



Quality Assessment of Condensate Water Generating From Air Conditioning Units

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Abstract: The growing demand for water resources in urban areas like Bangladesh is a pressing concern due to population growth. Air conditioning condensate water is being considered as a potential solution. A study at the European University of Bangladesh (EUB) examined the quality of AC condensate water from various systems. Results showed that the water generally met quality standards for drinking and household use in Bangladesh, with average parameters like pH (6.8), turbidity (1.08 NTU), total dissolved solid (TDS) (219 mg/L), iron (0 mg/L), alkalinity (41.67 mg/L), arsenic (0 mg/L), COD (3.67 mg/L), BOD (1.33 mg/L), chloride (30.77 mg/L), and more. AC units at EUB (1 ton, 2 tons, 4 tons) produced monthly volumes of 96, 177, and 354 L, highlighting the potential of AC condensate water. This emphasizes the need for local decision-makers to establish guidelines for its effective use in combating urban water scarcity.

Keywords: air conditioning unit; AC condensate; drinking water quality; drinking water scarcity.

I. INTRODUCTION

The rapid growth of urban populations is placing significant stress on their water resources, exacerbated by the scarcity of freshwater and escalating costs associated with water supply systems [1]–[3], [4]. This issue is particularly pressing in Dhaka city, where the water supply problem is intensifying [5]–[7]. Newly developed areas and some parts of the old city are grappling with a worsening water supply situation because the Dhaka Water Supply and Sewage Authority (DWASA) is unable to keep up with the increasing demand for safe drinking water [8], [9]. As of the present day, the daily water demand in Dhaka, serving approximately 9 million people, stands at 165 crore liters, and it is projected to surge to about 2.5 times that amount by 2030 [10], [11]. DWASA's current daily production capacity is 144 crore liters, as reported in 2005 [12], [13]. Furthermore, the physical leakage in the water distribution system currently ranges between 30-40%, as per data from 2007 [14], [15]. During the dry season, water demand experiences an approximate 25% spike, resulting in a shortfall of about 100-120 crore liters per day [16]–[19]. Over the last five years, DWASA has managed to increase daily production by 3.5 crore liters by installing deep tube wells [12], [13]. However, excessive groundwater extraction, coupled with inadequate aquifer recharge in the city, is leading to a rapid and concerning decline in groundwater levels [20]–[23]. To address the increasing water demand in Dhaka, the DWASA is increasingly prioritizing the use of surface water sources for providing clean drinking water. Nevertheless, a significant challenge arises due to the extensive pollution of surface water bodies in the vicinity of Dhaka, hindering the effective utilization of these water sources [7], [24]–[28].

To protect water supply systems, efficient solid waste management is vital [29]–[36]. It safeguards water sources against contamination caused by improper waste disposal [37]–[39]. In addition, the practice of recycling solid waste, with a particular focus on organic materials intended for biogas production, serves to mitigate the strain on conventional energy sources while simultaneously promoting sustainable energy generation [40]–[44]. As a consequence, this indirectly aids in the enhancement of water supply systems through the reduction of energy-intensive procedures associated with water treatment and distribution. The management of solid waste does not end there. Its influence on wastewater quality is direct [45]–[47]. Ensuring effective management is crucial to prevent treatment facility effluent from adversely impacting the quality of the overall water supply [48]–[51], [52]. This, in turn, contributes to the establishment of a more secure and dependable water supply system. Ensuring proper hygiene is an essential component of this equation [4], [53]–[55].

Ensuring responsible management and appropriate disposal of solid waste are critical in mitigating the health hazards linked to water sources that have been contaminated [33], [39], [56], [57]. In addition to safeguarding the quality of the drinking water supply and public health, ensuring the proper treatment and disposal of wastewater contributes to the creation of a safer and more sanitary environment for all [58]–[61]. Moreover, rainwater harvesting offers a sustainable alternative for augmenting the availability of potable water [62]–[64]. By alleviating strain on current resources and encouraging water conservation, it contributes to the overarching objective of guaranteeing dependable and secure water accessibility for communities. Amid the challenges posed by the COVID-19 pandemic, the interplay between efficient solid waste management, safeguarding water supply systems, and responsible rainwater harvesting practices has become even more crucial, as they collectively contribute to the enhancement of water quality, public health, and sustainable water resources in our communities [65]–[68].

Air conditioning condensate water presents a viable water-saving option, applicable at both the individual household and larger building scale [69]–[71]. Traditional cooling systems rely on evaporator coils, with condensate drains typically discarding the water [72], [73]. However, capturing and reusing this resource is a promising alternative. This untapped source of water from air conditioning systems can be repurposed for cooling towers and outdoor irrigation [74], [75]. Air-handling processes often involve the use of water and liquid desiccant, coming into direct contact with humid air, facilitating heat and mass transfer between the air and the liquid. The effectiveness of this water capture largely depends on the surface area available for collection. Various experiments worldwide have reported diverse yields. For instance, in a fishing village in Chile, a station with a condensing area of 48 m² produced 3.3 L/m² per day [76]. In Saudi Arabia, experiments achieved a maximum yield of 0.22 L/m² per night based on energy balance and 1.25 L/m² per day through moisture recovery under a glass cover [76]. Despite the potential of air conditioning condensate water, there is limited literature discussing its quality. A study suggested that it often exhibits purer content than tap water [77]. Similarly, a study conducted by Bryant et al. (2008) in Qatar concluded that the water tested met high-quality standards and could be suitable for human consumption with minimal biological contaminant treatment [78]. Nevertheless, there is a risk of contamination, particularly in warm environments, which is why chlorine treatment is commonly employed [79]–[82]. The objective of this study are to determine the quantity of water produced from different types of AC system; to assess the AC condensate water quality; and to identify the possible reuse of AC water.

II. MATERIALS AND METHODS

A. Sample collection

Sample collection involved classifying collection sites into three groups based on their air conditioning unit capacities: small, medium, and large. Samples were obtained from three units at EUB, with capacities of 1 ton, 2 tons, and 4 tons. High-density polyethylene bottles from a nearby supplier were used for collection, pre-cleaned through three DI water rinses and three rinses with AC condensate water. The samples were swiftly preserved at 4°C and allowed to reach room temperature before analysis. For more details, refer to Table 1 for sample information.

TABLE 1. SAMPLE COLLECTION INFORMATION

Sample No	Respective AC Units	Sample Volume (mL)	Sample Temperature (°C)	Sample Color	Sample Taste	Sample Odor
S1	1 ton	1000	26.7	Colorless	Tasteless	Odorless
S2	2 tons	1000	28	Colorless	Tasteless	Odorless
S3	4 tons	1000	29.4	Colorless	Tasteless	Odorless

B. Sample analysis

Various methods were employed to evaluate a diverse set of physical, chemical, and bacteriological variables at the sampling locations and in the controlled laboratory setting, as outlined in Table 2.

TABLE 2. SAMPLE ANALYSIS METHODS, PARAMETER UNITS AND RESPECTIVE BANGLADESH (BD) STANDARD (ENVIRONMENTAL CONSERVATION RULES' 1997 (ECR'97)) VALUES.

Parameters	Methods	Units	BD Standard (ECR'97)	
Physical	Temperature	Temperature Probe	°C	---
	Color	Visualization	---	---
	Taste	Tongue	---	---
	Odor	Smelling	---	---

	Total Solids (TS)		mg/L	---
	Total Dissolve Solids (TDS)	Filtration, Evaporation	mg/L	1000
	Total Suspended Solids (TSS)	Filtration, Evaporation	mg/L	10
	Turbidity (NTU)	Turbidimeter	NTU	10
Chemical	Acidity/Alkalinity (pH)	Electrometric	---	6.5 – 8.5
	Arsenic (As)	Atomic Absorption Flame Spectrometer	mg/L	0.05
	Alkalinity as CaCO ₃	Titrimetric	mg/L	150 – 250
	Chloride (Cl ⁻)	Titrimetric	mg/L	150 – 600
	Dissolve oxygen (DO)	Electrometric	mg/L	≤ 6
	Electrical Conductivity (EC)	Electrometric	μS/cm	700
	Iron (Fe)	Colorimetric	mg/L	0.3 – 1
	Carbon dioxide (CO ₂)	CO ₂ meter	mg/L	---
	Chemical Oxygen Demand (COD)	Colorimetric Method	mg/L	4
	Biochemical Oxygen Demand (BOD)	Standard Method 5210B	mg/L	2

Upon collection, water samples were visually examined without the use of any optical aids. The samples were evaluated for odor through direct inhalation and were subjected to taste evaluation to determine their quality. To ascertain the TS content, water samples of 50 mL were subjected to a drying process at a temperature of 105°C within 100 mL beakers, and subsequently, the resulting weight differential was computed [83]. The measurement of TDS involved the filtration of 50 mL samples, subsequent drying, and the subsequent determination of the mass of the remaining solid [83]. The determination of TSS was achieved through the subtraction of TDS from TS.

Chemical analysis of water samples involved various methods and instruments: pH using a pH meter (Hach 9532800), arsenic content with an atomic absorption spectrometer (Shimadzu AA-7000), chloride concentration via titration, DO levels with a digital DO meter (HACH DR 300), EC using a conductivity meter, iron concentrations analyzed by spectrophotometry (HACH DR 3900). CO₂ was measured with an OxyGuard CO₂ meter. COD was measured with HACH test kits (TNT 824) and BOD using the 5-day standard method [84], [85].

III. RESULTS AND DISCUSSIONS

A. Physical parameters

The study encompassed the evaluation of various physical parameters, namely color, odor, taste, temperature, TS, TDS, and TSS. Table 3 provides a summary of the physical parameters that were determined for each sample of water.

TABLE 3. SUMMARY OF THE MEASURED PHYSICAL PARAMETERS OF WATER SAMPLES.

Sample ID	Color	Odor	Taste	Temperature (°C)	TS (mg/L)	TDS (mg/L)	TSS (mg/L)	Turbidity (NTU)
S-01	Colorless	Odorless	Tasteless	26.7	244	240	4	0.80
S-02	Colorless	Odorless	Tasteless	28	224	220	4	0.69
S-03	Colorless	Odorless	Tasteless	29.4	193	190	3	1.66
BD Standard	---	---	---	---	---	1000	10	10

In all sampled instances, the visual attributes such as color, taste, and odor were deemed acceptable for potable water. However, when examining the physical parameters, specifically TS, TDS, and TSS, some variations were observed. Sample 1 exhibited the highest values among all parameters, with recorded values of 244 mg/L for TS, 240 mg/L for TDS, and 4 mg/L for TSS. Conversely, Sample 3 displayed the lowest values across these parameters, recording values of 193 mg/L for TS, 190 mg/L for TDS, and 3 mg/L for TSS.

The turbidity values were found to be 0.8, 0.69, and 1.66 NTU respectively for sample 1, 2 and 3. While some fluctuations were noted, it is noteworthy that all recorded values fell below the permissible limits set by the relevant drinking water quality standards. Figures 1 and 2 are showing the graphical presentation of TDS and Turbidity.

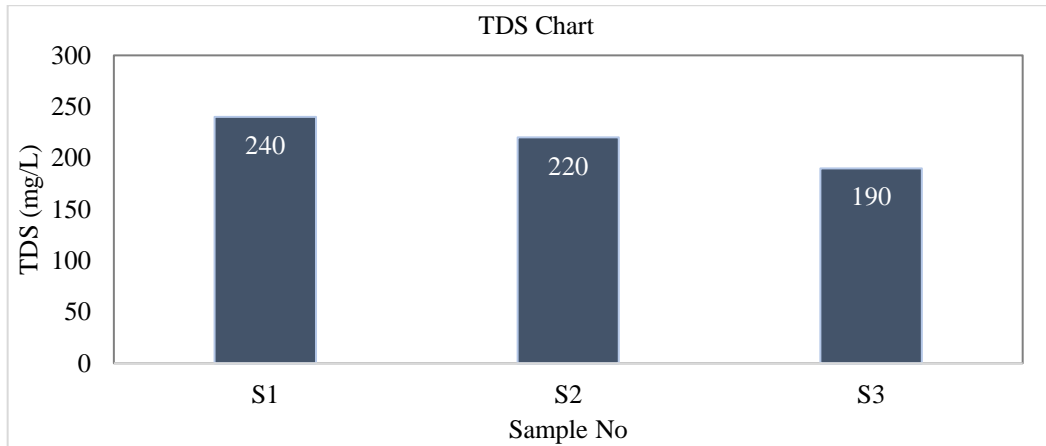


Fig. 1 TDS chart of the tested samples.

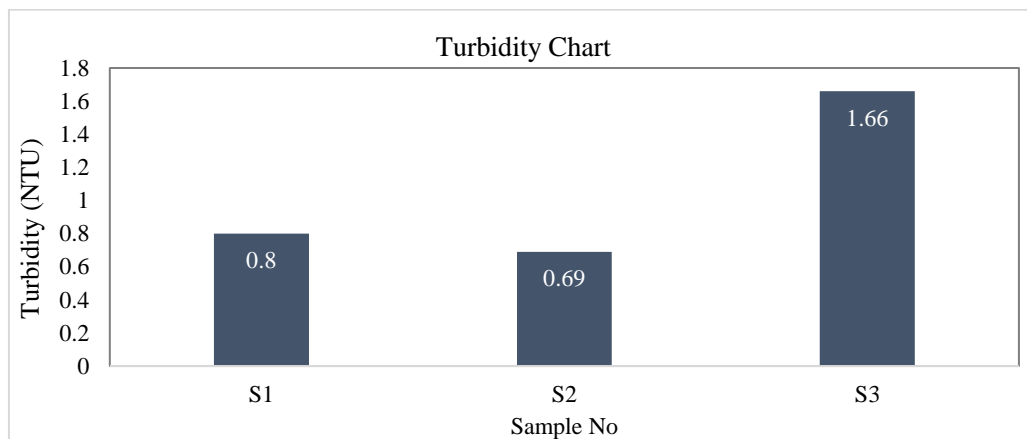


Fig. 2 Turbidity chart of the tested samples.

B. Chemical parameters

Table 4 presents a comprehensive summary of the chemical parameters that underwent analysis in relation to the water samples that were collected.

The parameters are significant in the evaluation of water quality, as they provide valuable information regarding the makeup of the water and its appropriateness for a range of uses, such as consumption, agricultural activities, and industrial processes.

TABLE 4. SUMMARY OF THE MEASURED CHEMICAL PARAMETERS OF WATER SAMPLES.

Sample ID	pH	COD (mg/L)	BOD (mg/L)	Alkalinity (mg/l)	Dissolve oxygen (mg/L)	Chloride (mg/L)	Iron ppm	Carbon dioxide (mg/L)	Arsenic (mg/L)
S1	6.6	4	1	40	6.5	30.175	0	8.8	0
S2	7.0	4	2	45	6.7	35.5	0	8.8	0
S3	6.7	3	1	40	6.7	26.625	0	8.8	0
BD	6.5-								
Standard	8.5	4	2	150-250	≤ 6	150-600	0.3-1	---	0.05

pH

The pH values for the three collected samples can be observed in Figure 3. All recorded values consistently lie within the narrow range of 6.6 to 7, with a calculated mean pH of 6.8 and lies between the BD standard guidelines. These results suggest that the pH measurements conducted in this phase of the research indicate the condensate water's near-neutrality, as is evident from the predominance of samples clustering around the neutral point. There is no substantial evidence to support the presence of pronounced acidic or alkaline characteristics within the collected condensate water samples.

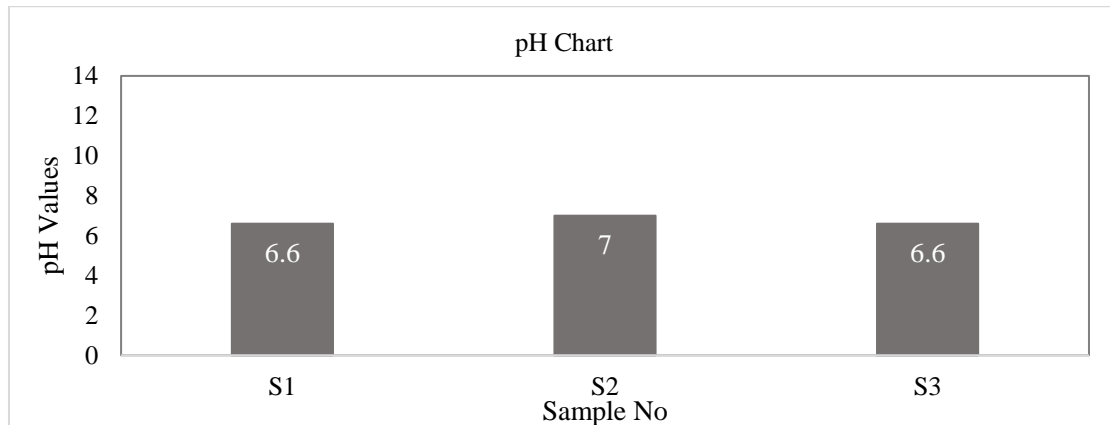


Fig. 3 pH chart of the tested samples.

COD

Figure 4 represents the COD values of the different samples. There has no significant difference was observed for the analyzed samples. All the samples were within the permissible limit set by BD standard. Sample 3 has the least value among all. High COD levels in drinking water may indicate organic pollutants, causing bad taste and odor. Disinfection byproducts from high COD water may increase the risk of gastrointestinal and other health issues [86], [87].

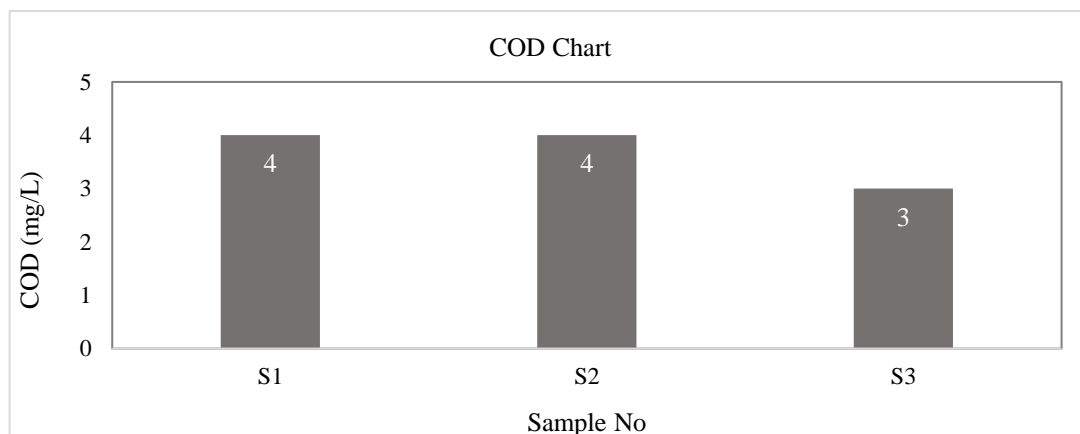


Fig. 4 COD chart of the tested samples

BOD

Figure 5 provides an overview of the BOD values obtained from the examined samples. The analysis demonstrates that the BOD values observed in all the samples fall well within the permissible limits established by the BD standard for drinking water purposes.

When looking at the samples, Sample 2 had the highest BOD value, measuring 2 mg/L. Samples 1 and 3 had the lowest BOD values, each measuring 1 mg/L. High BOD water indicates organic pollutants that deplete dissolved oxygen and harm aquatic life. High BOD in drinking water may indicate contamination, requiring thorough treatment to make it safe and tasty [88]. Direct health effects are rare.

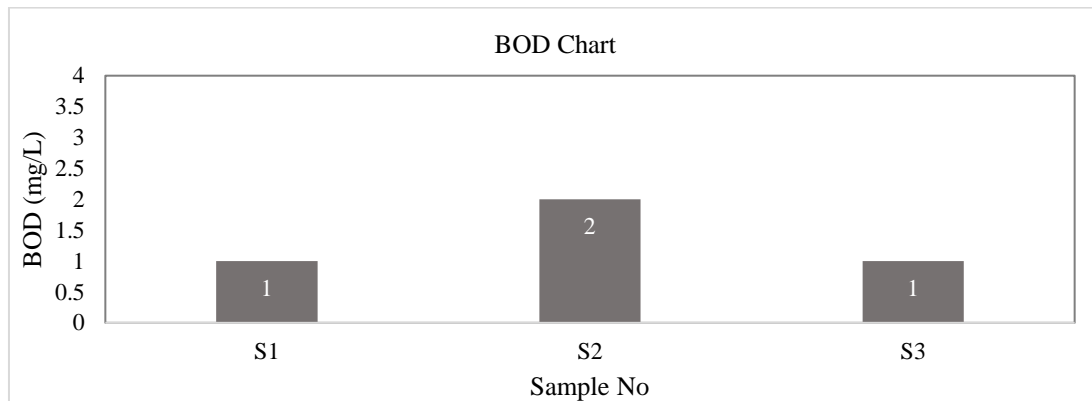


Fig. 5 BOD chart of the tested samples

Alkalinity

Alkalinity serves as the counterpart to acidity, with an increase in pH corresponding to a rise in alkalinity. Figure 6 represents the alkalinity values of the samples. The assessment revealed no substantial differences in alkalinity values among the samples. Although Sample 2 exhibited the highest alkalinity at 45 mg/L, Samples 1 and 3 had lower values, each at 40 mg/L, remaining consistent with the BD standard's lower limit for drinking water quality. It is noteworthy that alkalinity plays a pivotal role in evaluating the corrosive characteristics of water [89].

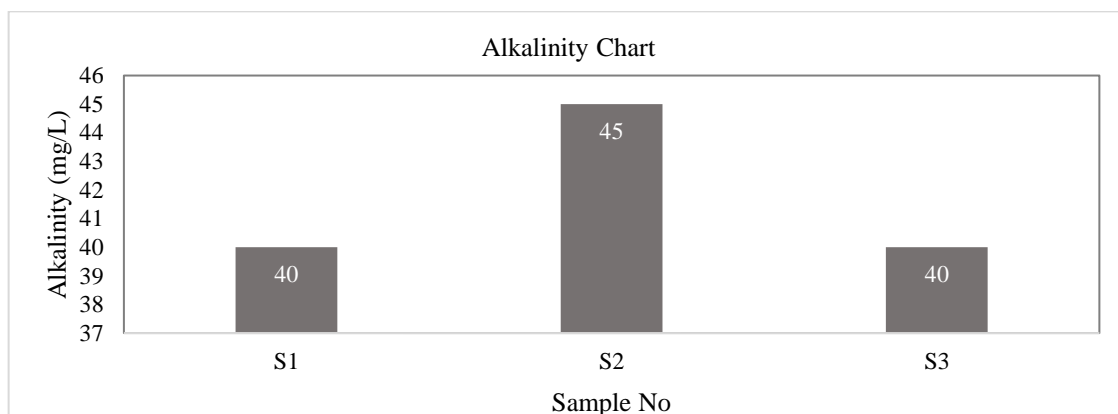


Fig. 6 Alkalinity chart of the tested samples

Dissolved Oxygen

DO measurements for the samples revealed values of 6.5, 6.7, and 6.7 for Sample 1, Sample 2, and Sample 3, respectively. Samples 2 and 3 exhibited the highest DO values, while Sample 1 recorded the lowest. It is worth noting that these DO values marginally exceeded the recommended limit set by the BD standard, which stipulates a maximum of 6. While this deviation could potentially pose minor concerns, it remains of minimal consequence in the context of drinking water quality. Adequate dissolved oxygen levels in drinking water are essential to support the well-being of aquatic organisms and prevent issues related to corrosion in distribution systems [90].

Chloride

Elevated chloride concentrations are known to impart a salty taste to water and beverages. As depicted in Figure 7, the chloride content across the samples exhibited a range of values. Sample 2 demonstrated the highest chloride content at 35.5 mg/L, followed by Sample 1 at 30.175 mg/L, and Sample 3 with the lowest recorded value of 26.625 mg/L. It is noteworthy that all these chloride values, although varying among the samples, remain below the minimum threshold established by BD standard guidelines. The maintenance of chloride levels within the standard limits ensures that the taste and palatability of drinking water are not adversely affected. Adequate chloride levels in drinking water are crucial to prevent corrosion in distribution systems and maintain water quality [91], [92].

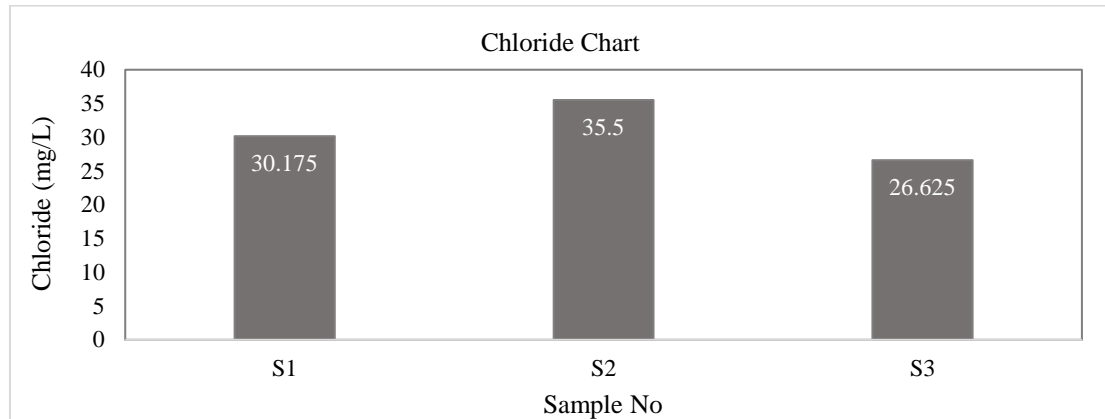


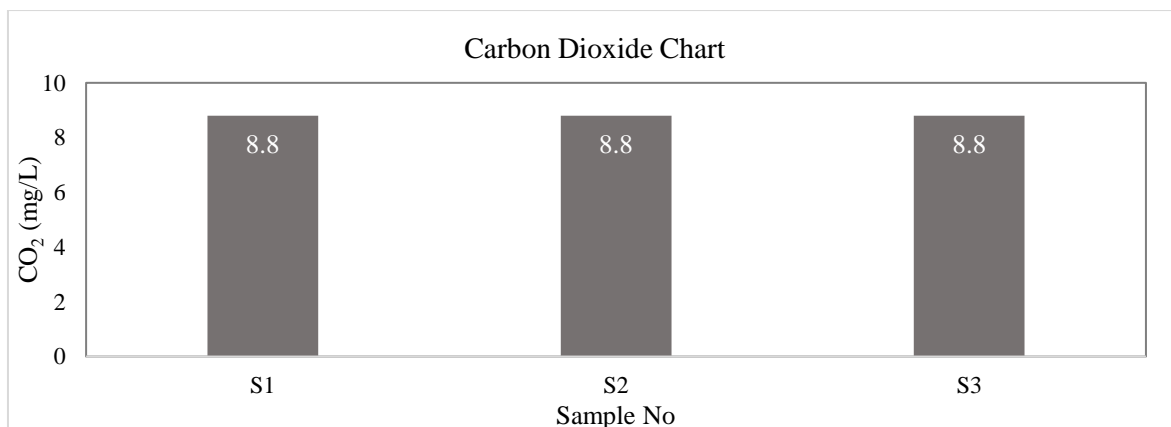
Fig. 7 Chloride chart of the tested samples

Iron

In situations where water is sourced directly from wells or involves anaerobic groundwater, it can sometimes contain ferrous iron in concentrations of several mg/L. However, it is noteworthy that none of the three samples exhibited any detectable presence of iron. According to BD standard guidelines for drinking water, the acceptable range for iron is set at 0.3 - 1 mg/L. The absence of detectable iron in the AC condensate samples indicates their suitability for drinking, particularly in terms of iron content. Maintaining low iron levels in drinking water is essential to prevent issues related to taste, odor, and potential staining of plumbing fixtures [93].

Carbon Dioxide

As illustrated in Figure 8, the CO₂ levels in the samples were uniformly present and notably consistent. Each sample exhibited a CO₂ value of 8.8 mg/L. The BD standard does not specify a particular limit for CO₂ in drinking water, although lower levels are generally preferred. The presence of consistent and relatively low CO₂ levels in these samples is advantageous, as excessive CO₂ can lead to a decrease in water pH, potentially affecting taste and corrosivity in distribution systems. Adequate control of CO₂ content is essential for maintaining water quality and minimizing potential concerns [94].

Fig. 8 CO₂ chart of the tested samples**Arsenic**

Arsenic was undetectable in all three samples, aligning with the BD standard's recommended limit for drinking water, set at 0.05 mg/L. The absence of arsenic in the samples indicates their suitability for drinking, with no concerns regarding the risk of arsenicosis-related diseases.

Maintaining arsenic levels within the specified limit is essential for ensuring the safety and health of individuals consuming the water. High levels of arsenic in drinking water can lead to severe health issues, including arsenicosis, making the absence of arsenic a positive indicator of water quality [95].

C. Quantity of AC condensate water

The determination of the quantity of AC condensate water involved continuous collection over a 24-hour period, where three distinct air conditioning units, each of varying capacities (1 ton, 2 tons, and 4 tons), were operated. The 1-ton AC unit produced approximately 3.2 liters of condensate water over the 24-hour duration, the 2-ton AC unit generated 5.9 liters, and the 4-ton AC unit yielded 11.8 liters within the same timeframe. These findings underscore the considerable potential of AC condensate water as a significant water source. If this water source proves to be potable, it has the capacity to substantially alleviate the demand for drinking water in densely populated urban areas like Dhaka, Bangladesh, and even globally. Given the widespread usage of air conditioning systems in households worldwide, the cumulative volume of condensate water holds promise as a valuable resource with far-reaching implications. While the data presented here pertains to just three specific AC units, the cumulative volume of condensate water could be substantial, bearing relevance for sustainable water supply considerations in various settings. Further exploration of the potability and treatment of AC condensate water could be a valuable avenue for research and practical application.

IV. CONCLUSION

In conclusion, the comprehensive assessment of both physical and chemical parameters in the context of the collected water samples has provided valuable insights into the potential use of AC condensate water as a source for drinking water supply. The results indicate that, in general, the AC condensate water exhibits characteristics that align with the parameters set by established water quality standards, affirming its potential as a viable source of potable water.

The physical attributes, such as color, taste, odor, temperature, TS, TDS, TSS, and turbidity, were all within acceptable limits, ensuring that the water maintains desirable sensory qualities. Furthermore, variations among these parameters, although present, remained within the prescribed standards. Regarding chemical parameters, pH levels, arsenic, chloride, and iron content were all found to be well within acceptable ranges, underscoring the suitability of AC condensate water for drinking purposes. The absence of harmful substances such as arsenic, low chloride levels, and undetectable iron are all positive indicators of water quality.

It was also found that, each operating continuously for 24 hours, demonstrate that AC condensate water production can be substantial, with the 1-ton AC unit yielding approximately 3.2 liters, the 2-ton unit generating 5.9 liters, and the 4-ton unit producing a remarkable 11.8 liters over a day. When extrapolated over a month, these figures become even more compelling. For instance, the 4-ton AC unit alone could generate approximately 354 liters of condensate water monthly, indicating the potential for high-volume production from a single source. Considering the extensive use of AC systems in households worldwide, the cumulative volume of AC condensate water is substantial and has the potential to significantly supplement the drinking water demand in urban areas, such as Dhaka, Bangladesh, and beyond.

In summary, AC condensate water represents a promising and underexplored resource for addressing drinking water supply challenges. While its potential volume is substantial, further research and practical initiatives are needed to harness this resource sustainably, ensuring its quality and safety, and to explore its broader implications for water sustainability.

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