INTEGRATED PERFORMANCE ASSESSMENT OF BANGABANDHU WATER TREATMENT PLANT IN KHULNA

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ABSTRACT

Rapidly growing populations and migration to urban areas in emerging economies have resulted in an essential demand for centralized water supply systems to provide inhabitants with drinkable water. Under the Khulna Water Supply Project (KWSP) project, the Bangabandhu Water Treatment Plant (BWTP) was introduced in September 2019 to provide safe and clean water to the community with a capacity of 1,10,000 m^3/day. The main goal of this study is to evaluate the treatment efficiency and the integrated performance assessment of the BWTP based on the Performance Indicator (PI) method. Standard Methods and procedures were followed in the sampling and analysis of several physicochemical and bacteriological parameters of the raw and treated water. PI Statistical Analysis techniques were used to evaluate the performance of the plant. BWTP scored 70PI out of 80PI which is quite satisfactory for consumers. The BWTP's treatment process units were also investigated. The overall removal efficiency of water turbidity, color, and total suspended solids in BWTP were 99%, 100%, and 100%, respectively. The obtained removal efficiencies for Total Coliform (TC) and Fecal Coliform (FC) were about 98%. These findings show that even though the quality of the treated water was quite satisfactory, the presence of TC and FC made the water unsafe for human consumption. To guarantee that all bacterial contamination in the treated water is eliminated and reduced to zero, an ultraviolet (UV) water treatment system or ozonation process can be set up, or the current post-chlorination process can be improved.

Keywords: *Bangabandhu Water Treatment Plant, Microbial Contamination, Performance Indicator*

1. INTRODUCTION

Safe water stands as a cornerstone of human existence, permeating every facet of life with its profound significance. Its essence extends far beyond the simple act of quenching thirst; it is the linchpin of human health, societal progress, and environmental stability. At the core of its importance lies the preservation of human health—safe water is pivotal for hydration, sanitation, and hygiene, safeguarding against a myriad of waterborne diseases that pose significant threats to communities worldwide. Its provision ensures healthier populations, reducing mortality rates and fostering overall well-being. Access to safe water in urban areas is not merely a convenience but a fundamental necessity that influences every aspect of urban life. Adequate water access enables proper sanitation facilities, reducing the risk of waterborne illnesses that can quickly escalate in densely populated urban centres. The World Health Organization estimates that inadequate sanitation or a lack of access to healthy water accounts for up to 80% of all diseases worldwide, making the provision of safe drinking water to the populace very important (Ibrahim et al. 2014). A water treatment removes impurities, contaminants, and pathogens from raw water sources. Water treatment plants purify water to meet regulatory standards, making it safe for human consumption.

Khulna is an expanding coastal urban centre in the southwestern part of Bangladesh (Uddin et al. 2006), beset with salinity intrusion in groundwater and aquifers (Sarker et al. 2021). The most menacing challenges to securing fresh and improved water are the salinity intrusion in surface water due to sea-level rise (Mahmud et al. 2020; Asma & Kotani 2021) and the consequent alteration of hydro-chemical properties of water due to salinization (Sarker et al. 2021). Groundwater was the only source of water for Khulna City. The yield from the deep tube wells was 30,100 m3/d. This covers deep tube wells managed by the Khulna Water Supply and Sewerage Authority (KWASA), hand-pumped tube wells, and additional privately constructed tube wells. There was an estimate of 113,000 m^3/day for total groundwater withdrawal. There has to be less abstraction in order to guarantee the sustainability of the groundwater resource. On June 14, 2011, the Khulna Water Supply Project received approval from the Asian Development Bank (ADB) in response to these worries. (ADB Completion Report). To address the increased demand without increasing groundwater abstraction and jeopardizing its sustainability, the project's design called for the construction of a surface water treatment plant with a capacity of 110,000 m3/day. In addition, the project was planned to withstand climate change; to prevent salinity, the intake facilities were situated upriver, and fresh water was stored in an impounding reservoir to maintain water quality even in the event of an anticipated rise in river salinity.

Ongoing research and development in this field improve the efficiency and sustainability of water treatment processes. The performance of a water treatment plant is critical to ensure that it effectively treats raw water to produce safe and potable water for consumption and other uses. The performance of a water treatment plant is typically evaluated based on several key parameters and criteria. The primary objective of a water treatment plant is to meet or exceed water quality standards and regulations set by local, state, and national authorities. These standards specify the maximum allowable levels of contaminants and parameters in treated water. The plant's ability to remove contaminants and impurities from the raw water is a critical performance indicator. This includes the removal of suspended solids, organic matter, pathogens, and chemicals. Efficiencies of different treatment processes like coagulation, flocculation, sedimentation, filtration, disinfection, and others should be assessed. The water treatment plant must have the capacity to handle the expected flow rates and demand.

Regular maintenance and inspection of equipment and infrastructure are necessary to ensure that the treatment processes run smoothly. This includes assessing the condition of pumps, filters, chemical dosing systems, and other components. Reducing energy consumption and optimizing resource utilization can result in cost savings and environmental benefits. Minimizing water loss and leaks in the distribution system is another aspect of performance. Reducing non-revenue water helps to ensure that treated water is effectively delivered to consumers. The overall performance of the water treatment plant should translate into customer satisfaction. Regular monitoring, testing, and reporting are essential to assess and maintain the performance of a water treatment plant. Continuous improvement, staff training, and staying up-to-date with the latest technologies and best practices are also important for ensuring the long-term effectiveness of water treatment facilities. As no study on the Bangabandhu Water Treatment Plant's performance has done yet, that's why this study will help to understand the overall performance of BWTP. This study aims to investigate the integrated performance of the Bangabandhu Water Treatment Plant & its impact on residents of Khulna city. The specific objectives of this study are outlined as to evaluate the effectiveness of various purifying units of Bangabandhu Water Treatment Plant, to evaluate the integrated performance of Bangabandhu Water Treatment Plant utilizing the Performance Indicator method, and to suggest a more effective strategy for the Bangabandhu Water Treatment Plant's operation and maintenance.

2. MATERIALS AND METHODS

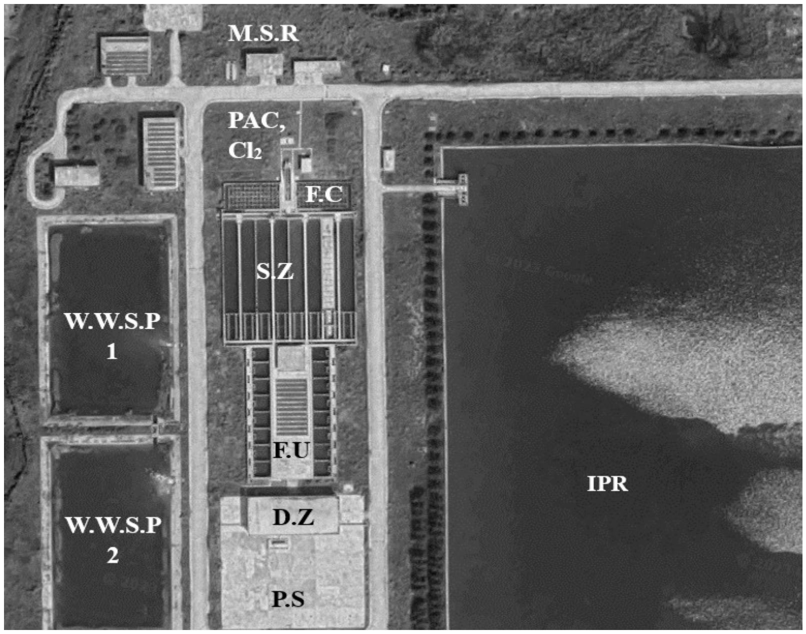
2.1 Bangabandhu Water Treatment Plant

KWASA established the surface water treatment facility at Samantasena in Rupsha Upazila to meet Khulna city's water demand and lessen its reliance on groundwater resources. Under the Khulna Water Supply Project, this plant has been built on 64 acres of land at Samantasena in Rupsha Upazila at a cost of Tk 470 crore. The plant has been producing water since September 2019. The water of the Madhumati River is treated in this treatment plant. The intake structure and the pump house were constructed 58 km northeast of the Khulna city center, on the bank of the Madhumati River adjacent to the Mollarhat bridge. From the intake structure to the treatment plant, a 33 km long raw water transmission pipe with a diameter of 1,400 mm was installed. Three 250 kW pumps with a combined daily capacity of 129.6 million liters were installed. Additionally, a 1,500 kV substation was constructed for a dedicated power source. As anticipated, Samantasena saw the construction of a surface water treatment plant with a production capacity of 110 million liters per day. Its continuous operation was ensured by a sufficient power supply with a backup facility of a 250kW solar system. The plant runs with an automatic control system. At the location of the treatment plant, a water quality testing lab was set up for ongoing observation using advanced technologies. The treatment plant's water quality is tested in the laboratory to ensure that it meets both national and international standards. The impounding reservoir, which is 331 meters long, 208 meters wide, and 12 meters deep (maximum), was built as part of the project. With a reserve capacity of 770 million liters, it can store enough water to last for seven days during the dry season or crises. The treated water enters through the main transmission line by pumping from 7 Distribution Reservoirs and 10 Overhead Tanks in Khulna City. With this, 40,000 customers are getting benefits. Water pressure is also sufficient. As a result, there is no need for electricity to be raised in the tank on the 2nd floor. Prime Minister of Bangladesh, Sheikh Hasina, inaugurated this with a video conference on January 26, 2020. Figure 1 illustrates the plan view with different treatment units of BWTP.

2.1.1 Treatment Method

Intake: The intake structure and the pump house were constructed 58 km northeast of the Khulna city center, on the bank of the Madhumati River adjacent to the Mollarhat bridge. At the intake station, there are six 100kW pumps that can gather up to 110,000m^3 of water each day. However, WTP typically collects water at an average rate of approximately 3000m^3/hr.

Coagulation/Flocculation: The water is treated using coagulants such as Cl_2 and Poly Aluminum Chloride (PAC). This chemical facilitates the easier removal of contaminants by causing small particles to clump together (coagulation) and create larger particles (flocculation). The maximum Chemical Flow used for the BWTP is 112.5mg/L of PAC solution. Approximately 5500L of PAC solution is needed per day. There are 4 tanks of chemical storage, each can carry 7000L of PAC which is enough for 1 week treatment procedure. Sometimes the adjustment of PAC dosage is done due to the seasonal variation of raw water. PAC is brought in the solid form of a 25-kg bag each. Workers make a solution of PAC with water under expert supervision.



[*A.B= Administrative Building, S.P= Solar Panel, IPR= Impounding Reservoir, MSR= Main Switch Room, PAC,Cl_2 Addition Zone, F.C= Flocculation Chamber, S.Z= Sedimentation Zone, F.U= Flocculation Unit, D.Z= Disinfection Zone, P.S= Pumping Station, W.W.S.P= Waste Water & Sludge Pond]

Figure 1: Aerial view of BWTP Sections

Sedimentation: The water then flows into large basins or clarifiers, where the velocity of the water is significantly reduced. This decrease in velocity allows gravity to take effect, and the heavier floc particles settle to the bottom of the basin over time. As the floc settles, it forms a layer of sediment at the bottom of the basin, leaving clearer water above. This settled material, often referred to as sludge, is periodically removed through automated mechanisms. Clarified water, which is now significantly cleaner due to the removal of most suspended particles, is collected from the top of the basins. There are 8nos. of settlers in BWTP, 7 of them were performed. All the settlers have automatic sludge discharge systems.

Filtration: In surface water treatment plants, the filtration process is a pivotal step following sedimentation that further purifies water by removing finer suspended particles, microorganisms, and residual impurities. Water from the sedimentation basins passes through various layers of filter media. These media layers typically include sand and gravel. As water percolates through the filter media, suspended particles are trapped. There are 16 nos. of Rapid Sand Filter at BWTP. They have 2m of depth vertically. All the filters are kept in inspection. Periodic backwashing is employed to clean the filters. When the rate of filtration gets reduced, then the backwash is performed.

Disinfection: To kill any remaining bacteria, viruses, or parasites, a disinfectant chlorine is added to the water. The chlorination process sanitizes the supplied drinking water, preventing the potential for contamination and waterborne illnesses in the outlet water. Chlorine gas, sodium hypochlorite, or calcium hypochlorite may be added to the water in controlled doses. The chlorine reacts with organic matter and pathogens, disrupting their cellular function and rendering them harmless.

Distribution and Storage: Once treated, the water is sent to Khulna city through a 1400mm pipe section with the help of a 4 nos. 250kW pump. Then the water is stored in 10 overhead reservoirs or tanks in Khulna city and distributed through a pipe network to homes, businesses, and other consumers according to demand. Due to the water pressure, the customer does not need electricity consumption to get the tank on the bottom floor. Water is always available. 40,000 customers are getting benefits from this.

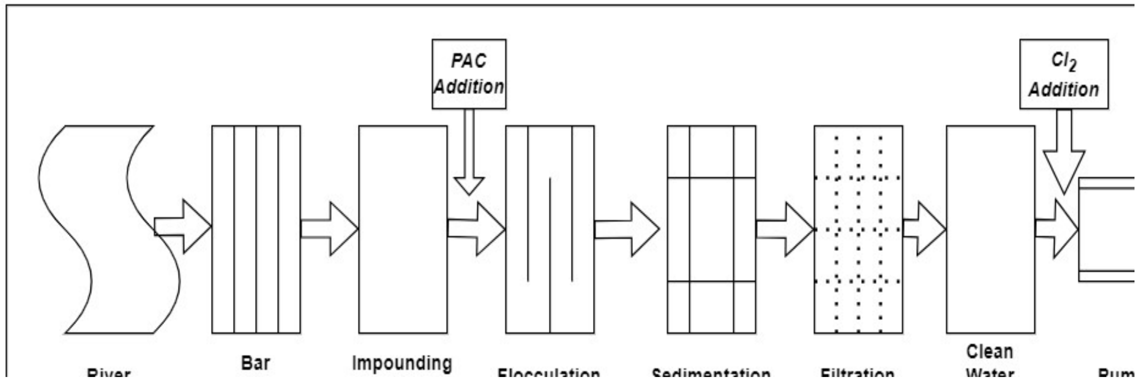


Figure 2: BWTP Treatment Units Flow Diagram

2.2 Performance Indicator System

A performance indicator (PI) is a numerical representation of how well a particular component of a water supplier's service is performing in terms of effectiveness (i.e., how well the intended goals are met) and efficiency (i.e., how well the resources of the water utility are used to produce a service). Performance indicators are typically expressed as ratios between variables that may be commensurate (e.g. %) or non-commensurate (e.g. $/m3) (Alegre et al. 2006).

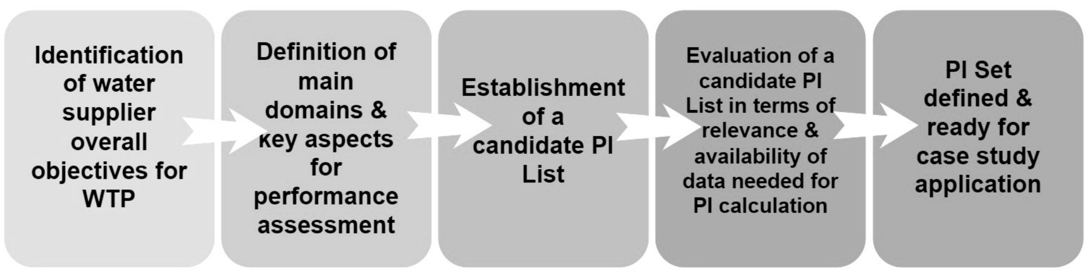


Figure 3: Methodology for PI System

Today, the IWA Performance Indicator System for water services is accepted as a global standard. The approach has been extensively quoted, modified, and employed in several projects for both internal performance evaluation and metric benchmarking since it debuted in 2000. Professionals dealing with water have profited from a well-organized and adaptable framework, wherein exact and comprehensive explanations have frequently been the norm. Any type of organization, be it public, private, or something in between, can use the Performance Indicators System, regardless of its size, complexity, or level of development. Performance Indicators for Water Supply Services, second edition, is an even better handbook than the first. It includes an updated and combined version of the indications based on the actual water needs.

2.2.1 Performance Indicator Main Domain

As part of a standardized IWA methodology for WTP performance assessment, this study describes an application of a PI system to the facilities of the Bangabandhu Water Treatment Plant. For the seven evaluation domains, a total of 80 PI have been defined and categorized into seven categories. Detailed characterization of each PI (objective, definition, processing rule, units of measurement, data required, results analysis, etc.) has been made elsewhere (Vieira et al. 2007).

- Domain ‘treated water quality’ assesses the WTP's ability to generate water that is of sufficient quality at the point of consumption as well as compliance with standards set by the water utility for the water at the WTP's exit.

- The "plant reliability" category assesses the WTP's technological robustness (technology must ensure that a sufficient level of contaminant removal efficiency is maintained over time and cannot fail) and flexibility in adapting to changes in raw water quality.
- Using "natural resources and raw materials" indicators to assess how well the WTP inputs—water, energy, chemicals, filter media, etc—are being used.
- Eight PI from the category "by-products management" evaluate the quantity of process treatment by-products and the suitability of related management strategies since they can have substantial adverse effects on the environment.
- The "safety" category assesses performance in terms of environmental and plant safety using four performance indicators.
- The "human resources" PI evaluates factors like staff availability, appropriate training and qualification, absenteeism, and overtime work.
- Finally, the "financial resources" indicators are associated with total annual costs, unit running costs, unit capital costs, manpower costs ratio, chemicals cost ratio, energy costs ratio, waste management costs, external services costs ratio, operation and maintenance costs ratio, and water quality monitoring costs ratio.

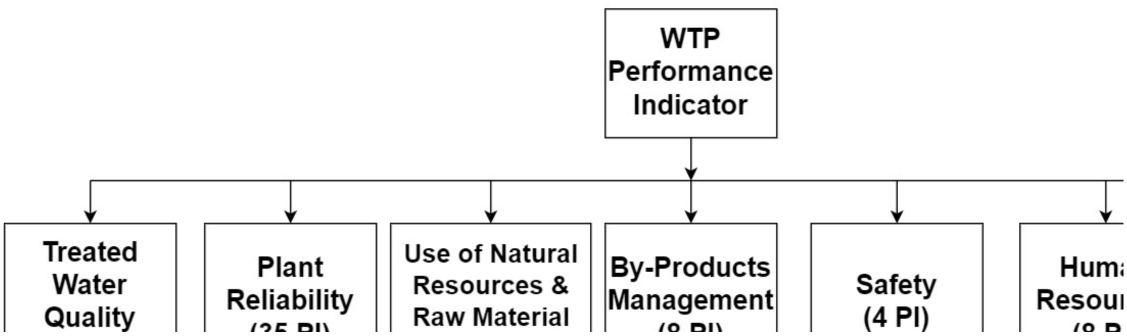


Figure 4: PI Main Domain

2.3 Sequential Steps of this Research

Khulna has severe water constraints as a result of unplanned urbanization and rising salinity levels in both surface and groundwater. Maintaining the standard level of BWTP-supplied water quality is essential to fixing this matter. For this reason, it's vital to conduct a BWTP performance assessment to create an integrated water distribution system that is sustainable. This part of the chapter introduces a structure for assessing the integrated performance assessment of BWTP. The following section provides the flowchart to complete the study:

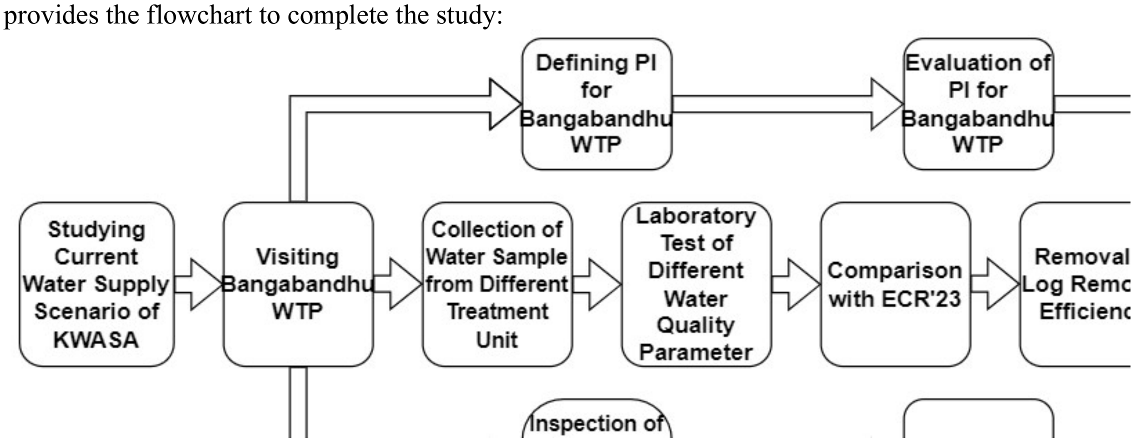


Figure 5: Flowchart showing the sequential steps in the research work

2.4 Efficiency and Log Removal Value (LRV)

The efficiency of a water treatment plant refers to its ability to effectively treat water to meet certain quality standards while minimizing resource use, costs, and environmental impact. Equation 1 states that the ratio of the concentration removal to the initial concentration of any parameter is used to measure plant efficiency. The current trend in treatment plant monitoring is based on the parametric values of input and output of the treatment system's log removal efficiency. (Ibrahim et al., 2014). Here, as indicated by equation 2 (Amber et al., 2004), LRVs are calculated by taking the logarithm of the ratio of the concentration of any contaminants in the influent and effluent water of a treatment process.

$$Efficiency = \frac{Initial\ Concentration - Final\ Concentration}{Initial\ Concentration} \times 100\% \quad \ldots\ldots (1)$$

$$LRV = \log_{10}\left(\frac{Influent\ Concentration}{Effluent\ Concentration}\right) \quad \ldots\ldots (2)$$

3. RESULTS AND DISCUSSION

3.1 Water supply scenario of KWASA

Bangladesh is among the most susceptible nations on Earth due to the depletion of groundwater levels, salty water intrusion, and rising salinity levels in rivers. Khulna City is located 9 meters above mean sea level and covers an area of 59.57 square kilometers. The annual rainfall is 1710 mm, with an average temperature of 26.5°C and a minimum of 12.5°C. Rupsa-Pasur, Bhairab, Shibsha, Dharla, Bhadra, Ball, and Kobadak are the principal rivers (LGED, Khulna). Water shortage was a common problem throughout the dry season, which decreased the amount of water available for both industrial and residential consumption.

Table 1: Overview of KWASA's Production

House Connection	Present Population	Covered Service Area	Number of Hand Tubewell	Number of production Tubewells	BWTP Capacity	Gilatola WTP Capacity	EMPLOYEE
40368	1.5M	45.60 sq km	9000	41	110MLD	5.5MLD	317

Conversely, the monsoon season posed challenges related to flooding and water contamination. The mission of KWASA is to provide optimal services through modern planning, efficient management and maintenance, human resource development, and increasing organizational capacity to ensure transparency and accountability through safe water supply and environmentally friendly sewerage systems (KWASA Website). However, since the commencement of BWTP production, KWASA is currently able to meet demand.

Tabel 2: Water Demand & Supply of KWASA

Population	1.5M
Per-capita Domestic Water Demand (lpcd)	130
Domestic Water Demand (m3/d)	195,000
Proportion of Nondomestic Water Demand to Total Water Demand (%)	10
Domestic & Non-domestic Water Demand (m3/d)	214,500
Leakage at pipe network (%)	15
Max. Day Water Requirement [peak factor 1.15] (m3/d)	284,000
Existing Supply Capacity (m^3/d)	180,000

But, right now KWASA can meet the demand after the start of production of BWTP. The total production of KWASA is around 180 MLD. The sources are the Production Tube Well, Mini Production Tube Well, Hand Pumps, BWTP, and Gilatota 5.5 MLD Surface Water Treatment Plant. BWTP can produce 110 MLD. But right now, it is enough for BWTP to produce around 45MLD of water to meet the demand from KWASA. Even after this, there are a lot of private tube wells throughout the city. The groundwater level is decreasing day by day due to massive water extraction from this private tube well. Currently, KWASA covers 65% of the total water demand of Khulna city. KWASA should increase awareness among them to take WASA's pipe water connection to stop this water extraction.

3.2 Water Quality in Various Unit Operations

Treatment processes eliminate maximum undesirable constituents from river water. Sedimentation and filtration processes were the two main techniques used in BWTP to reduce turbidity and total dissolved solids. Water was treated with chlorine to disinfect it and create a residue that was suggested to be delivered to consumers through distribution networks. The treatment plant's efficiency allowed the turbidity of the Madhumati River to be lowered from 114 NTU to 1 NTU in the clean water reservoir. Since raw water's pH was within ECR'23's limit, no additional pH treatment was required. There is no significant effect of Chloride in Madhumati's water. It was one of the major reasons for choosing the Madhumati River as a potential source over the Rupsa River.

Table 3: Water quality in various Units Operation

Parameters	Madhu-mati	IPR	Floccu-lation	Sedimenta-tion	CWR	Word No 27	ECR'23
pH	8.1	8.2	7.9	7.8	7.7	7.7	6.5-8.5
E. Conductivity (mS/cm)	0.388	1.222	1.298	1.304	1.258	0.713	--
Cl^-(mg/L)	50.7	362.5	407.5	407.5	412.5	57.5	250
TDS (ppm)	657	602	697	721	398	356	1000
BOD (mg/L)	0.72	0.65	0.83	0.45	0.75	0.83	≤2
Alkalinity (mg/L)	115	120	146	104	100	350	30-400
Turbidity (NTU)	114	36.30	19.20	5.04	1	0.99	5
Color (Pt-Co)	480	164	65	3	0	0	15
TSS (mg/L)	94	31	10	0	0	0	10
Hardness (mg/L)	740.8	351.9	379.7	388.9	370.4	143.5	500
Nitrate (mg/L)	0	0.4	0.6	0	1.1	1.4	45
OPR (mV)	214	199	196	195	194	205	200-600
Sulfate (mg/L)	19	51	57	56	57	0	250
Fecal Coliform (CFU/100mL)	320	15	10	5	5	50	0
Total Coliform (CFU/100mL)	1170	55	20	55	15	190	0

*IPR= Impounding Reservoir, *CWR= Clean Water Reservoir

A certain amount of dissolved minerals and ions, together with other organic and inorganic elements in water, are known as Total Dissolved Solids (TDS). Since some constituent concentrations may rise due to chemical additions, total dissolved solids are not a strong indicator of treatment effectiveness. The TDS level was 602 ppm in the impounding reservoir, where it got higher in the flocculation chamber at 697 ppm as PAC was added. Color in WTP can indicate organic matter presence, affecting water aesthetics and consumer perception. BWTP did an excellent job by reducing the color level 0 from 480 Pt-Co of the intake point. The primary sedimentation tank and flocculation process do a magnificent job in that they reduced the Total Suspended Solid to 0 level from 94mg/L. There was no major problem associated with Sulfate, Hardness, Nitrate, or Oxidation Reduction Potential (OPR), as all of them were within the range of drinking water according to ECR'23. Total coliforms are bacteria that are present in soil, water that has been impacted by surface water, and waste products from people or animals. The class of all coliforms known to be found only in the stomach and feces of warm-blooded animals is known as fecal coliforms (New York State Department of Health). The BWTP's treatment process converted the F.C. level to 5 CFU/100 mL at CWR from 320 CFU/100 mL of Madhumati's water. However, the water collected from Word No. 27 contained 50 CFU/100mL. The same scenario had happened in Total Coliform, too. Madhumati's water contained 1170 CFU. It decreased to 15 CFU in CWR. But again, the number increased to 190 CFU in every 100 mL of water. It means the water was contaminated in the pipe network or bacterial growth occurred. Table 3 illustrates different physicochemical and bacteriological parameter's value in different treatment units operation.

3.3 Removal & Log Removal Efficiency

The removal efficiency of a surface water treatment plant refers to its ability to eliminate or reduce contaminants present in the raw water taken from rivers before distributing it for public consumption. Using eq. 1 & eq. 2, the removal & the log removal was calculated. The result is presented as a pie chart & as the tabulated form below. The total removal efficiency of turbidity, color, TSS, Hardness, F.C, and T.C was 99.1%, 100%, 100%, 50%, 98.4%, and 98.7%, respectivelyThe removal efficiency of impounding reservoirs depends on the residence time of water in the reservoir, the design of the reservoir and the nature of the impurities present. Around 68% of the turbidity of water was removed in this unit. The removal efficiency of Color, TSS, Hardness, F.C, and TC was around 66%, 67%, 52%,95%, and 95%, respectively in this unit. After adding Cl_2 and PAC before the flocculation chamber, the further suspended particles became separate. So a good removal efficiency was obtained from the flocculation unit. The obtained removal efficiency of different parameters is shown below through a pie chart in Figure 6. It illustrates that the impounding reservoir helped to improve the raw water quality a lot without any chemicals.

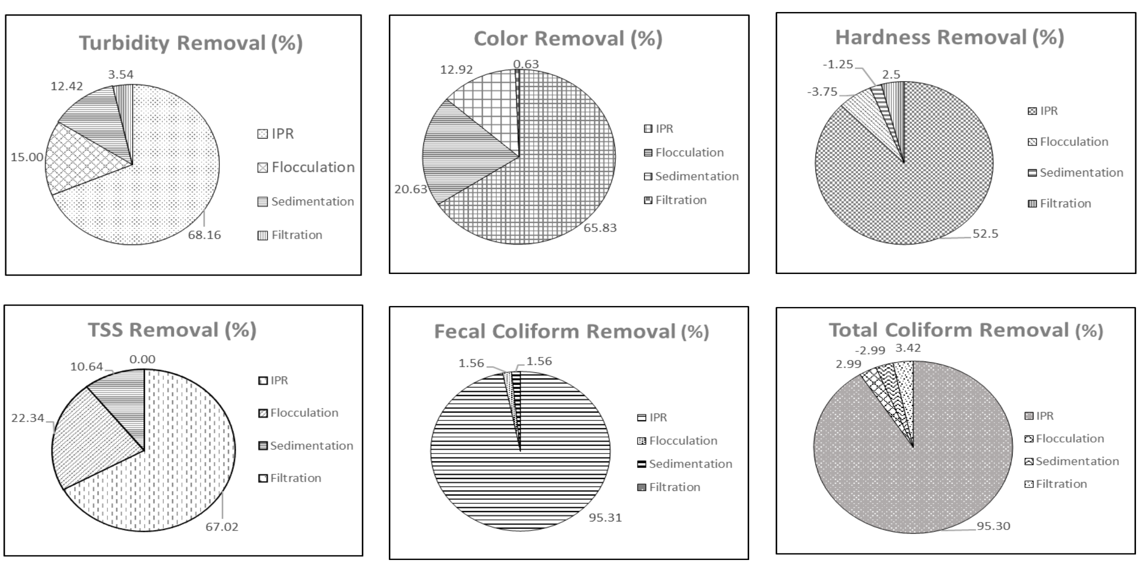


Figure 6: Percentage Removal Efficiency in Different Unit Operations

The log removal value (LRV) is a measure used to express the effectiveness of a water treatment process in removing contaminants. It signifies the degree of reduction achieved through a particular treatment step, typically in terms of microbial or particle removal. For surface water treatment plants, LRVs can vary based on the treatment processes employed. Here, table 4 presents the Log Removal Value of BWTP's different treatment units. Using eq. 2, the log removal was calculated.The United States Environmental Protection Agency's standard was used to compare the value. None of them remained in the standard range. The maximum removal value was achieved for Color & TSS. Hardness removal was only 0.301 log. The F.C. & T.C. removal values were around 1.8 log, which was not up to the mark. Figure 7 illustrates the CLRV vs. different physical & biological parameters.

Table 4: Log Removal Value of Different Units of BWTP

Unit	Obtained LRVs for Particles	Obtained LRVs for Pathogens	Standard LRVs for Particles	Standard LRVs for Pathogens
Impounding Reservoir	0.429	1.328	1-2	0.5-1
Flocculation	0.390	0.308	1-3	1-2
Sedimentation	1.639	-0.069	2-4	0.5-1
Filtration	1.727	0.282	2-5	1-4
Disinfection	0.000	0.236	0	2-5

Hardness removal was not satisfactory. Though there was no special arrangement for the removal of hardness, As the raw water's hardness was not alarming, it was not taken into consideration. However, the treated water's hardness is in the range of ECR'23. The removal of TC and FC was not satisfactory either.

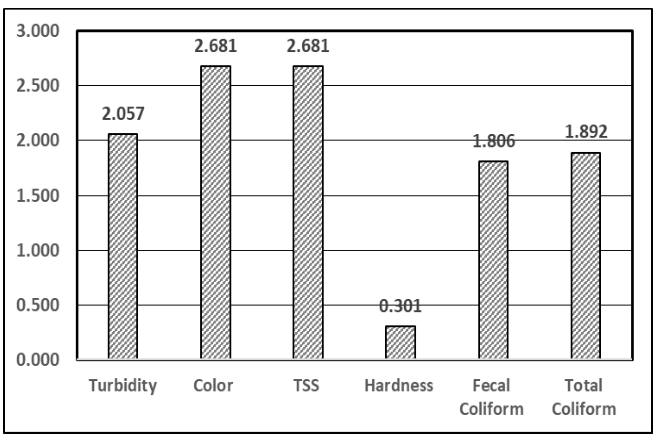


Figure 7: Cumulative Log Removal Value

3.4 Performance Indication (PI) for BWTP

Performance indicators for a water treatment plant (WTP) help assess its efficiency, effectiveness, and compliance with regulatory standards. This Performance Indicator system was introduced by the International Water Association (IWA). The seven performance domains and the PI distribution were discussed in the Methodology section. Table 5 contains the obtained PI lists in various domains. BWTP scored 70PI out of a total 80PI. Among these seven domains, the first was "treated water quality". The treated water quality was quite satisfactory. Only the presence of the pathogens in water violets the ECR'23. It makes the water unusable for drinking. However, the water is ready to be used in household work, hygiene work, and industrial work. By enhancing the disinfection unit and providing proper maintenance in the distribution network, water will be ready to take in glass to drink just by opening the tap. The second was "plant reliability." BWTP got 31 out of 35 PIs. Performance is assessed in terms of WTP technological robustness by plant reliability. Technology must not fail and must guarantee the continuous maintenance of a sufficient level of contaminant removal effectiveness as well as the WTP's adaptability to fluctuations in raw water. The BWTP has 100% water source utilization adequacy. The infrastructure capacity was massive. The chemical supply's adequacy was also sufficient. The PAC was stored for around 3 months. Continuity of operation was present in BWTP. Around 14–16 hours, the WTP was operated, which was sufficient for demand. The treatment plant was fully automated. Every unit had sampling points with online water quality monitoring. All the settlers had automatic sludge discharge systems. The Cl_2 and PAC additions were also automated. Pumps were inspected by the CCC. The operation time, voltage, current, and flow rate—all of these can be inspected. The rate of interruptions of WTP operation due to energy failure was negligible. They can fix any problem within 2–3 hours with the help of an expert technician. The power of the emergency electric generator was 1500 kW, whereas the total power of equipment at the WTP was 625 kW, 2.5 times higher than they needed. However, there was no step to calibrate the online water quality monitoring meter or flow meter. There was no initiative to repair the damaged meter. That's why it lost some PI.

Table 5: BWTP Performance Assessment Based on PI

Main Domain	Obtained PI	Total PI
Treated Water Quality	8	9
Plant Reliability	31	35
Use of Natural Resources and Raw Materials	6	7
By-Products Management	7	8
Safety	4	4
Human Resources	7	8
Economical and Financial Resources	7	9
Performance of BWTP	70	80

The third was the 'use of natural resources and raw material'. There was the same amount of water at the entrance and purified water. Nothing was wasted. The energy consumption was in standard form. The equipment was modern and used less electricity. The consumption of Cl_2 was 150 kg/day, and the PAC was used around 30 kg/day. The filter media was vertically 2m long. No refill has been done since the start of the plant. It decreased the level of filtration. The authority should change the filter media now. The wastewater from the sludge pond was again used as raw water.

The fourth was 'by-products management'. There was not enough data about the by-product. The sludge was stored in the two waste sludge ponds. No sludge has been discharged from the ponds since 2019. But the wastewater was recycled. The fifth domain was 'safety'. All kinds of safety products were served to the workers. The working environment was friendly. During the starting period, no chemicals were spilled. No working accident occurred. The sixth one was 'human resources'. Human resources play a critical role in the operation and management of a water treatment plant. The full-time equivalent employee at WTP was 32. Four of them had a university degree. There were three scheduled shifts. Workers worked there in three 8-hour shifts. The authority generally arranges 2-3 training sessions annually including safety training and technical skill development. The workers were well-trained, and they knew their duties very well. However, the water testing laboratory needs more expert chemists. The last domain was 'economic and financial resource'. The total capital cost of BWTP was 2700 crore taka. There were several numbers of costs, including running costs. Running costs contained internal manpower costs, chemical costs, electrical energy costs, costs with transport, valorization and final disposal of by-products, external services costs, operation costs, maintenance costs, and analytical control costs. After considering all these costs, the BWTP needs around 22.5 takas ($0.19) for each 1000 liters of water. But the water tariff was 8.98 taka ($0.075) for every 1000 liters of water. The government provides a lot of subsidies for KWASA's water production.

3.5 Recommendations for BWTP

A drinking water treatment plant's performance must be regularly monitored and evaluated for several reasons, including quality assurance, compliance, early detection of issues, optimization of processes, risk mitigation, operational efficiency, data for decision-making, and public confidence. During the study on BWTP, the performance of different units was quite satisfactory. But the disinfection unit couldn't remove 100% of the pathogen. The BWTP authority should assess the existing disinfection method (chlorination) being used in the plant. After the ensuring proper dosage of disinfectants based on water quality parameters, flow rates, and seasonal variations, they should conduct regular monitoring and adjustment of dosages. They can implement a Multiple Barrier Approach. Combining UV or ozone treatment with chlorine can provide added protection against pathogens. Improving the filtration unit of a WTP is crucial for ensuring the removal of contaminants and producing high-quality water. BWTP needs proper maintenance of filter media. The filtration media wasn't refilled after 2019. The performance of filter media has decreased over time. It's working and has good removal efficiency. For more efficient removal, the media should be replaced. KWASA can implement a proactive maintenance schedule for regular flushing and cleaning of distribution pipes to maintain water quality. By integrating these strategies into the operation and maintenance of the BWTP, the authority can guarantee compliance, cut expenses, increase efficiency, and support dependable and sustainable management of the water supply.

4. CONCLUSIONS

The study aimed to integrate the performance of the Bangabandhu Water Treatment Plant in Khulna. To complete this investigation, the performance indicator assessment method was used. The BWTP has gained 70PIs among 80PIs. This result is satisfactory to consumers. Though some pathogens were found in treated and supplied water, the removal efficiencies of other units were quite good. The authority should enhance the filtration chamber and disinfection unit to supply better drinking water. Much work has been done on groundwater from KWASA's pumps and tube wells. However, this research work is the first one that covers the surface water treatment plant of KWASA. The significance of this research work is to use the Performance Indicator Method for the very first time to determine the performance of a WTP in Bangladesh. Till this research work, the by-product management idea was not clear to the authorities as the sludge pond hadn't been covered with sediment from the start of production. That's why the by-product management domain wasn't covered fully.The author suggests determining the micro-plastic removal capacity of BWTP and the risk assessment of the micro-plastic in KWASA's supplied water on human health.

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