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Treatment of high turbidity water through plain and coagulated up-flow roughing filter

Ghalib Hasnain, Zahiruddin Khan*

Institute of Environmental Sciences & Engineering, National University of Sciences & Technology, H-12 Sector, Islamabad, Pakistan
Tel. +92 51 90854350; email: zahiruddinkhan@iese.nust.edu.pk

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ABSTRACT

Khokhar Zar Dam in Chakwal, Pakistan, serves as a main source of water supply to the area. This water is not only turbid but also biologically polluted. A hybrid slow sand filtration (SSF) plant, involving coagulation and sedimentation prior to SSF, is employed for the treatment. The treatment train is sensitive to wide variations in raw water turbidity and often results into short filter runs. Major objective of this research was to study the existing treatment process and conduct a pilot-scale investigation for the most appropriate treatment scheme, using an up-flow multistage roughing filter. A three-stage up-flow roughing filter (UFRF) was tested in plain and coagulated mode for a range of flow rates. Results showed that raw water turbidity reduced to 30 NTU in dry period and rose to over 2000 NTU after rainfall, whereas raw water pH and conductivity remained consistent. Jar tests showed that higher $FeCl_3$ dose (65 mg/L) would be required when compared with alum (47 mg/L). Plain multistage UFRF demonstrated 30–50% turbidity removal, whereas coagulated UFRF showed 99% turbidity removal at 35% of the dose applied by the treatment plant. Effectiveness of coagulated filtration continued even after the dose supply was ceased.

Keywords: Slow sand filtration; Turbidity; Coagulant dose; Alum; Ferric chloride

1. Introduction

Over exploitation of ground water by municipalities and industries, and, on-going changes in rainfall patterns are disturbing the water balance, especially the water recharge rate. Consequently, many cities of Pakistan, including Islamabad and Chakwal, are mostly or partly, depend upon surface water [1]. While surface water from a protected reservoir is good in quality, it is generally high in turbidity, suspended solids, natural organics, and particulate matter. Disinfection of turbid water requires higher chlorine dose. WHO recommends treated water turbidity to be less than 0.1 NTU prior to chlorination [2]. In emergency situations, up to 20 NTU is acceptable [3]. Turbidity is the principal parameter, which is caused by the suspended matters or impurities, interfering with the light transmission through water. Positive correlation between turbidity and pathogens

*Corresponding author.

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has been reported, and high residual turbidity in the treated water would promote the regrowth of pathogens in the distribution system, leading to waterborne-disease outbreaks [4,5]. Since 1990, the number of people without access to safe drinking water source has remained constant at approximately 1.1 billion. Out of this, approximately, 2.2 million lose their lives to polluted water ingestion each year [6].

High turbidity water, if not pretreated, requires high coagulant dose and produces large volume of sludge. In addition, such water even if treated under conventional train, i.e. coagulation, flocculation, sedimentation, filtration and chlorination, require higher dose of chlorine to ensure effective microbial inactivation. The present water treatment facility at Chakwal was established in 1980 as a hybrid slow sand filtration facility with coagulation and sedimentation prior to slow sand filtration. Since it is commissioning, this facility has been treating high turbidity water from Khokhar Zar Dam. For coagulation, a commercial alum sack is placed in the raw water channel. The consumption of the alum is not uniform as turbidity of the water keeps changing diurnally and seasonally. This results into large volume of sludge. The system remains efficient during normal turbidity conditions (40–200 NTU); however, during and immediately after the wet storm spell, the turbidity of the raw water rises as high as 2000 NTU, leading to substantially reduced efficiency of the system. High levels of settlable solids in the wet weather flow rapidly clog sand filters and necessitate frequent scraping of the filter bed.

To maintain the requirement of the relatively low turbidity of the filter influent, the management at Chakwal Water Treatment Plant (CWTP) is adding a heavy dosage of commercial alum (122 mg/L in dry season and 307 mg/L in rainy seasons on average). This amounts to US $ 5000.0 per month in dry season and US $ 18000.0 per month in rainy season.

Roughing filters are generally placed prior to slow sand filters for reducing the influent turbidity and suspended solids to a level that is effective for operation. It helps improving raw water quality without using any chemicals [7,8]. Roughing filters mainly act as a barrier between suspended and some colloidal solids and the other treatment processes. However, the large interpore volume available for sedimentation at relatively small filtration rates (0.5–1.5 m/h) also support adsorption as well as chemical and biological processes. Besides solids separation, roughing filters also partly improve the bacteriological water quality to a minor extent [9]. Table 1 gives a brief account of past studies on turbidity removal through roughing filtration in different parts of the world.

Specific objectives of this research were as follows: (a) to study the existing treatment process and highlight its shortcomings, (b) determine the optimum coagulant dose using common coagulants, such as alum and Iron salts, and (c) design, construct, and operate a pilot-scale up-flow roughing filter (UFRF) to determine its effectiveness against turbidity against plain and coagulated inflows.

2. Methodology

Following methodology was adopted to achieve the above mentioned objectives:

(a) Thorough assessment of the physicochemical characteristics of the existing influent and effluent at the CWTP using the equipment and methodology are given in Table 2.
(b) Determining the optimum coagulant dose and pH for the raw water from Khokhar Zar Dam before and after up-flow filtration.
(c) Testing coagulants such as aluminum sulfate (14% pure, purchased by the TMA[1] Chakwal from Hattar Industrial Estate, Pakistan), and ferric chloride before finalizing the coagulant dose and the treatment train.
(d) Design and construction of an UFRF pilot plant is shown in Fig. 1. Filter columns were designed on the basis of recommendations within the relevant literature [17,18].

The pilot-plant system includes the multistage and multilayer UFRFs followed by slow sand filter. However, the pilot system was unique with respect to its filter design parameters, a summary of which is given in Table 3.

A comparison was performed between multistage and multilayer UFRF. The multistage UFRF consisted of three different tank stations (tanks A–C) with media size 14–20, 9–14, and 5–9 mm. Media in each tank was one meter deep. In case of multilayer UFRF (tank E), three layers of gravel were placed upon each other, and the total depth of the filter bed was 1 m. Monitoring of the effluent from both RF's provided the opportunity to identity the influence of media size distribution and depth of the media bed.

(e) Studying the effectiveness of the multistage and multilayer UFRF for turbidity removal during wet and dry weather at flow rates of 30, 34, and 38 L/min.

[1]Tehsil Municipal Authority.

Table 1
Turbidity removal by roughing filtration—global experience

Reference	Filtration rate (m/h)	Filter medium	Average removal (% turbidity)
[10]	1.05	Gravel	60
[11]	0.03	Gravel	90
[12]	0.75	Gravel	90
[13]	1.05	Gravel	75
[14]	1.08	Local sand and Gravel	63
[15]	0.75	Gravel	75
[16]	1.0	Gravel	95

3. Results and discussion

To study the existing treatment process at the CWTP and highlight issues related to water quality, the turbidity and pH of the influent and effluent of the CWTP were recorded on daily basis. The following sections explain the results obtained from this research work.

3.1. Water quality at CWTP

A number of water samples from the CWTP were collected at various locations and analyzed for the physical and chemical parameters. All tests and analyses were carried out according to the Standard Methods for the Examination of Water and Wastewater, 20th edition, 1998.

Raw water turbidity in dry weather varied between 30 and 300 NTU. However, it rose to over 2000 NTU after the wet spell but fell to the normal 150–300 NTU within 72 h after the wet spell.

The treated water turbidity also fluctuated quite considerably, yet remained between 05 and 20 NTU in most instances. In order to keep the treated water turbidity below 10 NTU (WHO's Guidelines), the facility management widely varied the coagulant dose as well as the postcoagulation settling periods. For the same reason, filter effluent was sometimes augmented with low turbidity groundwater prior to chlorination. If these measures did not work, surface water supply was halted. Fig. 2 shows variations in raw and treated water turbidities at CWTP during the study period. In the same period, pH of raw water exhibited the alkaline nature. It remained above pH 8 in most cases as shown in Fig. 3.

3.2. Multistage up-flow roughing filtration

Based upon thorough the literature review [19–22], three flow rates were selected for the performance evaluation of the multistage UFRF.

Three filtration runs were performed at 30, 34, and 38 L/min. Fig. 4 shows the cumulative turbidity removal along with effectiveness of individual columns in removing raw water turbidity.

Turbidity removal trends of the UFRF for two consecutive runs at 30 L/min were quite consistent. On this basis, one filter run was performed at 34 and 38 L/min. No coagulant was added during these runs. Maximum turbidity removal at 30, 34, and 38 L/min was about 33, 55, and 50%, respectively. Raw water turbidity during filter run at 30 L/min ranged between 40 and 140 NTU which exhibited normal dry weather operating conditions. Raw water turbidity during filter run at 34 L/min ranged between 450 and 650 NTU which exhibited water quality after light rain spell. Raw water turbidity during filter run at 38 L/min ranged between 300 and 400 NTU which corresponded to a transitional period between wet spell and normal operating conditions.

Occasional power outage at the plant hampered the filter operation and did not allow the determination of filter run length based upon effluent turbidity. Fig. 5 shows the turbidity variations during the complete filter run excluding filter run suspension

Table 2
List of parameters characterized, analytical method, and equipment used in the study

Qualitative variable	Analysis method/description	Reference method	Equipment used
pH	Electrometric	APHA 4500-H B	InoLab PH/cond 720 Analyzer
Turbidity	Comparison with primary formazin standard of 4,000 NTU	APHA 2130 B	Turb 355 IR/T portable Turbidimeter
Conductivity at 25°C	Electrical conductivity	APHA 2510 B	InoLab PH/cond 720 Analyzer
Alkalinity	Potentiometric titration to end point pH 4.5	APHA 2320 B	–
Suspended solids	TSS and TDS total suspended solids dried at 103–105°C	APHA 2540-B	250-mi Gooch crucible under vacuum
Total settleable solids	Emhoff cone method	APHA 2540-F	250-mi Gooch crucible under vacuum

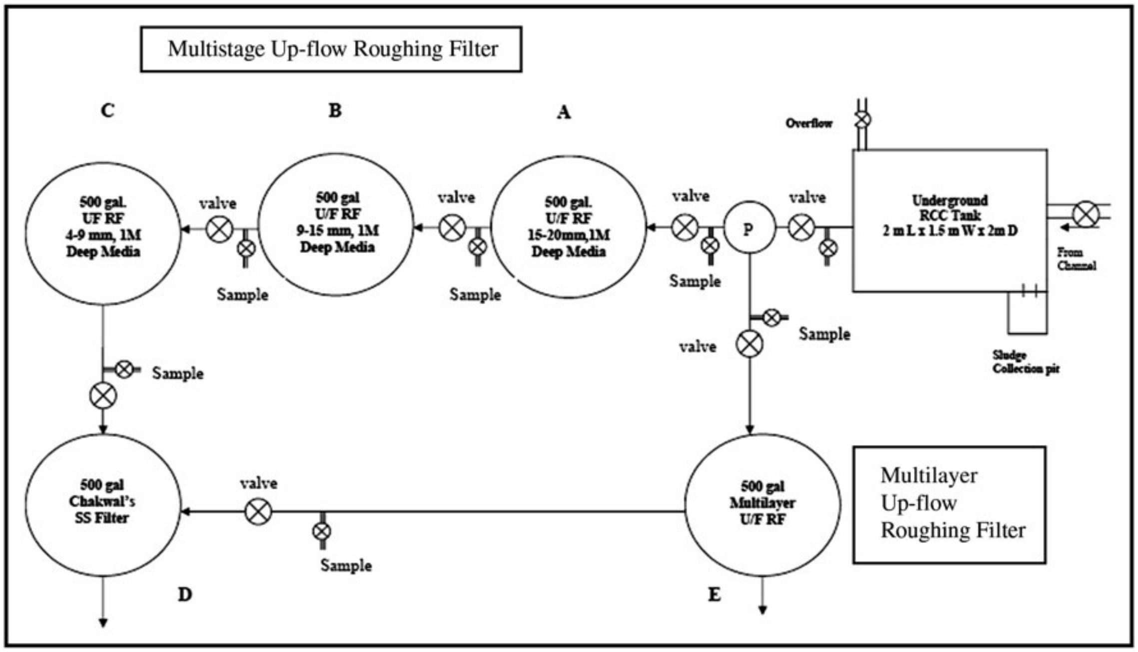

Fig. 1. Schematic of the UFRF used in this study.

Table 3
Design details of pilot plant for pretreatment of turbid water at CWTP

Tank	Material	Level	Dimensions	Media		Flow direction	Free board (mm)
				Size (mm)	Depth		
Pre-sedimentation	RCC	Under-ground	$2\,m \times 1.5\,m \times 2\,m$	None	None	Horizontal	450
Tank A	PVC	600 mm above ground	$1.9\,m^3$	15–20 Gravel	1 m above under-drains	Up-flow	300
Tank B	PVC	On-ground	$1.9\,m^3$ Dia ≈ 1.04 m	9–15 Gravel	1 m above under-drains	Up-flow	300
Tank C	PVC	600 m under-ground	500 Gallons Dia ≈ 1.04 m	4–9 Gravel	1 m above under-drains	Up-flow	300
Tank D	PVC	900 mm under-ground	500 Gallons Dia ≈ 1.04 m	Chakwal sand	CWTP	Down-flow	300
Tank E multi-media	PVC	On-ground	500 Gallons Dia ≈ 1.04 m	15–20 9–15 4–9 (Gravel)	270 mm layers (med)	Up-flow	300

during brief power outages at 34 L/min. This is just to highlight the facts that filter keep showing its effectiveness despite a few intermittent hours of power outage every day. This run had to be terminated due to substantial reduction in filtration rate as suggested in literature [23].

3.3. Multilayer up-flow roughing filtration

Next, a multilayer up-flow filter with the same media gradation but one-third thickness of each layer was tested to see the impact of the depth of the media. Fig. 6 shows the results of these experiments. The effectiveness of multilayer filter was obvious, but

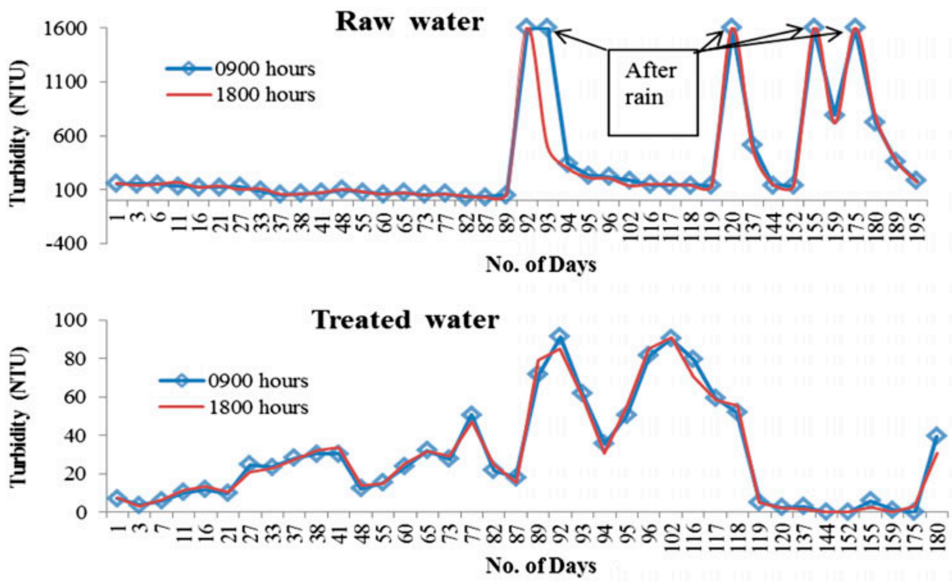

Fig. 2. Raw and treated water turbidities of the existing treatment plant.

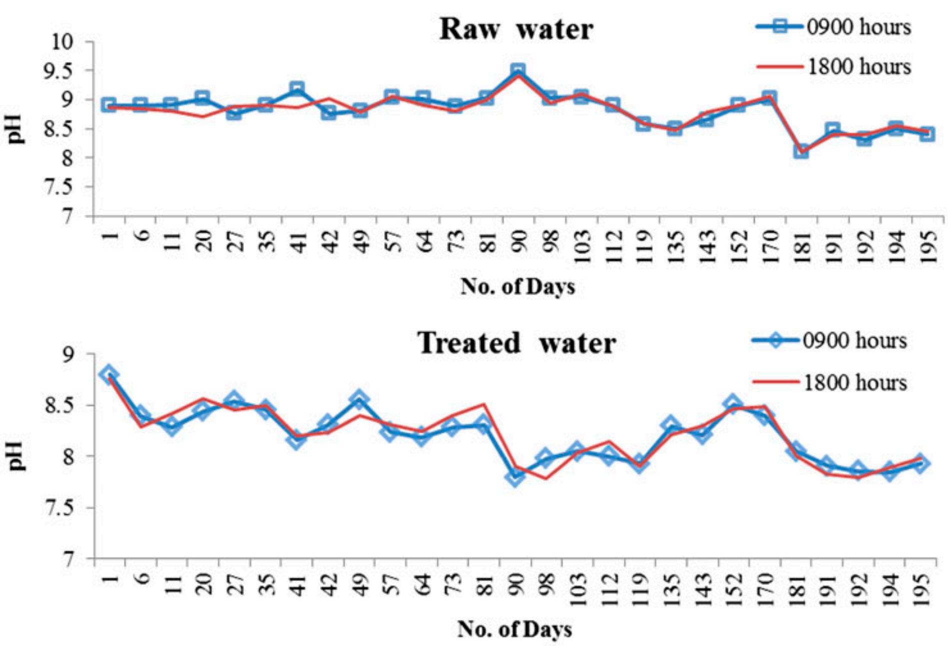

Fig. 3. Raw and treated water pH of the existing treatment plant.

its performance at 34 L/min and 38 L/min was not comparable with that of the multistage filter. Maximum turbidity removal in this case was about 33% (i.e. 150–100 NTU).

3.4. Coagulated UFRF

Keeping in view the limited turbidity removal by plain filtration, in-line coagulation was performed using alum and $FeCl_3$ as coagulants at the above-mentioned flow rates. Optimum coagulant dose was determined using the standard jar testing apparatus. The coagulant dosages were determined for dry and wet weather conditions to be compared with the dosages traditionally applied by the plant management under these conditions.

The results obtained from the in-line coagulation are illustrated in Figs. 7 and 8 and are discussed below:

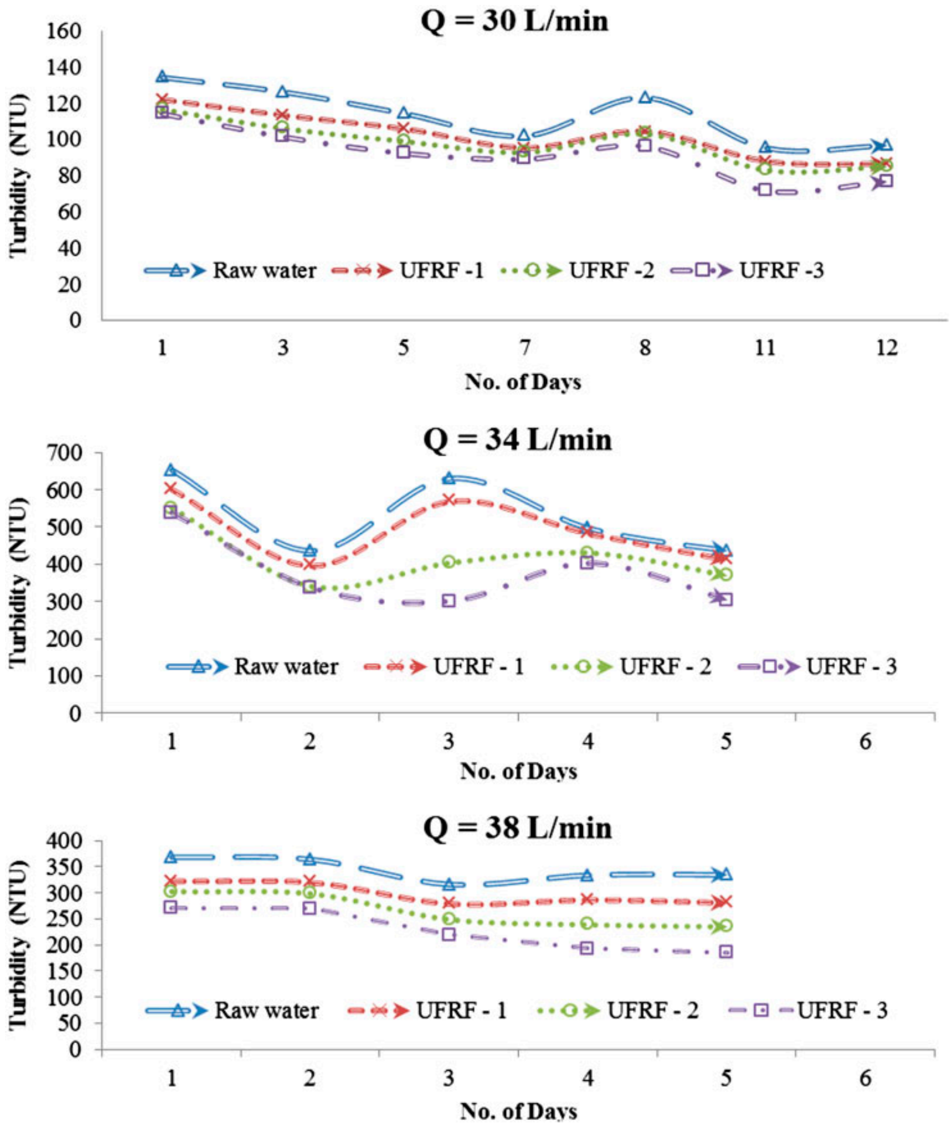

Fig. 4. Effectiveness of UFRFs at various stages of filtration and flow rate.

The optimum alum dose of 47 mg/L was determined by jar test experiments for dry weather flow vs. 122 mg/L of alum used at the filtration plant. The alum dose of 47 mg/L was applied to raw water line into the UFRF plant operating at flow rates of 30, 34, and 38 L/min. Roughing filter effluent turbidity fell steadily and reached below 10 NTU within first few hours of operation. Alum injection was stopped once turbidity of the filter effluent fell below 10 NTU. The objective was to determine the effectiveness of alum-coated filter grains even when no coagulant was applied.

The UFRF remained effective for turbidity removal for five hours after the dose injection was ceased. Filter effluent turbidity rose to near its minimum effectiveness without coagulant. It clearly shows that inline coagulation using alum is very effective in reducing raw water turbidity to below 10 NTU. Application of such low turbidity water to slow sand filters would enhance the effectiveness as well as filter run length of the slow sand filters.

Compared with 47 mg/L of alum, 65 mg/L of the ferric chloride was determined as the optimum coagulant dose for a settled water turbidity of 1–5 NTU. The

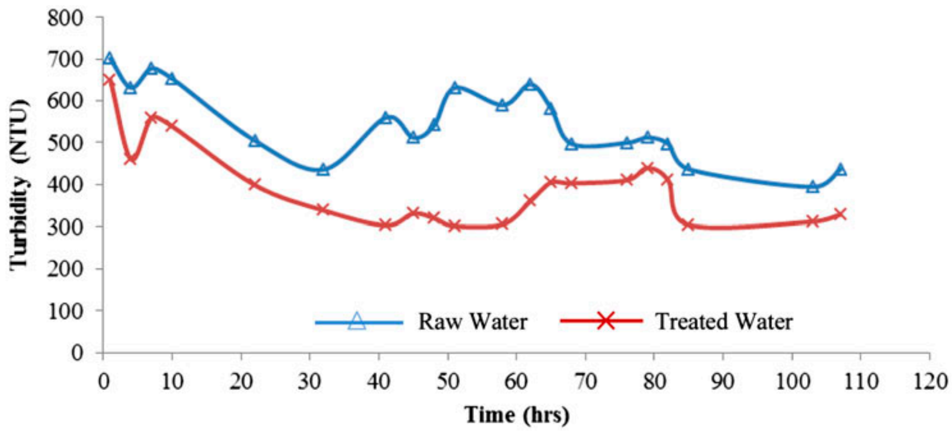

Fig. 5. Turbidity variation during complete filter run at 34 L/min.

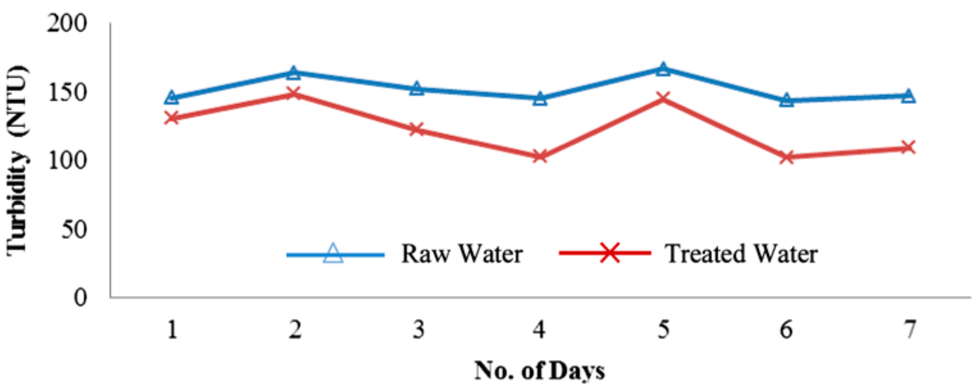

Fig. 6. Up-flow roughing filtration using multilayer filter.

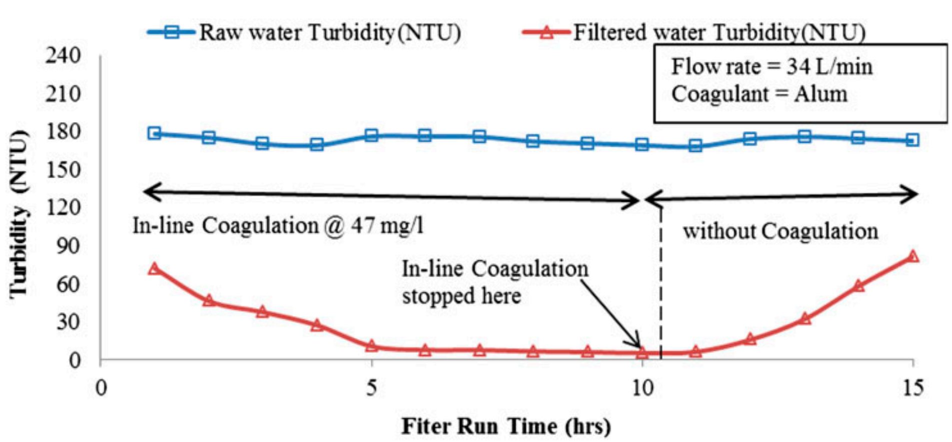

Fig. 7. In-line coagulation with 47 mg/L of alum and flow at 34 L/min.

ferric chloride dose of 65 mg/L was applied to raw water line into the UFRF plant using flow rates of 30, 34, and 38 L/min.

3.5. Chemical cost reduction

Keeping in view the crude alum dosing method at the plant where an alum sack is placed in the running

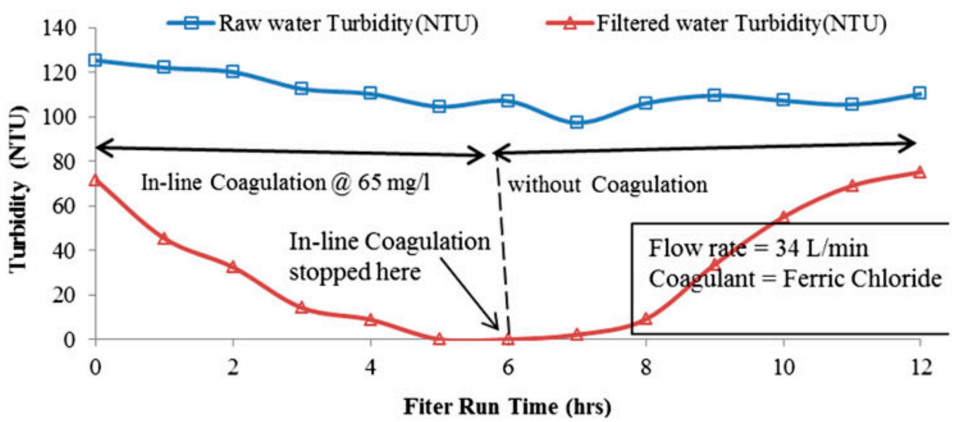

Fig. 8. In-line coagulation with 65 mg/L of ferric chloride and flow at 34 L/min.

raw water drain, jar tests were conducted to determine the optimum alum dose required for dry and wet weather. It is ironic to note that over 50% of the alum could be saved just by placing a coagulated UFRF system before slow sand filter. It would help the management in saving US $ 72,000 per annum.

4. Conclusions

(1) Raw water turbidity varies with times and is highly inconsistent. In dry weather, it varies from 30 to 300 NTU, whereas after wet weather spell, it runs over 2000 NTU. This high turbidity spell does persist but falls back to average 150–300 NTU within 72 h after the wet spell. The treated water turbidity also fluctuates quite considerable, yet remains below 10 NTU in most instances.

(2) Raw water pH varies between 8 and 9 and the treated water pH remains within 7.8–8.5, which is acceptable range of potable supplies.

(3) Roughing filter efficiency changes with time between 20 and 60% with more efficient in the beginning of the filter run and relatively low efficient after a few hours of run time. But the effectiveness of the roughing filtration is evident throughout the filter run. These results are consistent with the findings of Boller et al. [20,23,24].

(4) Jar testing results showed that coagulant dose used by the treatment plant during dry weather was about 2.60 times the required does (122 mg/L vs. 47 mg/L required) and during wet weather alum dose used by the plant was 3–40 times higher than required. For coagulation after roughing filtration, alum dose required was 60–70% less than the dose provided by the plant management.

(5) All flow rates tested in this research reduced 45–55% turbidity from the raw water in plain filtration mode. The coagulated filtration, removed turbidity from 90 to 99% eliminating the need for a sedimentation basin.

(6) Optimum ferric chloride dose (65 mg/L) was more effective in turbidity removal during coagulated filtration when compared with optimum alum dose (47 mg/L), but alum was recommended due to its cost-effectiveness as well as the availability in the local market.

(7) The UFRF remained effective with a removal efficiency of more than 50% for the half of the in-line coagulation time even when no in-line dose was injected.

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