

Turbidity in Drinking Water: Impacts and Mitigation

by

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Abstract

Turbidity is a measure of the degree to which the water loses its transparency due to the presence of suspended particulates. In this paper, turbidity is caused by the suspended sediment in the raw water abstracted from the river. Therefore, turbidity is considered the cause of 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.

In brief, the paper discusses drinking water resources in Sudan in general and in the capital Khartoum in particular. It identifies the main sources of turbidity in raw water and the negative impacts on the drinking water sector systems. The experiences of Sudan in this respect are highlighted. This encompasses various methods for managing turbidity, including manual, hydraulic, mechanical, chemical, and combined approaches. The main challenges faced by drinking water treatment plants regarding water turbidity are discussed. The environmental impacts and mitigation strategies are outlined. The paper discusses methods to address turbidity issues and therefore recommends appropriate solutions to ensure safe and healthy drinking water.

Keywords: Raw water, Turbidity, Treated water, Sediment, Environmental,, Coagulants.

1- 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 Main Nile rivers. In the last three decades, Khartoum has experienced a high population growth rate due to internal displacement for other economic and social reasons. While the population growth rate is about 2.6%, the present rate is about 6% (one of the highest in the world). This is attributed 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. Greater Khartoum has experienced significant vertical and horizontal growth over the last two decades. This rapid population increase has placed immense pressure on the water supply authority and heightened the challenge of providing 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 production was about 1.4 million m³/day. Currently, there are 1,800 wells and 11 water treatment plants. The latter uses the water of the Nile River system as a source of raw water, which passes through Greater Khartoum. The latter represents 50 % of the water supply for Greater Khartoum. Although this water system faces many operational challenges, the turbidity is the main

problem. 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.

2- Sediments in The Nile River System

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

The sediment carried by the Nile River system averaged 110 million tons as measured at the 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 reaching 6000 ppm. However, in the last 15 years, the sediment concentration increased to about 8500 ppm. 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 source 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. The latter can remain suspended over very long distances, as shown in Plate 1.



Plate (1): Turbidity in Raw Water

Figure 1 shows the relationship between the sediment, rainfall in the Ethiopian Highland and the discharge. The peak sediment concentration occurs two to three weeks before the peaks of discharge and rainfall.

3- 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.

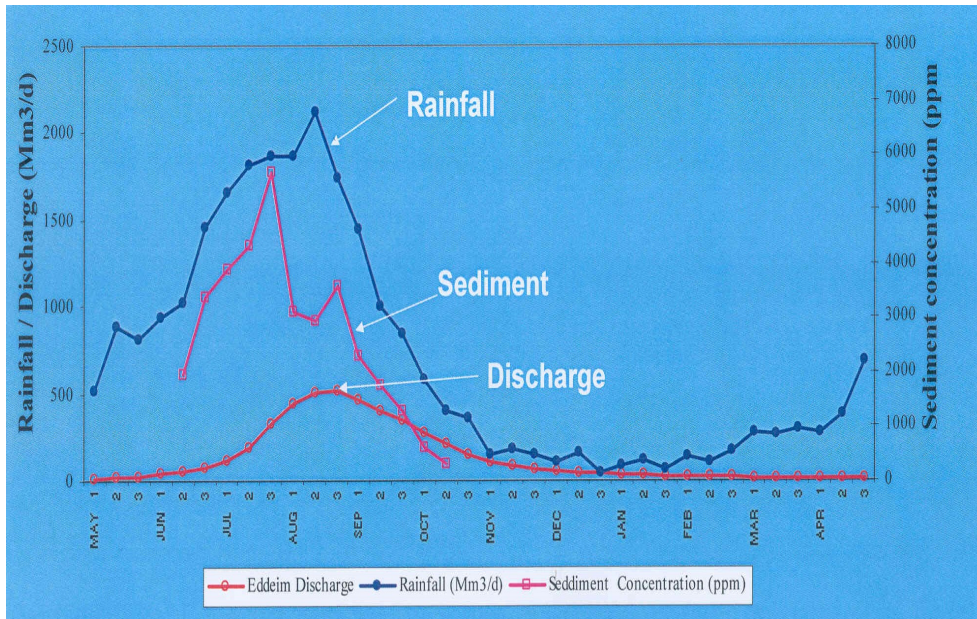


Figure 1: Comparison of Rainfall, Discharge and Sediment Yield in the Blue Nile

Turbidity is a principal physical characteristic of water, and it 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 water clarity. These impurities may include clay, silt, finely divided inorganic and organic matter, soluble coloured organic compounds, and plankton and other microscopic organisms. The turbidity is a measure of the relative clarity of a liquid. Clarity is important when producing drinking water for human consumption and in many manufacturing uses. There is significant evidence that controlling turbidity is a complementary safeguard against pathogens in drinking water.

The first practical attempts to measure turbidity began in 1900 when Whipple and Jackson developed a standard suspension fluid consisting of 1,000 parts per million (ppm) of diatomaceous earth soil mixed with distilled water. This method is illustrated in Figure 2 (Sadar, 1996). The introduction of the Nephelometric Turbidimeter (Nephelometer) in the 1970s marked a significant advancement in turbidity measurement. Nephelometry has become the standard method for measuring turbidity due to its sensitivity, precision, and applicability across a wide range of particle sizes and concentrations. Turbidity is primarily expressed in Nephelometric Turbidity Units (NTU).

There are several empirical equations which convert the sediment concentration (mg/litre) to turbidity units (NTU). Holiday et al. (2003) conducted a laboratory experiment to relate sediment to turbidity and hence, formulated a general empirical equation: $NTU = a \cdot TSS^b$, where a and b are coefficients from regression estimates. 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: $T = 1.0283 \text{ TSS}$, where TSS is the total suspended sediment in mg/l, and T is the turbidity in NTU.

4- 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. Figure 3 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 for its high turbidity. The turbidity in this situation arises primarily from suspended sediment particles in the water, significantly impacting its clarity and quality. Data on the turbidity of treated water has been collected, which is consumed by users without any further treatment. However, a simple analysis is carried out, and the results are discussed. The environmental impacts and social concerns are taken into consideration.

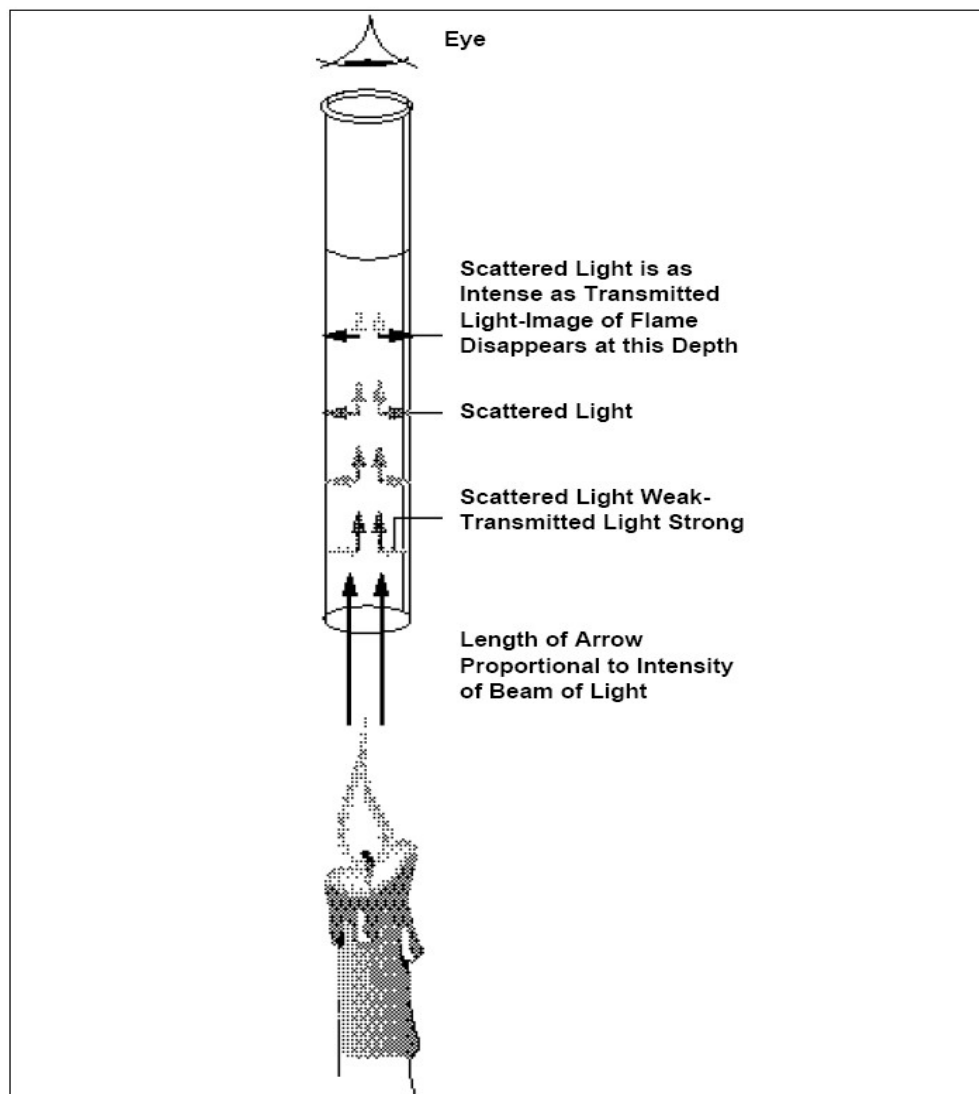


Figure 2: Jackson Candle Turbidimeter

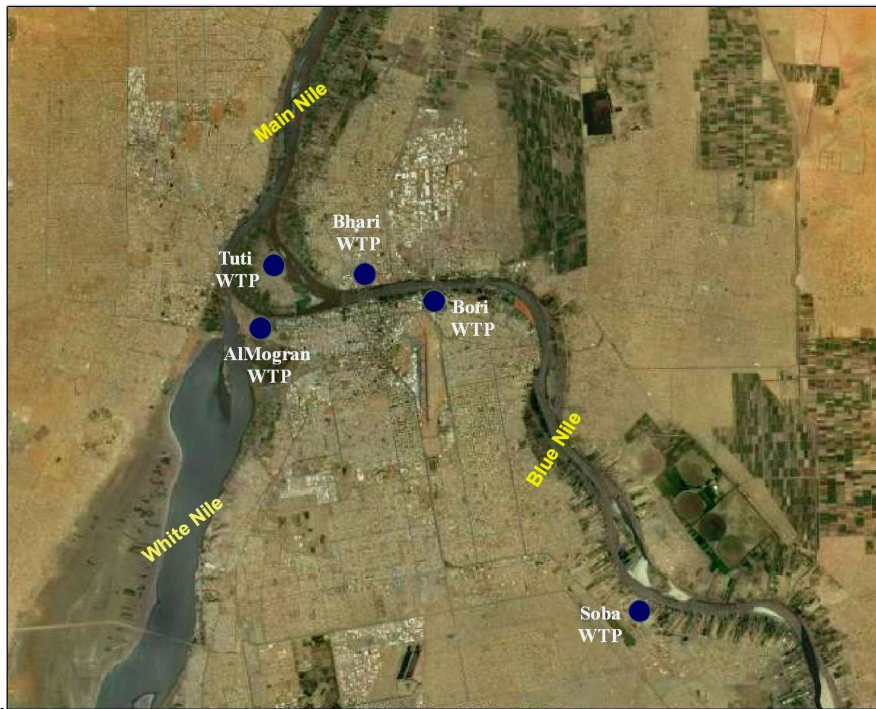


Figure 3: Locations of the Water Treatment Plants (WTP) on the Blue Nile River

5- Results and Discussions

The data presented in Figure 4 shows a significant increase in the turbidity levels of the raw water sourced from the Blue Nile River over time. Specifically, turbidity was measured at 2,000 NTU in 2007, but surged to 20,000 NTU by 2011. However, a unique record of 32,000 NTU was noted at the Bhari water treatment plant, which is exceptional. This could be due to three reasons: a false reading, a measurement error in the turbidity, or a local phenomenon that requires further study. The fourth significant reason is that the intake position of the raw water pumps is located at a lower elevation compared to the water level. The Bhari station's intake pumps operate at five stages, each positioned at a depth of 1.2 meters apart in the river. Generally, sediment concentration tends to increase with water depth, meaning it rises toward the riverbed. Figure 4 shows that the most critical period for turbidity is from mid-July to the end of August, when turbidity levels peak.

The World Health Organisation (WHO) sets a maximum turbidity value of 5.0 NTU for safe and healthy drinking water. Above this value, an adverse effect will occur, in particular from a 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 times the allowable value, e.g. at the Bhari station, the situation is even more critical.

The four large plants produced treated water that exceeded the acceptable turbidity levels according to WHO standards. This is a serious situation and should be rectified. However, Tuti's small water treatment 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

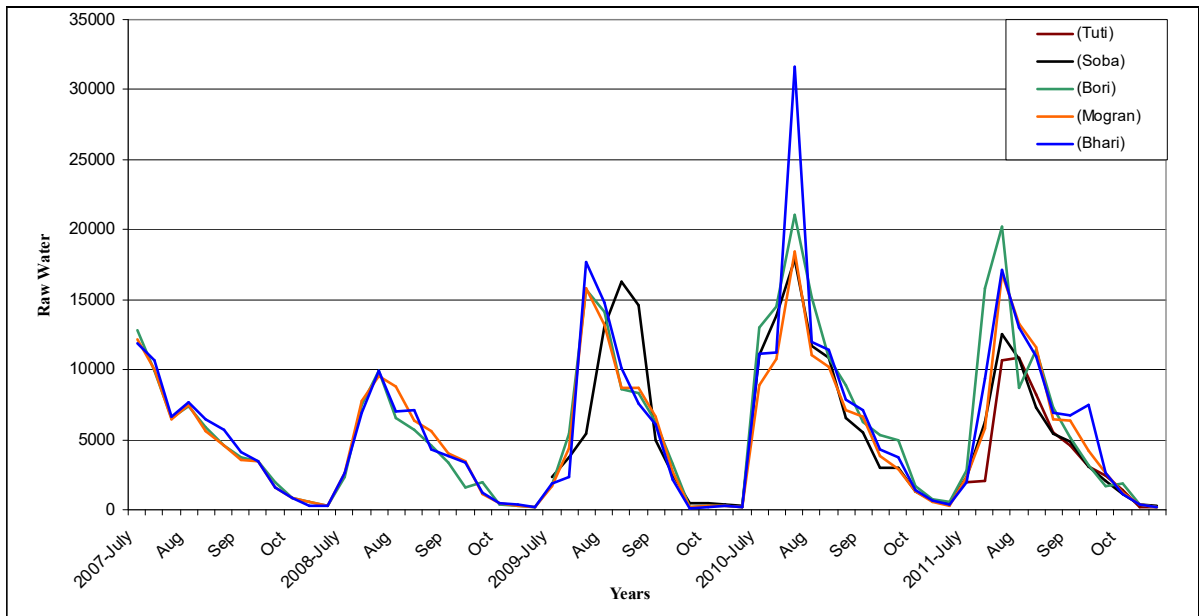


Figure 4: Turbidity in Raw Water (2007 – 2011)

The Soba plant produces higher-quality treated water than other plants in Greater Khartoum, even though it uses the same raw water. This is because the Soba plant is the only one among the five plants that includes a pre-sedimentation process using settling basins. Well-designed pre-sedimentation can remove nearly 50% of the sediment load. This is confirmed by data obtained from the newly established AlManara water treatment plant, as shown in Figure 7, which features a similar pre-sedimentation system. This is confirmed by data obtained from the newly established AlManara water treatment plant, as shown in Figure 7, which features a similar pre-sedimentation system.

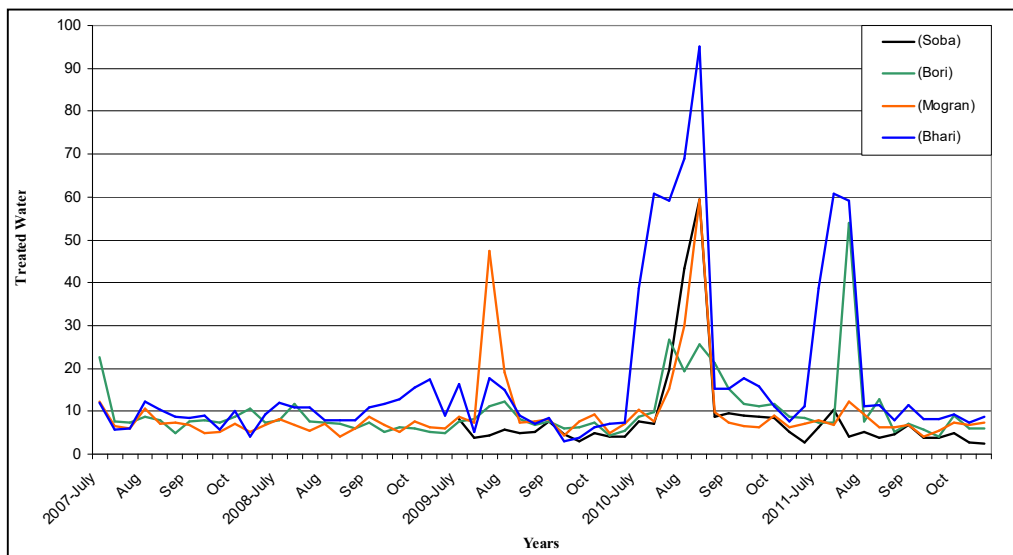


Figure 5: Turbidity in Treated Water Supply (2007 - 2011)

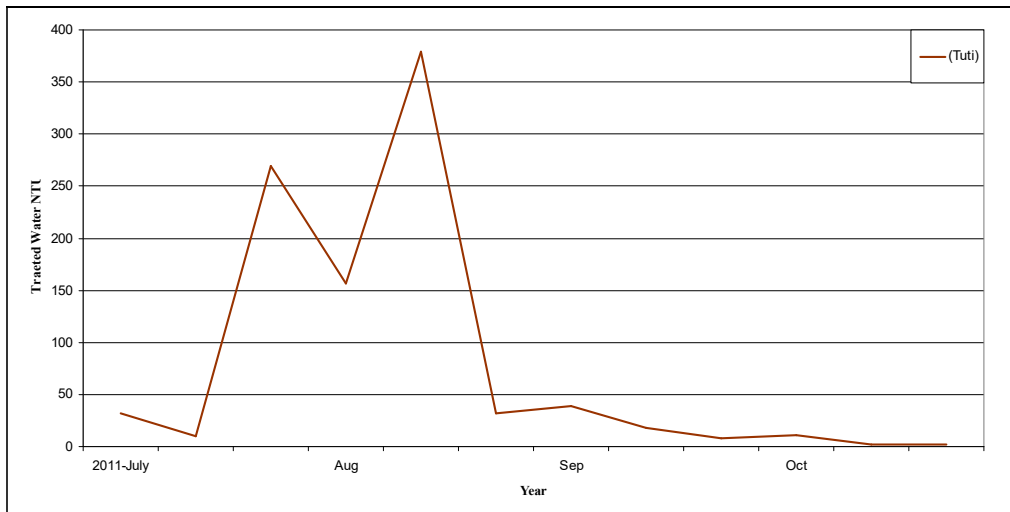
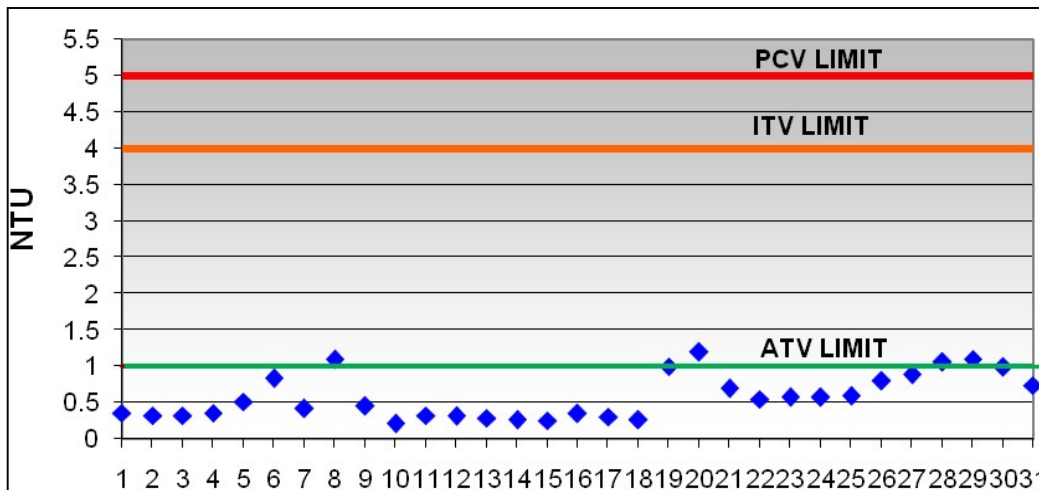


Figure 6: Turbidity in treated water – Tuti Water Treated Plant



August

Figure 7: AlManara WTP Turbidity in Treated Water

To effectively reduce turbidity, the Sudanese have developed several stages of experience in this field. Up to the nineties, the turbidity in raw water was treated chemically using aluminium sulfate as a coagulant, and then the polymer, which was widely used in all water treated plants in the 1990s. Recently, Poly-aluminium Chloride (PAC) was used as a coagulant to enhance the settling of fine sediment particles. Plate 2 illustrates the application of PAC to the raw water, clearly highlighting the high sediment content present in the Blue Nile River.

In the AlManara water treatment plant, the sediment particle settlement process is enhanced by the Lamella cone system, in addition to PAC. The Lamella system has proven to be very effective; however, previous coagulation processes have significant negative environmental impacts, especially due to the large quantities of sediment sludge deposits left behind. This happens when a coagulant (a chemical substance) is combined with sediment particles, facilitating their settlement. Safe disposal of this sludge is a significant challenge for all water treatment plants. The easy and dangerous method is to return the sludge to the Nile River system. It is well known that sludge deposits are highly dangerous and they will pollute the

river water with toxic and carcinogenic materials. In AlManara, sludge is treated by drying it in large ponds before transporting it to a burial site, Plate 3.



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



Plate 3: Drying of the sludge in large ponds

6- Conclusion

In conclusion, the issue of turbidity in drinking water is quite complex. The water supply authority in Sudan faces significant challenges in providing an adequate quantity of water at the right time and place while ensuring it is safe and of good quality.

Fifty per cent of the drinking water supply for Greater Khartoum comes from water treatment plants that use the resources of the River Nile system. During the flood season (from July to October), the Nile River experiences high sediment concentrations, leading to elevated turbidity. As a result, purifying the water during this period is complex, time-consuming, and costly, necessitating special considerations to ensure effective treatment.

Various techniques are used to coagulate and flocculate sediment particles, enabling them to settle for removal. The most effective way to significantly reduce total suspended solids, including sediment particles, is to use a pre-sedimentation process tank.

Water treatment plants equipped with pre-sedimentation tanks showed turbidity reduction and improved water quality. Water treatment plants equipped with pre-sedimentation tanks demonstrated enhanced turbidity reduction and better water quality. The pre-sedimentation process frequently faces challenges in removing sludge deposits from the tank. As a result, the removal of sludge and sediment deposits poses significant environmental issues for water supply facilities in general, and particularly in Sudan.

The location of raw water intake points from the river is crucial for managing high turbidity levels, as increased sediment concentrations significantly affect water quality. Therefore, it is important to take this into account during the design and operation of water supply facilities.

AlManara WTP is a good example of 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. Water has significant social implications, especially in the suburbs of Greater Khartoum, where it becomes a commodity transported by vehicles and animals at high prices that are unaffordable for the city's poorest communities. Consequently, those with lower incomes end up paying more for access to drinking water. Water has significant social implications, especially in the suburbs of Greater Khartoum, where it becomes a commodity transported by vehicles and animals at high prices that are unaffordable for the city's poorest communities. Consequently, those with lower incomes end up paying more for access to drinking water.

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