	5400	23,112	2.2	829	N.A.	NA	1.47	6.31
S-10	31 December 2017	13,893	23,879	6.9	1577	63.7	NA	2.37	-
S-10	14 March 2018	4277	7023	0.5	171	14.3	N.A.	0.31	0.26
S-10	27 April 2018	7258	29,290	4.4	1330	295.5	396.58	0.58	-
S-11	31 December 2017	2350	4804	5.9	1324	27.6	NA	1.97	-
S-11	16 March 2018	497	812	1.0	194	4.3	NA	0.02	0.05
Dholai Khal	27 April 2017	14,040	91,800	21.6	6890	N.A.	NA	4.75	30.67
Dholai Khal	31 December 2017	72,576	12,7008	32.8	7361	207.4	NA	69.12	-
Dholai Khal	27 March 2018	18,900	77,112	19.7	5613	136.1	NA	0.73	
Dholai Khal	23 April 2018	65,664	112,666	6.9	1885	933.1	357.70	2.76	-
Norai Khal	29 April 2018	8661	39,681	44.1	4129	N.A.	NA	0.47	35.90
Norai Khal	25 February 2017	17,963	34,728	128.7	11867	449.1	NA	5.99	-

Source: [22] (Adjusted).

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