REMOVAL EFFICIENCY OF DIFFERENT POLLUTANTS OTHER THAN AMMONIUM IN A BIOLOGICAL NITRIFICATION UNIT OF A WATER TREATMENT PLANT: A CASE STUDY

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ABSTRACT

For the past two decades, the water of the Shitalakshya River has exhibited a distinctive pollutant, namely ammonia, with an exceptionally high concentration. This pollutant is rarely, if ever, included in the list of fundamental surface water pollutants. The concentration of ammonia in the untreated water at Bangladesh's one of the largest treatment plants surpasses the capacity of removal through conventional water treatment processes. In response to this challenge, a full-scale biological pre-treatment unit named ‘Meteor’ was constructed. This unit, functioning as a ‘Moving Bed Biofilm Reactor’ focuses on the nitrification of the raw water. It was integrated at the beginning of the conventional treatment chain of the plant and became operational in 2012 with the primary objective of reducing ammonia levels in raw water.

The objective of this study was to explore the extent of removal of different pollutants other than ammonia, such as turbidity, nitrate, nitrite, sulfide, total COD, soluble COD, and conductivity, from the Shitalakshya River water within the nitrification unit called ‘Meteor’ during the nitrification process in the initial trial run of the unit. The average raw water flow rate was 226,000 m^3/d, and six Meteor MBBR reactors, each with a capacity of 45 MLD, were operationalized. The nominal dedicated aeration was achieved using six reactors, requiring the operation of six blowers, each with a nominal flow rate of 6,770 Nm^3/h.

Remarkably, the Meteor system achieved nitrification while meeting strict ammonia concentration criteria (< 4.0 mg NH_3-N/L) for influent concentrations < 15 mg NH_3-N/L. The system impressively reduced raw water turbidity by 0% to 96%, averaging 77% daily during the 64-day operational phase. Total Suspended Solids (TSS) removal ranged from 7% to 69%, averaging 19%. Total colloidal Biochemical Oxygen Demand (total cBOD) and total Chemical Oxygen Demand (total COD) removal averaged 10% and 25% respectively. Regarding nitrite, the average in raw water was 0 mg/L, rising to 2.97 mg/L post-pretreatment, fluctuating between 0.1 mg/L and 7 mg/L. Similarly, pretreated nitrate increased to an average of 14.7 mg/L from 2.58 mg/L, ranging from 5 mg/L to 23.8 mg/L. The system impressively removed 89% of sulfide and reduced conductivity by about 10%. Dissolved Oxygen (DO) levels at the Meteor system's inlet were nil (0 mg/L), exiting at 0 to 6.5 mg/L (average 4.7 mg/L). Water temperature and pH remained stable during the study.

The study's insights hold broad implications for current and future systems, offering vital guidance to design and operate biological pre-treatment systems, not just for ammonia but also for other applications.

Keywords: *Drinking Water Treatment, Biological Nitrification, Shitalakshya River Raw Water, Moving Bed Biofilm Reactor (MBBR)*

1. INTRODUCTION

1.1 Background

The history of drinking water supply development in Bangladesh's capital city, Dhaka, is intrinsically linked to the evolution of groundwater. Until 2002, approximately 90% of the water supply system relied on groundwater. Paradoxically, the initiation of Dhaka's first modern water supply system dates back to 1874 with the establishment of the Chandnighat water treatment plant based on conventional treatment process.

Over the decades, continuous groundwater extraction has transformed the once abundant and cost-effective groundwater source into a technically and economically challenging option, necessitating a shift towards surface water. Consequently, the Saidabad Water Treatment Plant (SWTP) Phase I was built with 225 MLD capacity, becoming the then largest WTP in the country. It commenced operations on July 27, 2002, drawing raw water from the Shitalakshya River, an eastern peripheral river of Dhaka (Figure 1). Subsequently, SWTP II, with the same capacity and design started operation in 2012, while the third phase, with a water treatment capacity of 450 MLD and intake at Haria point in Meghna River, is currently under implementation since 2022 (Serajuddin et al., 2022).

A few months after SWTP I started operation, Shitalakshya River showed serious pollution problems, especially during dry months of the year presumably due to man-made pollution. At the outset of the implementation of SWTP II, there were complaints of unpleasant colour and odour with the treated water delivered from SWTP I. Overviewing the intricate situation of water quality and water quality data, the Experts opined that the problem of colour, odour and taste of the treated water observed during the dry seasons, was due to primarily presence of an excessive concentration of a specific pollutant – Ammonia and which gave rise to a number of cause-effect relations. For instance, high concentration of ammonia make it hard to disinfect the water, resulting inability to fully control growth of algae and ensuring the hygienic quality of water showing the limits of traditional water treatment process (DWASA, 2007).

While drawing up the project of SWTP II, the necessity for a pre-treatment unit came across the discussion. Initially, three apparent possibilities for pre-treatment were prophesied namely:

- Nitrification and de-nitrification
- Stripping of ammonia
- Breakpoint chlorination

After the commissioning of phase I, the records of operational data exhibited an approximately 3 mg NH_4-N/L increase in the average monthly and max values of ammonia, over the four years from 2002 to 2006 (DWASA, 2007). The trend of ammonia pollution, the Bangladesh Standard for Nitrate of 10 mg NO_3-N/L, and the initial design criteria of max 4 mg NH_4-N/L for SWTP I, and, the increases are significant in such a short period. Thus, the trend must be taken into consideration. In the internal discussion of the service provider, it was concluded that Nitrifications might solve the ammonia problem and partly the sulfides and organic carbon problems, and a biological pre-treatment process (before the conventional treatment process) was considered as an alternative that might be an effective and economical treatment process for removal of the above-mentioned pollutants from the raw water (DWASA, 2007). This idea was a bit revolutionary in the context that almost no large drinking water treatment plant in the world like the Dhaka WTP ever used biological nitrification as a treatment option though it is popularly used in wastewater treatment plants. The experts proposed MBBR before the conventional treatment process, as an alternative for pre-treatment (Serajuddin, 2012).

MBBR, an innovative fixed biofilm reactor, has gained prominence in the wastewater treatment industry, successfully applied in full-fledged treatment of industrial and municipal wastewater. Developed in the late 1980s by a Professor named Hallvard Ødegaard from the Norwegian University of Science and Technology, based on conventional activated sludge and biofilter process, MBBR features continuous operation, low head-loss, non-cloggable biofilm reactor, no requirement for backwashing, and high specific biofilm growth on small carrier parts that move along with the water in the reactor (Ødegaard et al., 1994; Rusten et al., 1996; Pastorelli et al., 1997; Aspegren et al., 1998).

There is a significant amount of research on the application of biofilm reactors in wastewater treatment (Ødegaard, 2006; Rusten et al., 2006; Chen et al., 2008; Kermani et al., 2008; Gulhane and Kotangale, 2013; Palmer, 2013). Currently operating in 22 different countries worldwide are more than 400 large-scale wastewater treatment plants built on this methodology (Rusten et al., 2006). Nevertheless, the pre-treatment of drinking water has not yet been implemented using this novel biofilm reactor (Xie et al., 2005). Very little information, especially on the usage of MBBR, is available in the literature regarding the use of biological drinking water treatment (Rittmann and Snoeyink, 1984; Bouwer, 1988; Evans et al., 2010; Takó, 2012; Lytle et al., 2014).

It has been mentioned that "Biological filtration has not been historically accepted, at least not in North America" (Takó, 2012). With this backdrop in mind, a pilot study was also carried out using a laboratory-scale MBBR prior to making the important and ground-breaking decision to install a full-scale biological pre-treatment unit for a drinking water plant in Dhaka to reduce the pollution load of drinking water. It was a convincing outcome. In 2012, the largest drinking water treatment plant in Dhaka finally had a full-scale MBBR pre-treatment unit installed.

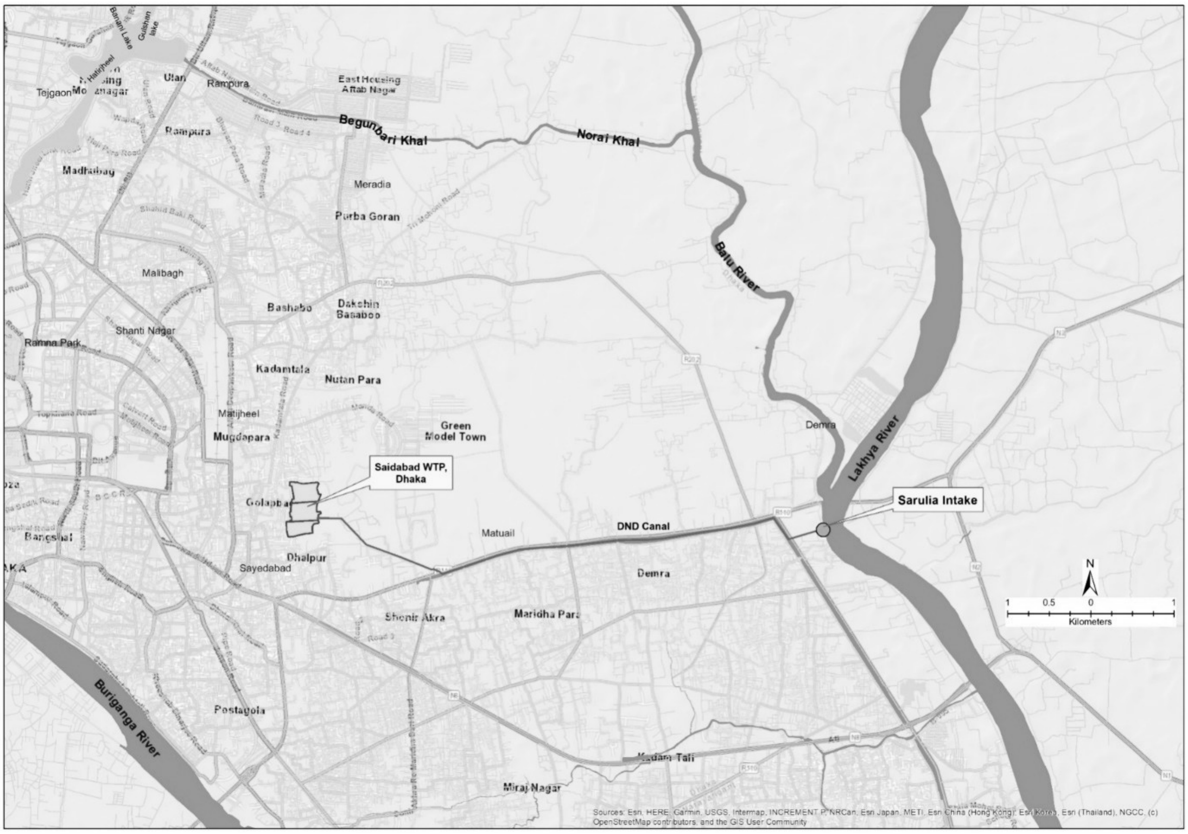

Figure 1: Raw water intake and its transmission network from Shitalakshya River to the SWTP

1.2 Objective of the study

With these backdrops,the objective of this study was to explore the extent of removal of different pollutants other than ammonia, such as turbidity, nitrate, nitrite, sulfide, total COD, soluble COD, and conductivity, from the Shitalakshya River water in the nitrification unit called 'Meteor' during the nitrification process in the initial trial run of the unit. It was intended to get the results of its performance throughout a dry season and to get some clear idea regarding its potential, as to be demonstrated in the actual operating condition, in providing a sustainable solution to those challenging issues pertaining to Dhaka water. The outcome of this investigation would be beneficial and reference data in designing the future water supply projects based on surface water in Dhaka considering the Shitalakshya river water as the raw water source and also elsewhere given that this biological processes are similar at those locations. The other factors that affect the efficiency of a biological treatment such as temperature range, time since comissioning, oxygen level required, pollution loading rate, resulting oxygen in the pre-treated water, pH, and sudden shock of pollution loading were also noted.

2. METHODOLOGY

2.1 Meteor Reactors Operation

The six Meteor reactors (also referred to as cells, units, or tanks) used in the inaugural year of trial operation are designated A, B, C, F, G, and H (Figure 2). This marked the first full-scale operation of a 225 MLD pretreatment unit, urgently employed in 2012 for WTP I before the completion of the entire 450 MLD pretreatment unit construction.

In the dry season of 2012, temporary walls were installed within the inlet and outlet channels to segregate the six cells in operation (A, B, C, F, G, H) from the remaining four cells (D, E, I, J), which were slated for operation during the subsequent dry season after the completion of phase II construction.
The pretreatment unit and the testing facility regarding water quality in the Dhaka plant laboratory were used for the study from February 6 to May 1, 2012.

The Meteor utilizes the 'Meteor 660 media'. The key characteristics of the media are as follows: corrugated cylindrical shape with a black color, with surface area of 650 m^2/m^3, nominal length and diameter of 12 mm, bulk density of 146 kg/m^3, filling rate of 50%, material being high-density polyethylene, and specific gravity of 0.95. In the reactor's bottom, aeration units are arranged on one side to induce a helical flow, ensuring optimal oxygen transfer and mixing to utilize the reactor volume effectively. This facilitates the circulation of water and uniform distribution of dissolved oxygen in the reactor's mixed liquor.

Raw water from the intake of the WTP is pumped into the bottom part of the reactor, while compressed air is supplied to the Meteor from the air blower installed in the plant. No outside organic sources, other than the feed water, were introduced to the plant. The expected and actual average and maximum concentrations of different parameters are presented in Table 1.

Table 1: Expected and Actual Raw Water Quality

	Raw Water Quality			
	Expected		**Actual**	
Parameters	**Average**	**Maximum**	**Average**	**Maximum**
NH_3-N (mg/L)	4	15	14.8	20.3
COD (mg/L)	20	60	51	76
Turbidity (NTU)	15	100	54	128
pH	6.5	8.5	7.4	7.9
DO (mg/L)	1	3	0.05	0.78
Temperature ^{0}C	20	30	28.35	31
NO_3(mg/L)	0.02	4.2	2.55	13.8
PO_4(mg/L)	0.3	4.9	0.53	-
Sulphide (mg/L)	6	25	0.04	0.07

2.2 Process air

The process aeration capacity of the pretreatment plant is 67,700 Nm^3/h for 10 reactors. Nominally, the dedicated aeration for phase 1 operation (using 6 reactors) is achieved by running 6 blowers (nominal flow 6,770 Nm^3/h each), theoretically producing 40,620 Nm^3/h at nominal speed, and slightly more in practice. During phase 1, the Meteor pretreatment was operated with generally 6 blowers or fewer. However, extra process air could be introduced during phase 1 by connecting additional blowers to the aeration network. In critical situations of excessive pollution, up to 8 blowers were utilized, raising the process aeration flow to 8,800 Nm^3/h per reactor in extreme cases, given the crucial importance of WTP I water production quality and quantity for Dhaka city in its first year.

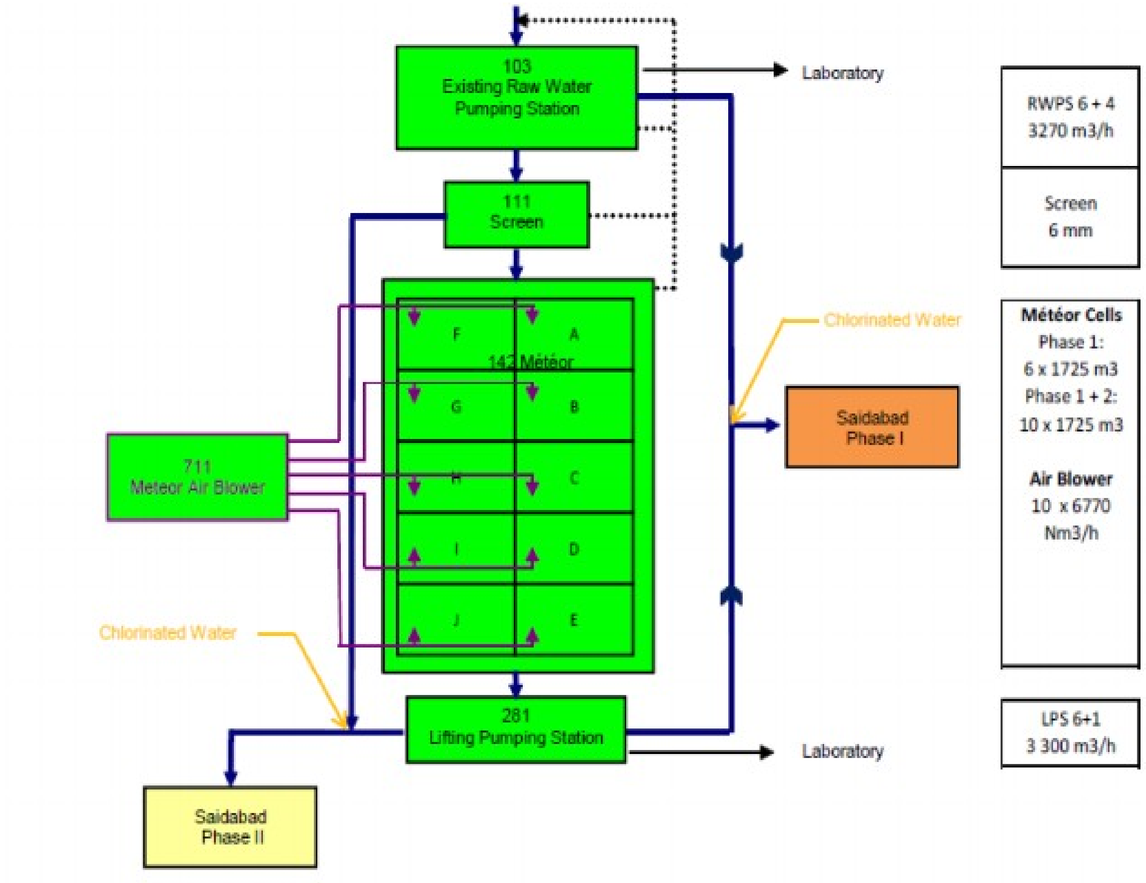

Figure 2: Meteor Reactors

2.3 Hydraulics

The water flow to pretreatment phase 1 was governed by the WTP I demand, typically ranging between 220,000 m^3/d and 240,000 m^3/d. The water level in reactors was maintained at approximately 40 cm below the nominal level of 5.0 m. The retention time in the 6 process tanks was slightly higher (+10%) than it would be for full-scale operation of two phases of WTP. However, within the considered ranges, it is known not to significantly influence the process. Operating at a reduced water level slightly lowered the theoretical aeration transfer efficiency. Overall, the hydraulic conditions during the tests were similar to full-scale pretreatment.

2.4 Water Testing and Laboratory Analysis

Water quality analysis was conducted in the water testing laboratory of WTP, with some additional analysis performed in the Bangladesh University of Engineering and Technology's (BUET) Civil Engineering Laboratory. Internationally recognized methods of sampling and testing, such as APHA, were employed in the analysis. For instance, ammonia was tested using Nessler method, No. 8038 & HACH DR 6000 spectrophotometer (HACH LANGE, USA); COD was tested using HACH DRB200 COD reactor (HACH LANGE, USA), HACH DR 890 colorimeter (HACH LANGE, USA) and by reactor digestion.

3. RESULTS AND DISCUSSIONS

The Meteor reactors were filled gradually with influent water from 6/2/2012 with a water flow of 1000 m^3/h from the Plant 1 inlet, and from this date until 27/2/2012 the reactors were only periodically aerated and fed with influent, as it was not possible to run in full capacity for some administrative reasons. The 3-week time period from 6/2/2012 to 27/2/2012 enabled the mixing and seeding of the bio-media. The full influent flow of Phase I was diverted on 27/2/2012 to feed the Meteor units, and 6 air blowers were placed in service.

The average raw water flow from 28/2/2012 through 1/5/2012 was 226,000 m^3/d. varying from 207,500 m^3/d to 242,500 m^3/d (Figure 3). During the first ten days of operation, the flow was maintained to a lower side between 207,500 m^3/d and 225,000 m^3/d due to the very high ammonia concentrations surpassing the design and expected raw water ammonia loads of 15 mg/L. Afterward, during the times when the concentrations of raw water ammonia were <15 mg/L, the inlet flow was maintained to a flow value greater than 225,000 m^3/d. During the 14 days, the period between 17/3/2012 through 30/3/2012 dual sampling was done, and water quality analysis was carried out simultaneously at the plant laboratory and an outside laboratory for verification and cross-checking.

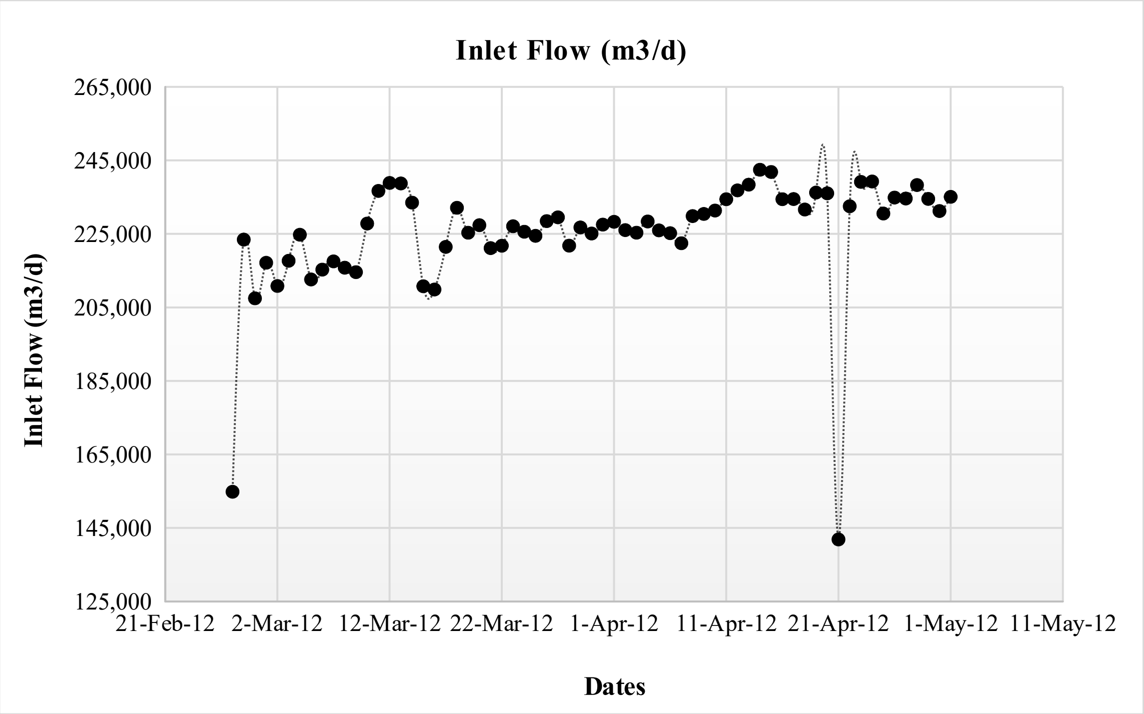

Figure 3: Influent water flow with dates

The flow was maintained between 221,131 m^3/d and 232,100 m^3/d, with an average flow for this period of 225,567 m^3/d. Several grid power shutdowns occurred which is visible in Figure 3 by the sudden fall of the water flow line. The raw water ammonia concentrations varied significantly, from 2.1 mg/L to 20.3 mg/L, during the 65 days from 28/2/12 through 1/5/12. It is observed the raw water had an ammonia concentration above the maximum value of 15 mg/L for 39 days (60% of the time). The average, minimum, and maximum ammonia concentration were found respectively as 14.79, 2.1, 20.3 mg/L.

Figure 4 summarizes the variations in raw water and Meteor effluent temperature and pH from 28/2/12 through 1/5/12. During this period the Meteor temperature increased progressively from 25 to 31°C then starting on 6/4/12 the temperature abruptly dropped back to 25°C due to a rain event and then progressively increased again to 31°C. Overall there is no significant difference in temperature between the raw water and the Meteor effluent. The average pH of the raw water was 7.4 and that of Meteor effluent was 7.2 during this period.

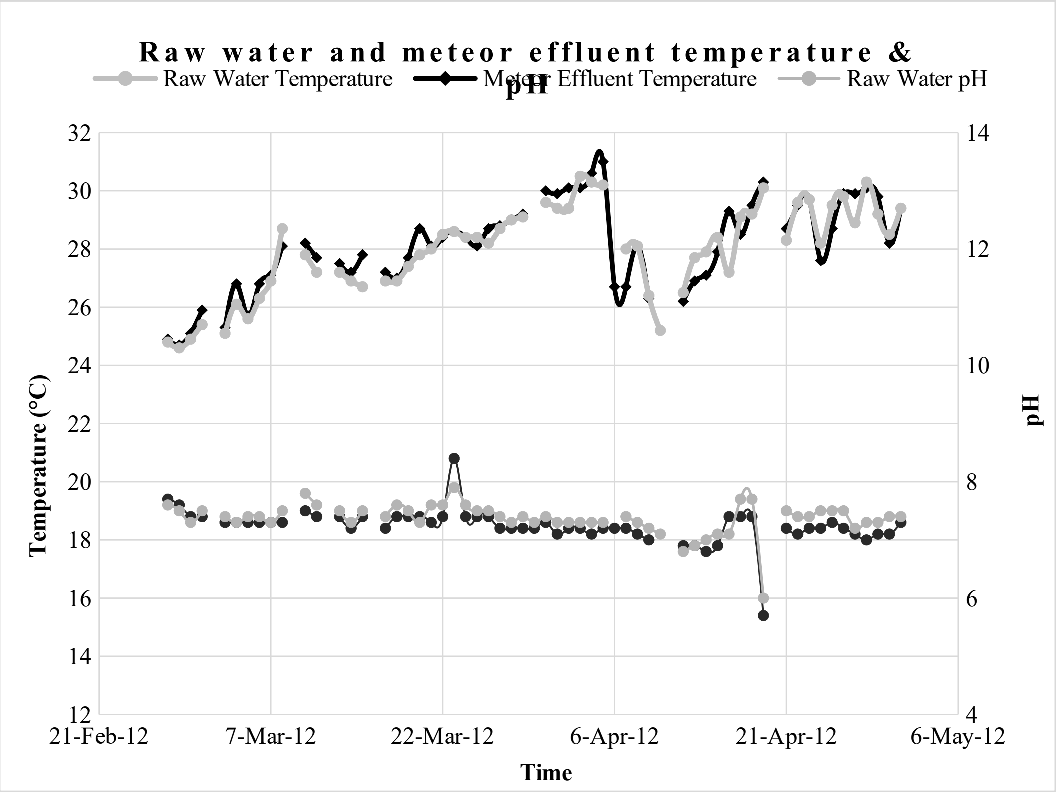

Figure 4: Raw water and meteor effluent temperature & pH

Figure 5 shows the dissolved oxygen (DO) in the raw water, combined Meteor and effluent. The Meteor effluent DO vary from 3 to 6.5 mg/L.

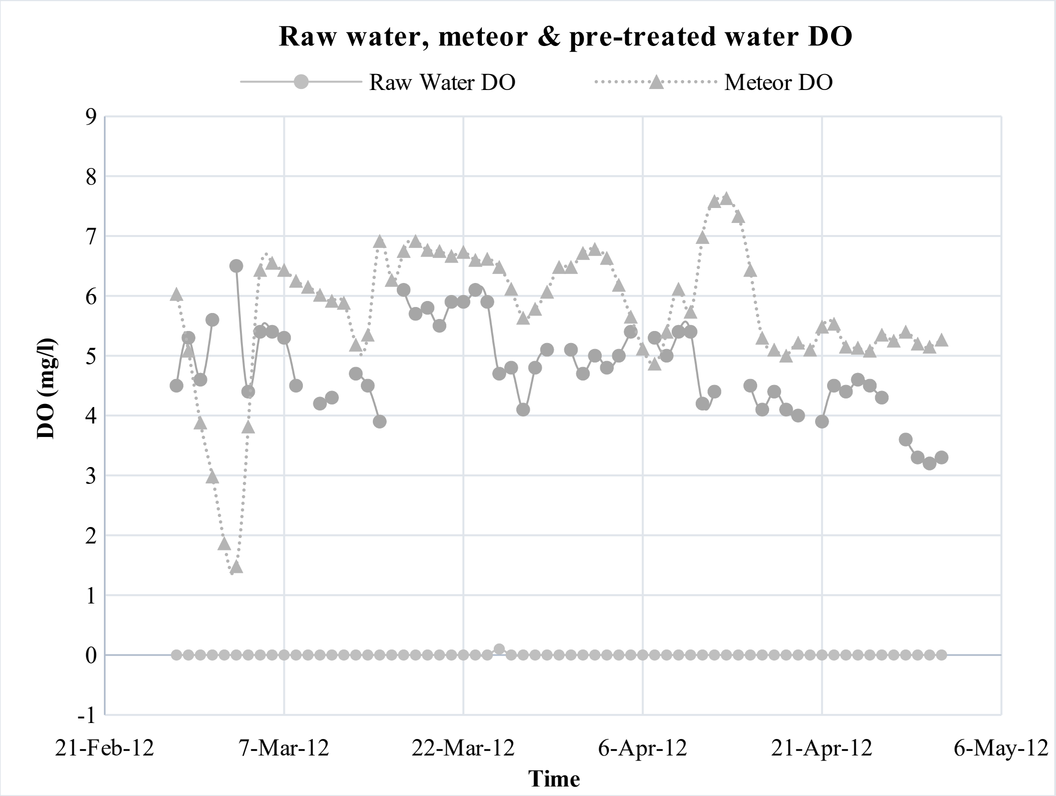

Figure 5: Raw water, meteor & pre-treated water DO

Remarkably, the Meteor system achieved nitrification while meeting strict ammonia concentration criteria (< 4.0 mg NH_3-N/L) for influent concentrations < 15 mg NH_3-N/L. The system impressively reduced raw water turbidity by 0% to 96%, averaging 66% daily, some days with negative values during the 64-day operational phase. The raw water global average, minimum, and maximum turbidity were respectively 67, 7, and 157 NTU. Generally, when the raw water ammonia concentrations were at a higher level the turbidity concentration was also at a higher level. The removal rate of turbidity was not as high as ammonia. When the global average ammonia removal was 80%, in the case of turbidity it was 66%. Total Suspended Solids (TSS) removal ranged from 7% to 69%, averaging 19%, some days with negative values. Total colloidal Biochemical Oxygen Demand (total cBOD) and total Chemical Oxygen Demand (total COD) removal averaged 10% and 25% respectively. Removal of COD ranges from 0 to 68% and that of cBOD 0 to 51%. Air flow to the Meteor and ammonia removal is shown in Figure 6.

After the start-up was achieved, from 7/3/2012 through 7/4/2012 except two days the raw water has an exceptionally high level of pollution above the design concentration. Due to these high levels of pollution at least 6 process air blowers were put into operation continuously. During the two peaks pollution periods (13 days ammonia $\geq$ 18 mg/L) up to 8 blowers were running to provide adequate oxygen for the nitrification process and verify the maximum ammonia removal rates for the 6 Meteor reactors while feeding the WTP-1 plant with the highest possible pre-treated water quality. During the start-up period of 3 weeks, the process aeration was run close to the maximum design value of 6,770 Nm^3/h for each reactor due to the high inlet loads and to ensure a quick start-up and development of the biofilm.

Regarding nitrite, the average in raw water was 0 mg/L, rising to 2.97 mg/L post-pretreatment, fluctuating between 0.1 mg/L and 7 mg/L. Similarly, pretreated nitrate increased to an average of 14.7 mg/L from 2.58 mg/L, ranging from 5 mg/L to 23.8 mg/L. The system impressively removed 89% of sulfide concentration when raw water's average sulfide concentration was 39 µg/L ranging from 19 to 76 µg/L whereas pre-treated water's average sulfide concentration was 3.38 ranging between 2 to 7 µg/L. The system also reduced conductivity by about 10% when raw water average conductivity was 955, varying from 624 to 1134µS/cm. Pretreated water conductivity ranges from 614 to 1065 with an average of 895 µS/cm. Dissolved Oxygen (DO) levels at the Meteor system's inlet were nil (0 mg/L), exiting at 0 to 6.5 mg/L (average 4.7 mg/L). Water temperature and pH remained stable during the study. From 8/4/2012 through 15/4/2012, the raw water ammonia, COD, turbidity, and other pollutants decreased significantly due to a rain event (Figure 7). During this period, the number of process air blowers was accordingly decreased to three blowers corresponding to the minimum fluidization flow for 6 reactors.

The analytical results of the raw water during this 56-day monitoring period indicate that the pollutant loads and concentrations are significantly higher and that the dry season lasts longer than assumed in the design. However, the pretreatment configuration used during the 2012 dry season was different from the future configuration when both WTP I and WTP II conventional plants will be in operation: 6 reactors were in operation this year, versus 5 for each WTP in future (i.e.: +20%) up to 8 blowers were in operation this year, versus 5 for each WTP in future (i.e.: up to +60%). Because of the anticipated high pollution in the raw water, the following detrimental effects on the biological process performance and WTP are likely to happen when the oxygen supply is a limiting factor:

- The pretreatment effluent's ammonia content will exceed 4.0 mg/l, overwhelming the WTP's capacity for chlorination. Nitrite NO2-N is produced by an unstable nitrification process brought on by ammonia overloading and oxygen deprivation, which will put too much demand on chlorine and exceed the water treatment plant's (WTP) capacity for chlorination.
- Excessive residual soluble COD pollution can hinder the WTP's ability to function and will not be removed there.
- As anticipated, the amount of ammonia nitrified and therefore nitrate produced would be greater than 10 mg NO3-N/L during the times of peak ammonia concentration in the raw water, above the nitrate standard for drinking water.
- Dhaka plant's raw water appears to have a rather high alkalinity (150–250 mg/L), particularly during the dry season. Therefore, it is doubtful that more chemicals will be required.

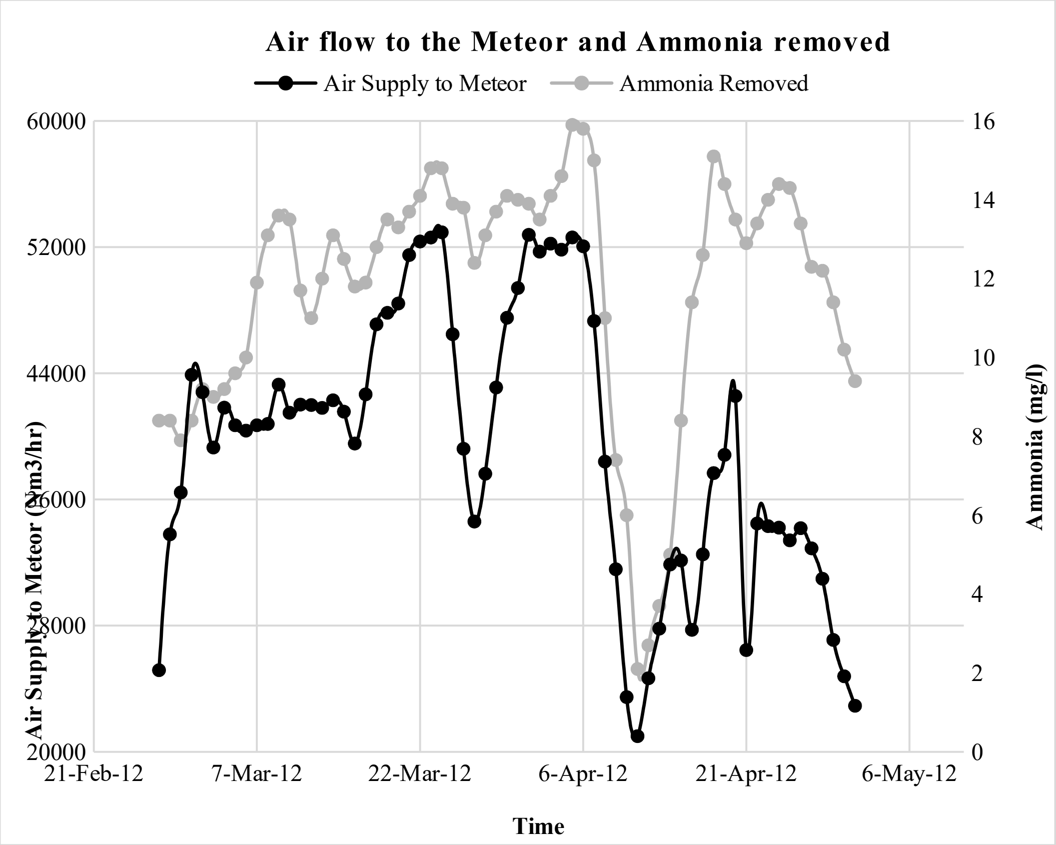

Figure 6: Air flow to the Meteor and Ammonia removed

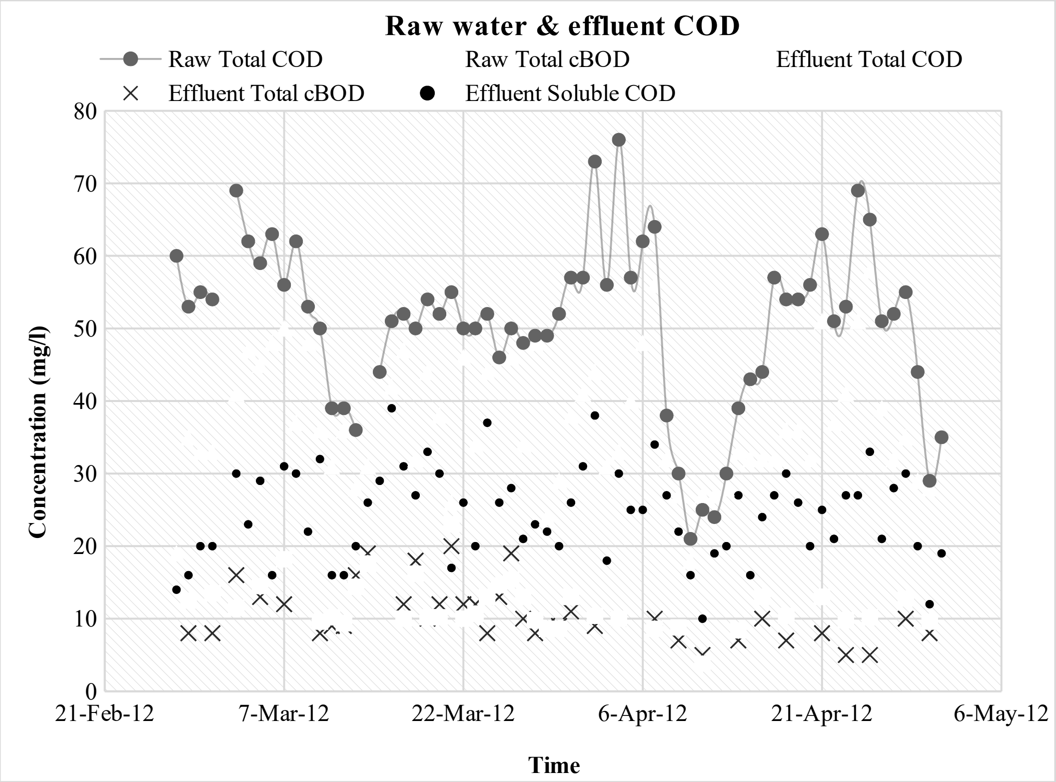

Figure 7: Raw water and effluent COD

4. CONCLUSIONS

The performance of a full-fledged biological pretreatment unit equipped with MBBR in a municipal water treatment plant in removing other pollutants than ammonia was studied. The removal target of 11mg/L of ammonia was possible. The system's complete development and full-scale startup since commissioning took three weeks. The ammonia concentration and removal rate were low at the beginning. Along with the designed ammonia concentration, the process can remove also turbidity, COD, TSS, cBOD, Sulfide, and Conductivity. However, it increases nitrite and nitrate. Water temperature & pH remain stable when it increases DO considerably also from the raw water.

In case the raw water pollution continues to reach the exceptionally high levels observed in 2012, the situation would require certain actions to enable the existing WTP I and future WTP II to meet the treated effluent quality requirements during the dry season.

The study's insights hold broad implications for current and future systems, offering vital guidance to design and operate biological pre-treatment systems, not just for ammonia but also for other applications. A feasibility assessment should include an evaluation of the financial and economic analysis, as well as the opportunity cost of the entire system.

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