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Performance Evaluation of Rapid Sand Filters in Potable Water Purification and Production- A Case Study of Chanchaga Water Works

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Abstract

In this research investigation, the performance evaluation of rapid sand filters for water treatment plant (WTP) was examined using Chanchanga Water Works (CWW), Niger State, as a case study. During the investigation, a filter was chosen out of the eight filters in operations in the plant. The performance indicators used in the studies were the head loss on the filtration rate, turbidity, and pH of clarified and filtered water through the filter unit operation equipment. These indicators were observed on the daily basis for a period of 29 days. It was found that the time when the filter was newly cleansed, the turbidity of filtered water was higher than before it was backwashed. This is the breakthrough point when it reduces to minimum level after the maturing time. The time required for the turbidity to reach a certain maximum value after backwashing was also found to be dependent on the quality of clarified water's turbidity. Acidity of the treated water was also found to be slightly affected by sand filter. It was observed that the filtered water is still ineffective against taste and odour which must be further treated in other unit operation equipment. It was also noticed that the filter produces large volumes of sludge which needed to be disposed immediately.

Keywords: Performance evaluation, rapid sand filter, head loss, turbidity, pH, filtration rate, Potable water

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1. Introduction

Rapid sand filters (RSF) are referred as the mechanical filters (MF) for the fact that auxiliary equipment such as pumps and compressors are needed to execute some certain operations of the system. They are largely utilized in today's modern public potable water treatment and purification plants (WTPPs). The increased demand of potable water for drinking purposes triggered the process development of RSF due to the limited supply of the quality drinking water, in which the older plant was primarily controlled by the slow sand filtration (SSF) technology. An account on one of the earliest developments of the municipal RSF plant was in 1885 at Somerville, New Jersey, USA, reported by Johnson [1]. A lot of research on how the filtrate quality and clogging of the filter media depend on both filter depth and the run-length-of operation have been reported [2-9]. Chang et al. [10] developed a framework for setting up the performance indicators and evaluation system of a typical water treatment plant (WTP). The chosen performance indicators were further analysed by the analytic hierarchy process (AHP) method to find the relative weighted value of each indicator and their major evaluation items. Two objective functions, water production cost and removal efficiency were developed and analysed to draw out an implementation plan for optimizing the performance indicators and achieving qualities of water source and treated potable water. More recently, there are several reported research on the performance assessments of municipal WTPPs.

Al-Jeebory and Gahawi [11] investigated the performance of WTP of Al-Dewanyia, Iraq to have a better understanding, monitor and evaluate the essential design and operating parameters of the plant. Their findings from the study disclosed that the treated water was not in conformity with the standards such as that of the World Health Organization (WHO) for the safe drinking water. Yousaf et al. [12] conducted a study characterize and treat the canal water by employing RSF. However, the study initially examined the canal water both chemically and microbiologically but found it was not safe and suitable for drinking purposes. The results for the investigation of the performance evaluation of WTP at Nangloi, New Delhi, India carried out by Khan and Ahmad [13] found that the quality parameters of the treated water met the standards of IS:10500 for the safe drinking water. Similarly, Brunner et al. [14] developed a framework for monitoring the formation of transformed products (TPs) during ozonation and RSF, while Sembiring et al. [15] and Wang et al. [16] considered RSF as one the processes for adsorbing the microplastics (MPs) after the following unit operations and processes: pre-sedimentation, coagulation-flocculation, and sedimentation, and the promising cost-effective techniques for the removal of organic micropollutants (OMPs) through adsorption, chemical oxidation, and biodegradation in WTPs, respectively. The works of Beshr et al. [17] accounted for the consumption of filtered water in the backwashing process of RSF in the WTP to be between 10% and 15%. Moreover, Olukowi et al. [18]

viewed RSF as a tool that can be utilized for the performance enhancement of the coagulation process, in addition to the composite coagulants like poly aluminium chloride/poly di-methyl di-allyl ammonium chloride (PAC/PDMDAAC).

Chanchaga Water Works was established in 1963 with the construction of Paiko water treatment plant to serve Minna and its surrounding environments, then being a small community. However, with the increase in population size, the need for more drinking water arose which led to the construction and subsequent expansion of the old plant with new water treatment facilities called Biwater and Impresit treatment plants in 1976 and 1982, respectively. These three (3) facilities make Chanchaga water works to have three (3) different water treatment plants for the purification and production of potable water. The current capacity of the three plants has a total production capacity of 71 million litres per day on full effective operation. However, this is less than a half of the town water demand that was roughly estimated to be about 150 million litres per day.

2. Materials and methods

2.1 Water sampling

The samples of raw and treated water were obtained from Tagwai dam and Chanchaga water treatment and purification plants (CWTPP) for the research studies, respectively. Tagwai dam is one of the greatest valleys in addition to Shiroro and Kainji dams. However, it has been mainly utilized for decades to

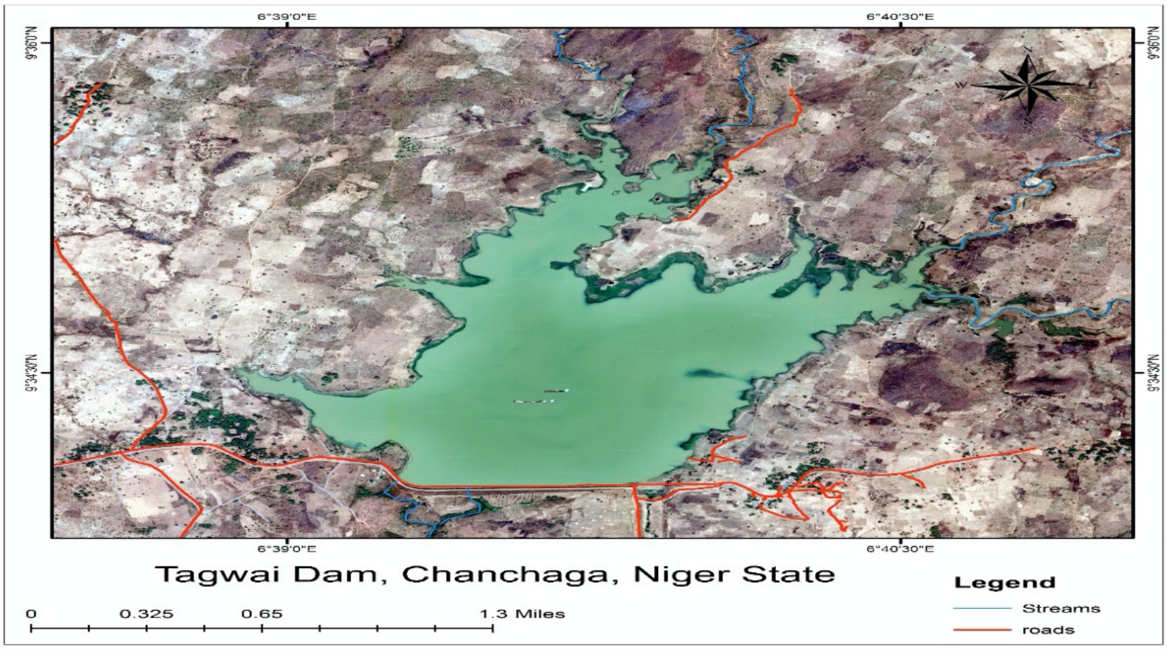

Figure 1. Map of Tagwai Dam, Niger State-Nigeria

source the raw water for potable water production, unlike the other two dams around the state used for hydroelectric power generations. Figures 1 and 2 are the maps of the study areas for the Tagwai dam and CWTPP, respectively.

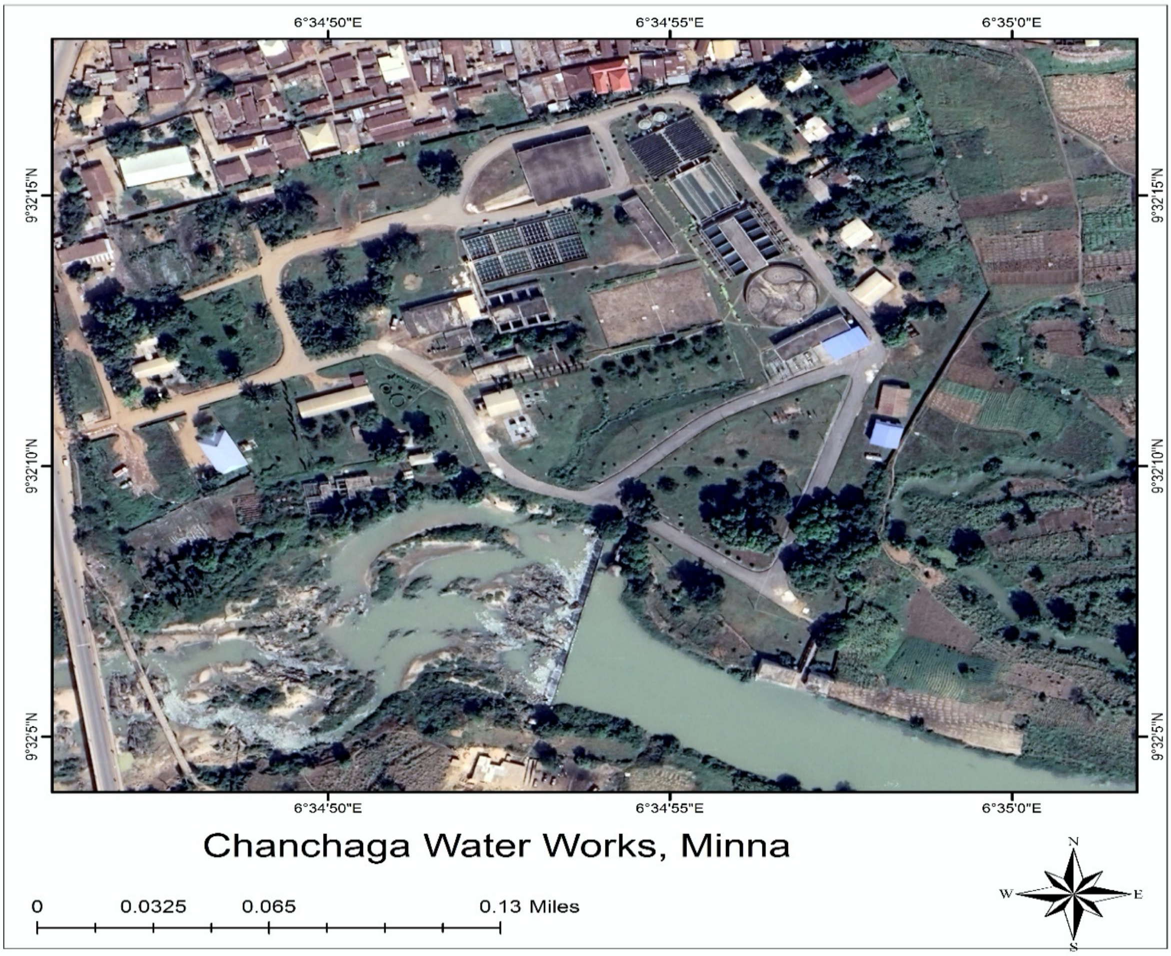

Figure 2. Map of Chanchaga Water Treatment and Purification Plant, Minna, Nigeria.

2.2 Chemicals and Reagents

All the chemicals, reagents, and other consumables used in the analysis of water quality performance indicators of the raw and treated water are of analytical grades.

2.3 Methodology

Aquazur filters, each with a filter bed of uniform grain size with a total capacity of filtering surface area of 93.28 square meters were utilized with the aid of centrifugal pumps for transportation, level and flow control valves and controllers for the research investigations. A highly sensitive pH and turbidity meters for detecting variations of 0.01 pH and turbidity up to 200 NTU were employed for the pH and turbidity measurements of the clarified and filtered water samples, respectively. Eight filters labelled A, B, C, D, E, F, G, and H with clogging indicators, hydraulic controllers, siphons and splitting boxes, and other auxiliary equipment built-in together with an equal amount of water passing concurrently through each of them. The experimental study was conducted over a period of twenty-nine (29) days from 2nd to 30th January 2010. For each day, the process monitoring, and observations of the process data for the experiment took about three (3) hours. Clarified water samples were fed to the filter with the aid of centrifugal pumps and then filtered out, which were controlled from the control panel of the control room. Head losses across all filters were recorded from the clogging indicators which continuously records them in meter (m). The filtration rates of each filter were obtained by dividing the volumetric flow rate of water recorded as the volumetric flow rate per unit filtering surface area (m^3/m^2. hr). The pH and turbidity for the clarified and filtered water were observed and measured using the pH and turbidity meters, respectively. For the detailed comprehensive performance assessments of the plant, eight filters A, B, C, D, E, F, G and H were wisely monitored and observed over the period of 50 hours filter run lengths, from 2nd to 4th January 2010, and the outcome of the evaluation are shown under the results section. Filter A was further examined over 648 hours filter run length, from 4th to 30th January 2010, and the results for the detailed assessments are presented under section of the results. The filtration rates, head losses across the filter, the pH and turbidity of the clarified and filtered water were monitored, observed, and recorded.

Backwashing of the filter beds were conducted when the grain sizes are no longer uniform and homogeneous for the continuous filtration operations due to the retained particulates of the foreign materials on the filter media, and the clogging indicators display the head losses reached a displacement of not more than1.5 m. The flowrates for the water and scour air for backwashing operation have the following characteristics from 13 to 15 m^3/m^2. hr and 50 m^3/m^2. hr, respectively. The clogging indicator was controlled manually. It was conducted from the control panel by closing both the filtered water outlet and the clarified water inlet valves. Then, followed by opening the wash water outlet and the air inlet valves to lower the water level and blow air for stabilizing the system before the wash water pump was started, respectively after ensuring the suction and discharge valves were opened. Then, the wash water inlet valve was adjusted to a flowrate around 1400 m^3/m^2.hr, if there was no loss of sand to the drain, otherwise, the flowrate must be reduced. The backwashing with air and water were continued from 6 to 30 minutes until the bed become less turbid. Then, the wash water was allowed to fill up the filter up to 1.2 m above the sand before completely shutting down the air blower. The air inlet valve was closed to stop blowing while the wash water inlet flowrate was reduced to only 14 m^3/m^2.hr into the media until the filter was no longer turbid and then closed. Afterwards, the filter was set for the next filtration operation by opening the inlet and outlet valves for the clarified and filtered water.

3.0 Results and Discussion

3.1 The changes of head losses across the filters

The results for the filtration rates and average head losses across the eight filters labelled A, B, C, D, E, F, G, and H that were monitored, observed, and recorded over the period of 648 hours (27 days) filter run lengths, from 4th to 30th January 2010 are shown in Table 1. From the outcome of the study conducted on the RSFs, it can be observed from Table 1 that the head losses across all the filters progressively increase with respect to time at constant filtration rate. This is due to the increase in the number of foreign materials and particulates being retained within the pores of the filter media, resulting in clogging the filter. The blank spaces and values with asterisks on Table 1 indicate the days when backwashing was carried out and the initial values of the head losses after backwashing. Likewise, the results for the comprehensive performance assessments of filter A over the period of 696 hours (29 days) filter run length are shown in Table 2. It can be seen from the results for filter A that the initial lost head increased from 0.22 m after backwashing on 4th January to 0.32 m on the 18th of January as shown in Table 2. Moreover, it was backwashed on the 19th and 27th of January as shown in Table 2. It was noted that the head loss across filter A was always less than 0.25 m after backwashing. This is in conformity with the heuristics for the filter operations. Filters B, C D, E, F, G and H were all backwashed on the 3rd of January, and their results show similar trends to that of filter A of increased of lost head after backwashing. Nevertheless, it was observed in the rare cases that the head loss across a newly backwashed filter was higher than 0.25 m as in the cases of all filters B, C, D, E, F, G, and where the loss of heads was 0.3 m. That might be resulted due to the improper backwashing or inaccuracy of the process instrumentations and control system.

3.2 The dependency of head loss on the filtration rate

The process monitoring of the eight filters were commenced 3 hours after the plant became under steady state. During the steady operation, the filtration rates were observed to be from 680 to 691 m^3/m^2. hr when the lost heads across the filters were from 0.63 to 0.75 m. However, in the case of filter A, the head loss across the filter dropped from 0.63 m to only 0.42 m when the filtration rate sharply reduced

Table 1. Average head losses across all the filters from A to H for a period of 27 days

Date	Filtration rate (liter/m^2.h)	Head loss (m)							
		A	B	C	D	E	F	G	H
04/01/2010	5.58	0.22	0.40	0.32	0.25	0.33	0.84	0.32	0.26
05/01/2010	5.58	0.22	0.42	0.30	0.25	0.32	0.84	0.31	0.29
06/01/2010	5.58	0.25	0.42	0.27	0.25	0.32	0.47	0.32	0.25
07/01/2010	5.58	0.22	0.48	0.27	0.25	0.36	0.47	0.33	0.27
08/01/2010	5.58	0.22	0.49	0.25	0.25	0.47	0.38	0.32	0.27
09/01/2010	5.58	0.23	0.55	0.26	0.37	0.43	0.40	0.32	0.26
10/01/2010	5.58	0.24	0.55	0.30	0.30	0.40	0.38	0.33	0.28
11/01/2010	5.58	0.25	0.55	0.30	0.25	0.44	0.38	0.33	0.30
12/01/2010	5.58	0.25	0.57	0.35	0.25	0.41	0.40	0.32	0.30
13/01/2010	5.58	0.25	0.58	0.35	0.25	0.35	0.45	0.31	0.32
14/01/2010	5.58	0.26	0.55	0.35	0.25	0.45	0.44	0.31	0.33
15/01/2010	5.58	0.26	0.55	0.34	0.25	0.33	0.42	0.34	0.34
16/01/2010	5.58	0.30	0.40	0.25	0.28	0.30	0.45	0.37	0.37
17/01/2010	5.58	0.30	0.42	0.26	0.26	0.32	0.45	0.37	0.35
18/01/2010	5.58	0.32	0.30	0.25	0.30	0.32	0.45	0.35	0.40
19/01/2010	5.58	0.20	0.35	0.25	0.23	0.30	0.48	0.40	0.40
20/01/2010	5.58	0.25	0.36	0.32	0.25	0.33	0.25	0.49	0.24
21/01/2010	5.58	0.25	0.35	0.35	-	0.33	0.30	0.24	0.25
22/01/2010	5.58	0.25	0.35	0.37	0.20	-	0.30	0.30	0.28
23/01/2010	5.58	0.30	0.40	0.33	0.32	0.20	0.30	0.32	0.25
24/01/2010	5.58	0.24	0.34	0.35	0.25	0.30	0.40	0.30	0.30
25/01/2010	5.58	0.25	0.40	0.30	0.25	0.35	0.40	0.30	0.35
26/01/2010	5.58	0.20	0.40	0.25	0.24	0.35	0.40	0.30	0.35
27/01/2010	5.58	0.20	0.40	0.27	0.25	0.30	0.40	0.35	0.40
28/01/2010	5.58	0.20	0.48	0.34	-	0.30	-	0.35	0.43
29/01/2010	5.58	0.20	0.40	-	-	0.32	-	-	0.45
30/01/2010	5.58	0.20	-	-	-	-	-	-	-

to only 4.91m^3/m^2.hr. However, a slight decrease in the filtration rate per filter on the 3rd of January does not affect the lost heads across filter G and H but has caused the head losses across the filter A and B to increase slightly as if the filtration rates were constant. That unusual trend might be resulted due to the bed instability of the filter or other sudden disturbances before the process become under steady state. Figure 3 displays the lost heads for the eight filters A, B, C, D, E, F, G, and H over 50 hours filter run lengths. The lost heads of the eight filters over 50 hours period of operations can be viewed in Figure 3. It can be inferred from the profiles that there were less variabilities during operations indicating that the filtration processes were under total control.

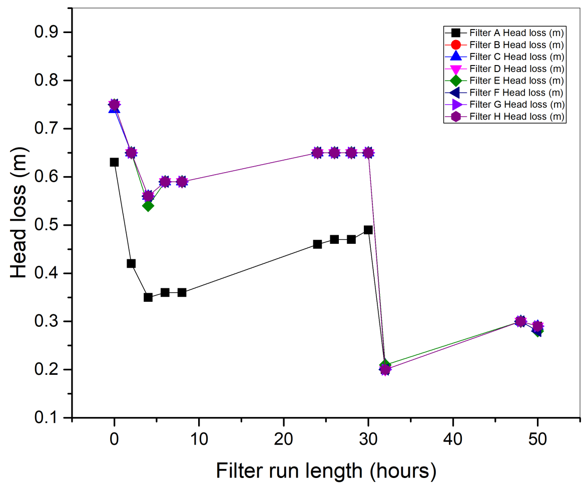

Figure 3. Head losses of filters A, B, C, D E, F, G, and H over a period of 50 hours filter run lengths.

Nonetheless, the increase in filtration rates was not expected to affect the head loss across filter A for the fact it was backwashed on the 4th of January and had no effect. Similarly, filter H does not respond positively to those variations in the filtration rates. That could also be resulted due to the backwashing of the filter H on the previous day 3rd of January 2010.

3.3 Water quality parameters

The quality parameters of the clarified and filtered water were monitored, observed, and measured using turbidity and pH meters. The detailed responses of the eight filters A, B, C, D, E, F, G, and H that were monitored and observed over the period of 50 hours filter run lengths are depicted in the following Figures 4, and 5. These Figures exhibit the comparison of the turbidity and pH water quality performance indicators of the clarified and filtered water for the eight filters A, B, C, D, E, F, G, and H. Figure 3 shows the comparison of the performance of filters A, B, C, and D, while Figure 4 displays that of filters E, F, G, and H, respectively. The responses of the eight filters can be seen clearly depicted using both turbidity and pH of the clarified and filtered water as the quality performance indicators. It can be noted that there are only some slight variations in both the first and the last four (4) filters responses as vividly represented in the Figures.

For instance, in the case of monitoring water quality across filter A, the turbidity for the clarified and filtered water varies from 2.30 to 7.60 NTU with corresponding pH values of 6.55 to 6.67, and from 0.32 to 0.22 NTU with corresponding pH values of 6.43 and 6.79, respectively. In addition, the study utilized the turbidity parameter as a function of filtration run time from 2nd to 27th January to assess the media of the filter A. This study conducted was divided into two (2) stages.

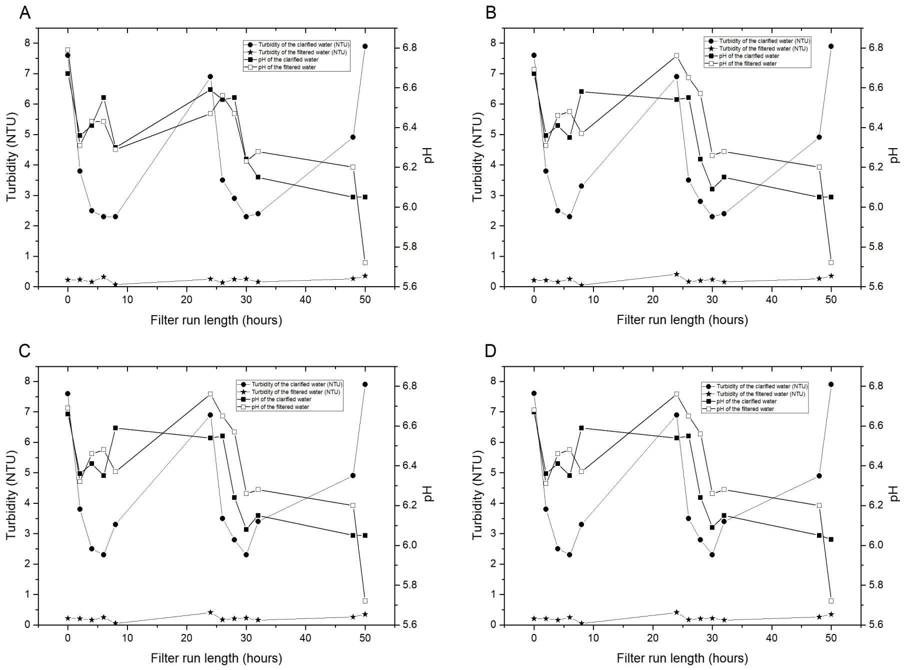

Figure 4. Performance assessments of filters A, B, C, and D over a period of 50 hours filter run lengths.

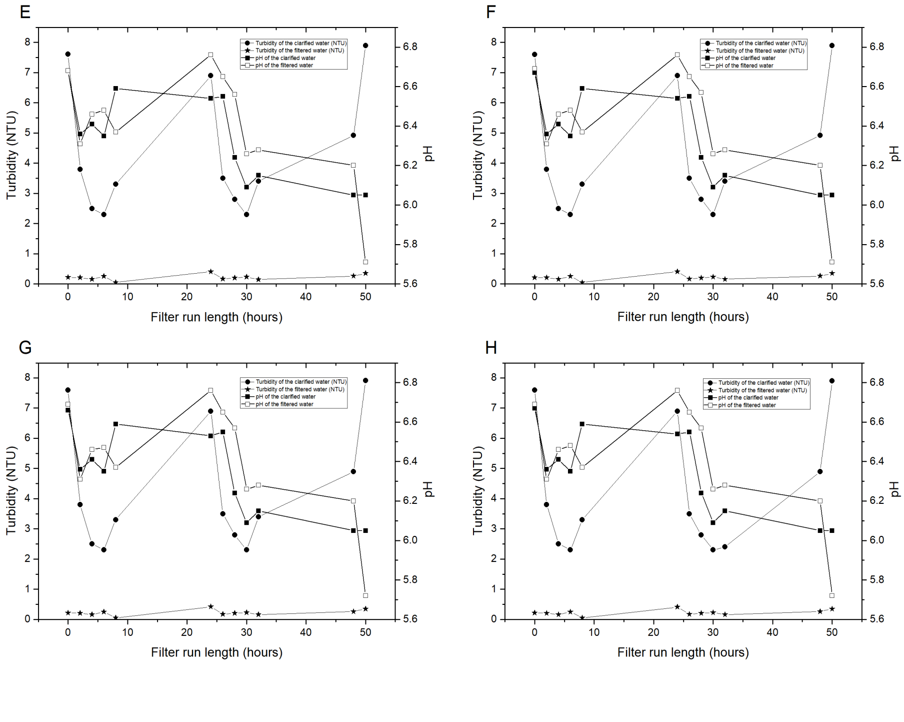

Figure 5. Performance assessments of filters E, F, G, and H over a period of 50 hours filter run lengths.

Table 2. Comprehensive performance assessment of filter A over a period of 27 days

Date	Filtration rate (liter/m^2.h)	Head loss (m)	Turbidity (NTU)		pH	
			Clarified water	Filtered Water	Clarified water	Filtered water
04/01/2010	5.58	0.22*	7.90	1.00	6.15	6.00
05/01/2010	5.58	0.22	10.10	0.40	6.80	6.67
06/01/2010	5.58	0.21	8.90	0.70	6.55	6.75
07/01/2010	5.58	0.22	6.40	0.60	6.65	6.70
08/01/2010	5.58	0.22	5.30	0.40	6.18	6.29
09/01/2010	5.58	0.22	4.30	0.25	6.00	6.78
10/01/2010	5.58	0.24	11.70	0.30	6.29	6.32
11/01/2010	5.58	0.25	7.20	0.80	6.20	6.85
12/01/2010	5.58	0.25	8.00	0.30	6.29	6.68
13/01/2010	5.58	0.25	6.20	0.36	6.50	6.72
14/01/2010	5.58	0.26	7.70	0.40	7.00	6.90
15/01/2010	5.58	0.26	4.00	0.50	6.90	6.83
16/01/2010	5.58	0.30	10.10	1.00	6.92	6.93
17/01/2010	5.58	0.30	7.80	0.60	6.80	7.00
18/01/2010	5.58	0.32	15.40	1.20	6.79	6.39
19/01/2010	5.58	0.21*	12.90	1.63*	6.04	6.50
20/01/2010	5.58	0.21	15.30	0.82	6.00	6.00
21/01/2010	5.58	0.25	11.20	0.30	6.56	6.75
22/01/2010	5.58	0.25	10.00	022	6.45	6.50
23/01/2010	5.58	0.30	2.50	0.44	5.55	5.68
24/01/2010	5.58	0.30	12.00	1.00	6.11	6.21
25/01/2010	5.58	0.30	12.90	1.90	6.42	6.41
26/01/2010	5.58	0.30	23.00	2.00	6.48	6.34
27/01/2010	5.58	0.20*	21.00	3.30	6.23	6.39
28/01/2010	5.58	0.20	21.00	3.00	6.40	6.59
29/01/2010	5.58	0.20	7.20	2.40	6.51	6.62
30/01/2010	5.58	0.20	10.20	1.69	6.64	6.60

The first phase was examined from 4th to 18th January. During these days, the highest head loss of the filter was observed to be 0.32 m on the 18th of January with the highest turbidness's of the clarified and filtered water as 15.40 and 1.20 NTU with pH of 6.79 and 6.39, respectively as shown in Table 2.

Consequently, this condition of the filter A indicates the need for the backwashing, and it was done on the 19th of January. Likewise, during the second phase of filtration operation from 18th to 27th January, the turbidity of the filtered water tends to be generally increasing after the backwashing. This rapid change in the turbidity of filtered water is known as the breakthrough point of the filter. The highest loss of head reached a displacement of 0.3 m and remained constant from 23rd to 26th January while the highest turbidness's of the clarified and filtered water was 23.00 and 2.00 NTU with pH of 6.48 and 6.34, respectively on the 26th of January as shown Table 2. The cause of these variations was mainly due to the non-uniformity and homogeneity of the grain sizes of the filter media as results of the retained particulates and foreign materials. Generally, it was observed that the turbidity of the filtered water was slightly increasing after backwashing with the filter run lengths until the filters become unstable and there were overshoots on the losses of head displacements. Again, the quality of raw water will certainly affect the rate of head loss development, and the filter run length. This will thereby determine the actual time needed for the backwashing of the filter media [7-9,19].

4. Conclusions

In conclusion, the experimental study was successfully conducted to examine the performance of the rapid sand filtration (RSF) unit of a water treatment and purification plant (WTPP) using Chanchaga water works as the case study. The following findings were found from the investigations, and inferences can be drawn based on our research observations:

1. The slight variations in filtration rates do not affect the lost heads across newly cleansed filters.
2. There is a breakthrough point of turbidity after backwashing of the filter due to the high porosity that exist within the filter media. That is the pores are very large compared to size of the particle to be filtered out.
3. The length of filter run between the backwashing and the lost head development varies based on the quantity of the suspended matter or particulates in the clarified water.
4. The following variables: the increase in the filter run length, the lost head, and the reduction in filtrate quality measured by turbidity are observed to be the key primary indicators for the backwashing of the filter media.
5. The performance of filters for the quality filtration and safe potable water purification and production is crucially dependent on the design of filter underdrain and the grain sizes of the bed.
6. The key requirements for the effective and efficient fast rapid sand filtration (RSF) operation under all constraints are the total cleaning of the filter media and the quality of the raw water.

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Conflict of Interest

The authors declare that there is no known conflict of interest in this research paper.

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