



TURBIDITY AND DRINKING WATER TREATMENT: ENVIRONMENTAL IMPACTS AND MITIGATION MEASURES

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Abstract

Turbidity is a measure of degree to which the water loses its transparency due to the presence of suspended particulates. In this paper turbidity is mainly caused by the suspended sediment in the raw water abstracted from the river. Taking the latter meaning of turbidity into consideration it causes many difficulties and hazards in the drinking water treatment plants in Sudan, especially those located on the Blue Nile River system, where the sediment content carried by the river is high during the flood period.

The paper explains in brief the drinking water resources in Sudan in general and in the capital Khartoum in particular. It identifies the main sources of turbidity in the drinking raw water and the negative impacts on the drinking water sector systems. The experiences of Sudan in this respect are highlighted. This includes various processes to deal with turbidity, such as manual, hydraulic, mechanical, chemical and combined methods. The main challenges facing the drinking water treatment plants with regard to the turbidity of water are examined. The environmental impacts and mitigation measures are explained. The opportunities to deal with turbidity phenomenon are considered in this paper with recommendations for proper solutions leading to safe and healthy drinking water.

Keywords

Raw water, Turbidity, Treated water, Sediment, Environmental impacts, Coagulants.

INTRODUCTION

The Greater Khartoum (Khartoum, Omdurman and Khartoum North), is the capital of Sudan, located at the confluence of the Blue Nile, white Nile and the Main Nile rivers. In the last three decades Khartoum has experienced high increase in population growth rate due to the fluxes of internal displacement and other economic and social reasons. While the population growth rate is normally about 2.6%, the recent and present one is about 6% (one of the highest in the world) due to previous reasons. The total population increased from 505,000 in 1956 to 1.7 million in 1983, 3.4 million in 1993, 6.0 million in 2009 and 8.0 million in 2012. It is worth noting that the population increases to about 10 million during the day. However, Greater Khartoum exceptionally has expanded vertically and horizontally in the last two decades. This rapid population growth put huge pressure on the water supply authority and increases the challenge to meet the demand for safe drinking water.

On the other hand, the water supply sector which started in 1900 with only two wells increased to 210,000 m³/day in 1984, 328,000 m³/day in 2002 and by 2012 the production is about 1.4 million m³/day. At present the number of wells amount to 1800 and 11 water treatment plants using the Nile River system flow, which passes through the Greater Khartoum, as a source of raw water. The latter represents 50 % of the quantity of the water supply for Greater Khartoum. Although this huge water system faces many operational challenges, however one of the main problems is the turbidity issue. The turbidity negative impact is not limited to the water quality, but it has its impact on the operation

of the water treatment plants and final production efficiency. However, it effects the water quantity that produced by the several water treatment plants, especially those using the Blue Nile River as a source of raw water.

The objective of this paper is to understand the behavior of the turbidity which is originated from the presence of the sediment in the river flow, and at the same time to evaluate the impact of it on the water supply management. Moreover, the environmental impact of the turbidity will also be discussed and examined.

SEDIMENTS IN THE NILE RIVER SYSTEM

It is well know that the main source of the water supply in Greater Khartoum is the Nile River system (Blue Nile, White Nile and Main Nile), with its contribution to the recharge of the groundwater. Therefore, it is important in this paper to highlight the issue of sediment in the Nile river system flows. The White Nile River is usually carries insignificant amount of sediment compared to that of the Blue Nile River. Hence, the main source of the sediment in river Nile system is Blue Nile and its tributaries (Dinder river and Rahad river), and Atbara river. However, Atbara River joins the Main Nile river course few hundred kilometers downstream Khartoum.

The sediment amount carried annually by the Nile river system was average to 110 million tons as measured in Aswan High Dam (Egypt). However, in the (1990s) the average increased to 140 million tons annually. The average sediment concentration is about 4000 ppm with maximum values reaches 6000ppm. However, during the last 15 years the sediment concentration increased to about 8500ppm. The sediment composition according to several studies is 45% sand, 15% silt and 40% clay, Ahmed and Ismail, 2008. It is well known that the origin of the sediment in the Blue Nile River is the Ethiopian Highlands. It is referred to in some studies as wash load, i.e. its particles are very fine sediment, which can be in suspension for very long distances, Plate (1).



Plate (1): Turbidity in Raw Water

Figure1 shows the relation between the sediment, rainfall in the Ethiopia Highland and the discharge. It is clear that the peak of the sediment concentration comes about two to three weeks before the peak of the discharge and the rainfall, respectively.

TURBIDITY

Since the first part of the twentieth century the most widely applied water treatment process is a combination of some or all of the following: coagulation, flocculation and sedimentation plus filtration and chlorination for disinfection.

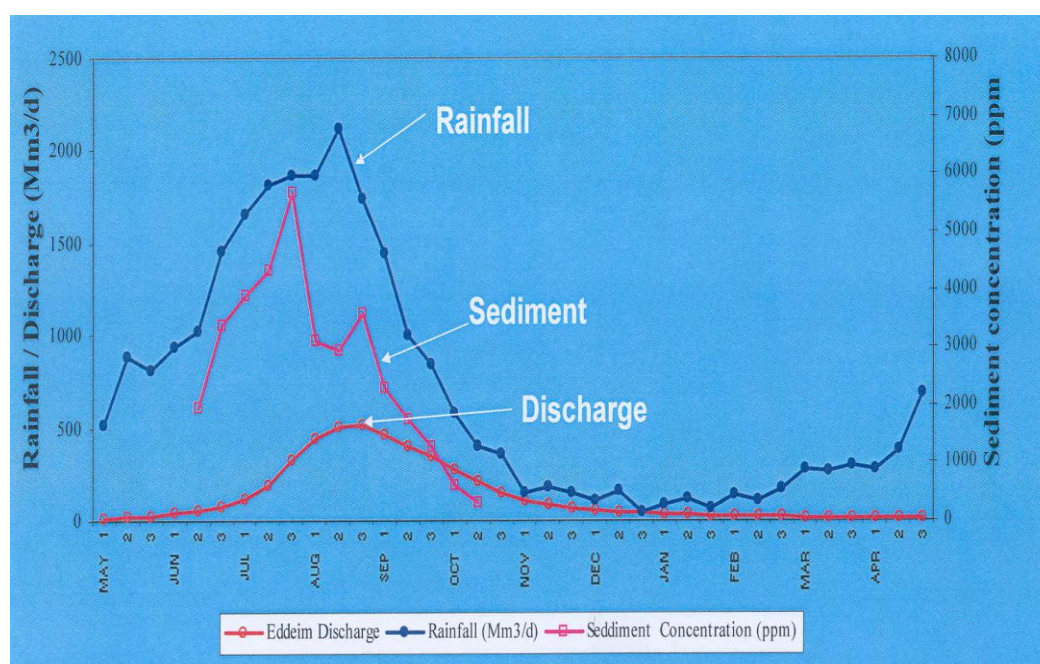


Figure 1: Comparison of Rainfall, Discharge and Sediment Yield in the Blue Nile

Turbidity is a principal physical characteristic of water and is an expression of the optical property that causes light to be scattered and absorbed by particles and molecules rather than transmitted in straight lines through a water sample. It is caused by suspended matter or impurities that interfere with the clarity of the water. These impurities may include clay, silt, finely divided: inorganic and organic matter, soluble coloured organic compounds, and plankton and other microscopic organisms. Simply, turbidity is the measure of relative clarity of a liquid. Clarity is important when producing drinking water for human consumption and in many manufacturing uses. There is significant evidence exists that controlling turbidity is a complement safeguard against pathogens in drinking water.

The first practical attempts to quantify turbidity date to 1900 when Whipple and Jackson developed a standard suspension fluid using 1000 parts per million (ppm) of diatomaceous earth in distilled water, Figure2, Sadar, 1996. Turbidity measurement used NephelometricTurbidimeter (Nephelometer) was introduced in 1970's. Nephelometry has been adopted by standard methods as preferred means for measuring turbidity because of the method's sensitivity, precision and applicability over a wide range of particle size and concentration. The preferred expression of turbidity is NTU.

There are several empirical equations which convert the sediment concentration (mg/litre) to turbidity units (NTU). Holiday et al, 2003 carried out a laboratory experiment to related the sediment to the

turbidity and came out by a general empirical formula: $NTU = a TSS^b$, where a and b are regression estimates coefficients. The ratio between NTU and TSS is 1:1 for silt plus clay fractions, but is lower for the whole soils (NTU is approximately 48% of TSS) and for the clay-only fraction (approximately 77%). They reported the following empirical formula: $T = 1.0283TSS$, where TSS is the total suspended sediment in mg/l and T is the turbidity in NTU.

LOCATION MAP AND DATA COLLECTION

In this paper a simple and practical methodology is followed. Primary data is also collected from five water supply treatment plants. Figure3 shows the locations of the water treatment plants with respect to the Blue Nile River. All the plants take their raw water from the Blue Nile River, which is known with its high turbidity. The turbidity in this case is mainly the sediment particles in suspension. Moreover, turbidity of the treated water data is collected, which is usually consumed by the users without any further treatment. However, a simple analysis is carried out and the results are discussed. The environmental impacts and social concerned are taken in to consideration.

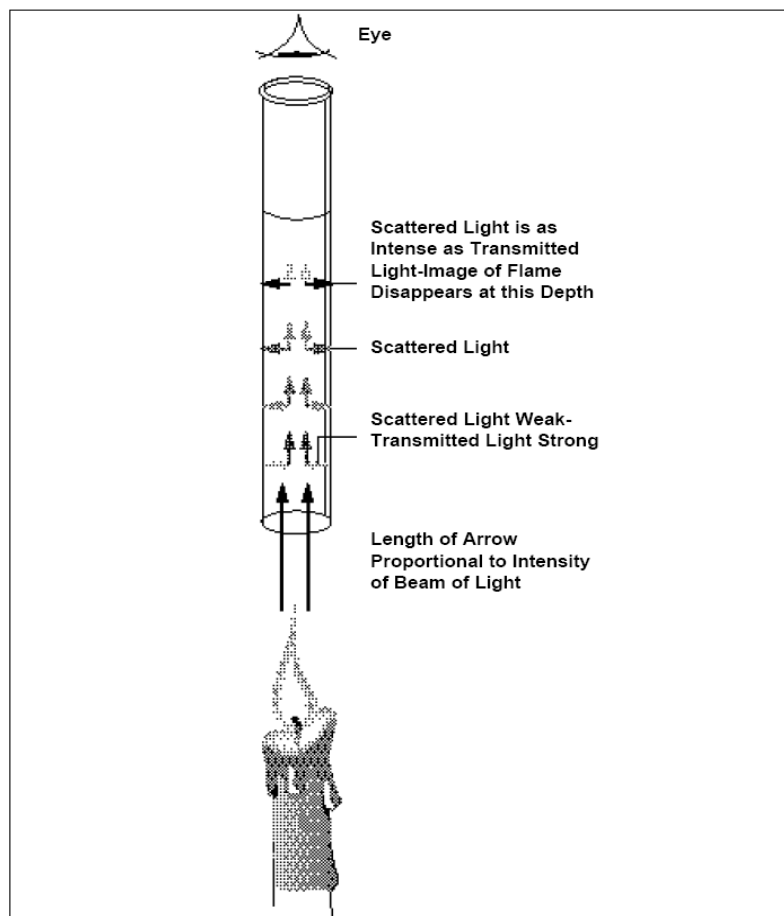


Figure 2: Jackson Candle Turbidimeter

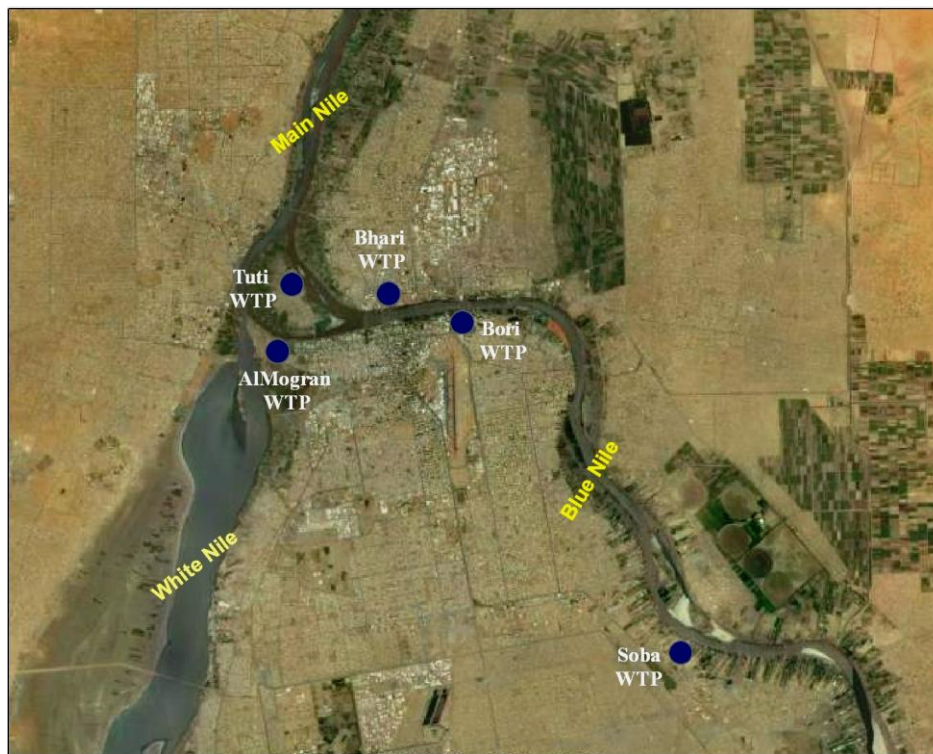


Figure 3: Locations of the Water Treatment Plants (WTP) on the Blue Nile River

RESULTS AND DISCUSSIONS

It is clear from the Figure 4 that the rate of turbidity in the raw water, which is originated from the Blue Nile River, increases rapidly with time (from year to another), i.e. it was 2,000 NTU in 2007 while it reached 20,000 NTU in 2011. However, a unique record of 32,000 NTU appeared in Bhari water treatment plant, which is an exceptional one. This can be attributed to three reasons; either it is a false reading or a mistake in measuring the turbidity or may be a local phenomenon, which requires further study. The third strong reason is that the raw water pumps' intake location was positioned at a lower stage with respect to the water level. The intake pumps in Bhari station have five stages along the depth of the river. The difference between each stage and another is 1.2m. The distribution of the sediment concentration usually increases with the water depth in any river, i.e. increases toward the bed of the river. Figure 4 shows that the most critical period is from the mid of July to end of August, where the turbidity has high values.

The World Health Organization (WHO) standards and specifications for potable water adopted 5.0 NTU as a maximum and acceptable turbidity value for safe and healthy drinking water. Above this value an adverse effect will occur, in particular from the health point of view. It seems from Figure (5) that in all the water supply treatment plants the turbidity exceeded this value. In some cases the turbidity value reached 20 fold the allowable value, e.g. in Bhari station the situation is even most critical.

The four large plants produced treated water far away from the acceptable one according to the WHO standards with respect to the turbidity values. This is a serious situation and should be rectified. However, Tuti small water treated plant is totally out of the scene, where the turbidity in the treated water reached 400 NTU, Figure (6), i.e. 80 fold that of the WHO indicator

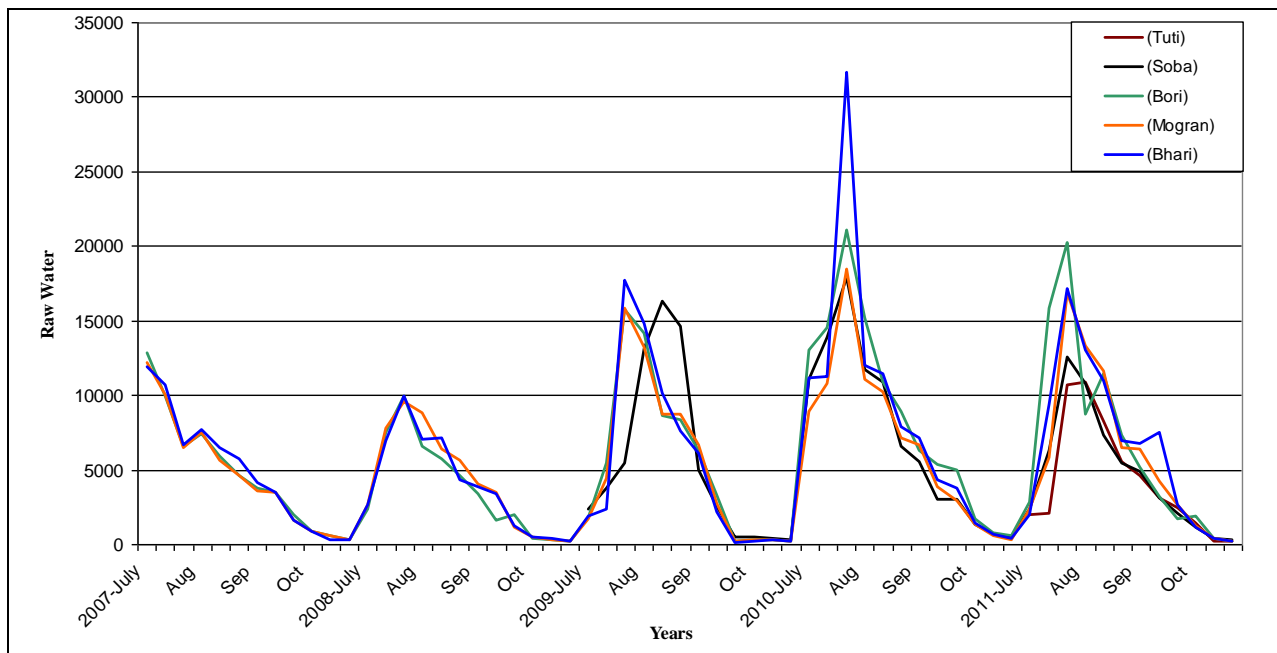


Figure 4: Turbidity in Raw Water (2007 – 2011)

A very important observation is that Soba plant produces treated water with a good quality compared to the other plants although they are using the same raw water. This is attributed to the fact that the Soba plant is the only one among the five plants which has a pre-sedimentation process (settling basins). It is proven that the pre-sedimentation gets rid hydraulically from almost 50% of the sediment load in the system, if well designed. This is confirmed by a data obtained from the new established AlManara water treatment plant Figure 7, which has a similar pre-sedimentation system.

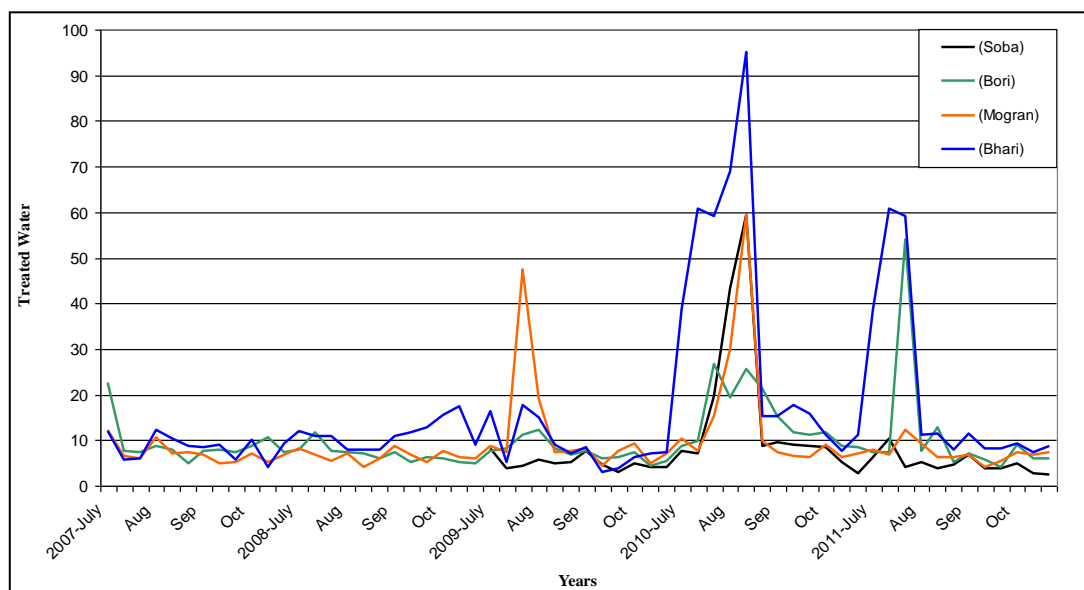


Figure5: Turbidity in Treated Water Supply (2007 - 2011)

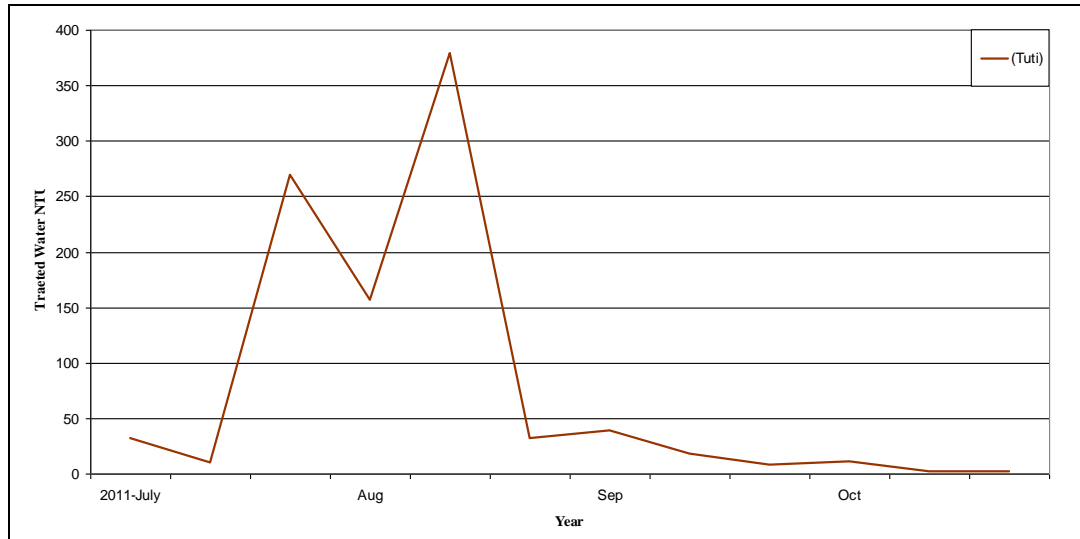


Figure 6: Turbidity in treated water – Tuti Water Treated Plant

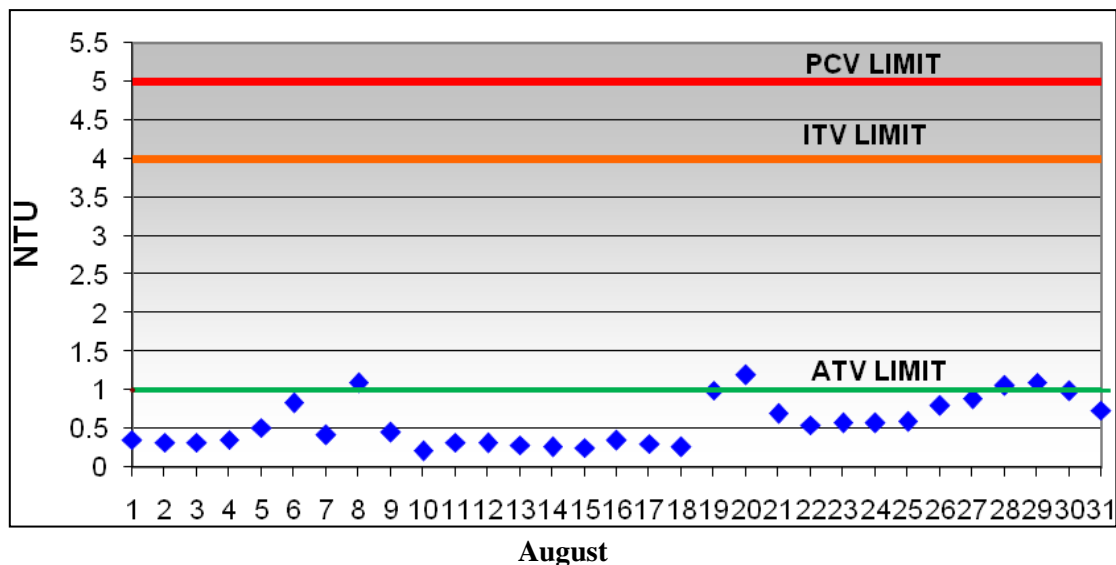


Figure 7: AlManara WTP Turbidity in Treated Water

To reduce the turbidity or to get rid of the majority amount of it, the Sudanese experience in this field came across several stages. Up to the nineties the turbidity in raw water was treated chemically using Aluminum Sulfate as a coagulant, then the polymer which was widely used in all water treated plants in 1990s. Recently the Polyaluminum Chloride (PAC) was used as a coagulant material causing the fine particles of sediment to settle; Plate (2) shows the application of the PAC as a coagulant to the raw water. This shows clearly the high sediment content of the raw water.



Plate 2: The application of the Coagulant to the raw water

In AlManara water treatment plant the process of sediment particles settlement is enhanced by the Lamella cones system, beside the addition of the PAC. The Lamella system is proved to be very effective; however, all the previous coagulations processes have environmental negative impacts, especially when a large quantity of sediment sludge is left behind. This is produced when the coagulant (chemical material) is mixed with the sediment particles and settled down. Safe disposal of such sludge is really a challenge facing all the water treatment plants. The easy and dangerous method is to return the sludge back to the Nile river system. It is well known that the sludge is highly dangerous and it pollutes the river water as a toxic and carcinogenic material. In AlManara a special treatment of this sludge is carried out by dry it in large bonds and then transported to a burying yard, Plate (3).



Plate 3: Drying of the sludge in large bonds

CONCLUSION

To conclude this important topic, it worth noting that the presence of turbidity in drinking water is a complicated issue. However, the water supply authority in Sudan faces a great challenge to deliver reasonable water quantity at the right time and place, with good and safe quality.

50% of drinking water supply for Greater Khartoum is supplied from water treatment plants utilizing the River Nile water resources. During the flood season (July to October), the River Nile flows with high sediment concentration causing turbidity problems. During the flood season, purification of the water requires complex, lengthy, costly and special consideration to be put in place.

Different methods are used to coagulate and flocculate the sediment particles so that they settle down and then removed. However, the most effective method to get rid of a considerable amount of the total suspended solids, including the sediment particles is the pre-sedimentation processes.

WTPs aided with pre-sedimentation tanks showed better performance in turbidity reduction and improved water quality. However, the process of pre-sedimentation is faced by the challenge of removal of sludge and deposited materials. Thus, sludge removal and sediment deposits are considered as a major environmental challenge to water supply facilities in Sudan.

It is observed that the location of the water plants off takes is very critical to the level of turbidity, obviously, due to the higher sediment concentrations. Thus, these are to be considered during the design and operation of the water supply facilities.

AlManara WTP is a good example in dealing with this toxic and carcinogenic sludge material. It is evident that the turbidity issue has not only an adverse effect on water supply quality, but it is the main reason for drinking water shortage in Greater Khartoum. This is due to the reduction in operation efficiencies of the WTPs. Therefore, it has major social implications, particularly in the suburbs of the Greater Khartoum, where water becomes a commodity transported by cars and animals with high prices intolerable for the poorest communities in the city, i.e. the poorer pays more money for getting drinking water.

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