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IMPACT OF DAILY AND SEASONAL VARIATION OF RAW WATER QUALITY ON TREATABILITY: A CASE OF GABA COMPLEX

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ABSTRACT

Conventional water treatment is constrained by factors such as variation in raw water quality, inefficient coagulation, use of inappropriate sand for filtration, and poor backwashing process among others. The objective of this study was to find out the impact of daily and seasonal variation of raw water quality on conventional water treatment through the jar testing process. Short filter run times as low as 12 h were experienced at Gaba complex requiring emergency backwashing. The short filter run times were envisaged to be resulting from the inability of the coagulation process to cope with the varying water quality. Generally, the pH of the water samples showed no significant ($p>0.05$) difference in both the dry and wet period. The water turbidity and colour were significantly ($p<0.05$) higher in the dry period compared to the wet period. The optimum alum dose (60 to 70 mg L-1) for each jar test showed up to 92% turbidity removal and complete colour removal. Variation in the raw water quality both daily and seasonally did not significantly ($p>0.05$) affect the amount of coagulant required for optimal water treatment. The short filter run times therefore, could be due to other factors to be investigated.

INTRODUCTION

Gaba water treatment complex in Kampala (Uganda) is under National water and sewerage corporation (NWSC), an entity responsible for water treatment and sewerage services in Uganda. Uganda's capital city Kampala is supplied with clean and safe water from Gaba water treatment complex. The complex is located at Gaba on the shores of the inner Murchison bay (IMB), lake Victoria, and has three water production plants namely; Gaba I, Gaba II and Gaba III. Gaba I and II are old manual dispensing plants whereas Gaba III is an advanced auto plant. Gaba I was constructed in 1928 and commissioned in 1930. However, due to the increasing demand for clean and safe water, the plant was enlarged by the construction of two more plants; Gaba II and Gaba III in 1992 and 2007, respectively. Therefore, NWSC has been able to supply clean and safe water to the city and its suburbs through its Gaba complex.

At Gaba complex, raw water under goes conventional water treatment processes to produce clean and safe water. Among these processes are; coagulation flocculation, sedimentation and filtration. These processes are intended to remove impurities in water such as; inorganic substances, organic colloids and microbial organisms. The first process, coagulation, is defined in Letterman and Association (1999) as a complex process of several reactions and mass transfer steps. Categorically, three sequential steps are defined and they are: coagulant formation, particle destabilization and finally inter-particle collisions. With reference to coagulation using aluminium salts, chemical species, termed aluminium hydroxo complexes are formed, and enable coagulation process. Some of these species are; Al^{+3}, $Al(OH)^{2+}$, $Al_2(OH)_2^{4+}$, $Al(OH)_4^{5+}$ and $Al(OH)_4^-$(Edzwald and Tobiason, 1999, Duan and Gregory, 2003). Particles, mineral and organic matter present in water contain negatively charged surfaces according to Letterman and Association (1999) and therefore charge neutralization occurs in the presence of the positively charged aluminium species. It can therefore be summed that coagulation works to convert particles, solids, and natural organic matter (NOM) in to large, heavy, and settleabe flocs.

The efficiency of processes preceding filtration largely affects the filtration process. Wang et al. (1991), classified the types of filters in to five types and include: gravity filters, pressure filters of plate and frame or shell and leaf construction, vacuum or suction filters of rotating drum or disk type, edge filters and diatomaceous earth filters. Among the five types, the most commonly used in water purification is gravity filters. At Gaba complex, rapid gravity filtration employing a thick bed of granular sand is applied to further remove turbidity and colour unremoved from coagulation, flocculation and sedimentation processes. However, the short filter run times at Gaba I and II of about 12 h as compared to the recommended of 96 h (according to Gaba plant operators experience) experience has resulted to reductions in the final water quantity. This is due to the frequent backwashing process which utilizes the final water. The implication of the frequent backwashing process is limited water supply to the city. The short filter time was pointed to the variations in the source raw water quality among other factors, and that was a basis for this study

In fresh water lakes, biochemical and hydrodynamic processes occur. These processes are influenced by factors such as sunshine, wind, temperature, rainfall and evaporation (Payne, 1986). Malmaeus et al. (2006) established that water temperature influences internal lake processes such as; diffusion, mineralization and vertical mixing. The lengthened period of lake stratification and the deepening of the thermocline layer have been pointed to higher water temperatures (Hassan et al. 1998). However, tropical lakes receive relatively constant solar radiation therefore, the seasonal variations in water temperature are small (Bartram and Ballance, 1996).

Variations in raw water quality resulting from natural processes are difficult to control however; the variations from non-natural forces can be controlled. In water treatment, coagulation and flocculation should cope with changing raw water quality for an efficient filtration process. Studies by Amuda and Amoo (2007), and Yang et al. (2010) noted increased turbidity removal efficiencies with increasing pH especially with the pH lower than 6.0. However, the latter study reported a drastic decline in removal efficiency with pH between 7.0 and 9.0 while using $Al_2(SO_4)_3$. Hurst et al. (2004) found that storm periods impacted negatively on the water treatment process. Their study pointed this behaviour to the variation in the concentration and amount of NOM, not necessarily directly related to the amount of turbidity. However, Tambo and Kamei (1998) suggested that for natural water, the suspended and colloidal parts from both organic and inorganic sources can be effectively removed through coagulation irrespective of their chemical nature. Water aesthetics is mainly compromised by particles forming the turbidity and NOM which defines the water colour (Van Benschoten and Edzwald, 1990). NOM is an important index of total organic carbon (TOC) and dissolved organic carbon (DOC) (Ouyang et al. 2006). In a study by Sharp et al. (2006), it is reported that the required amount of coagulant does not necessarily increase with increased turbidity, but rather varies according to the composition and characteristics of the NOM. Furthermore, Shin et al. (2008) through experiments suggested that in determining the minimum effective alum dose for water containing both NOM and particles forming the turbidity, NOM dictated the amount of coagulant especially in low turbidity cases. Through coagulation, most of the turbidity and water colour can be removed to acceptable levels. Therefore, the efficiency of the coagulation process is paramount in improving water aesthetics. Final water quality is a function of coagulation process and filtration process and hence, have a bearing on water meter accuracies. According to a study by Mbabazi et al. (2015) to determine domestic meter accuracies, water quality was pointed out as one of the factors affecting meter degradation rates.

In water treatment, variation in raw water quality may necessitate varying the coagulant dose to remove most of the turbidity and colour. Some of the practices employed by water plants in choosing the type and dosage of a coagulant include; jar tests, zeta potential measurements Morfesis et al. (2008), and plant experience, dependent on turbidity and colour records (Edzwald and Kaminski, 2009). Briefly, zeta potential measures the level of charge neutralization on colloids after coagulation. Zeta potential can be negative, zero or positive (Engelhardt, 2010). Negative, zero and positive results mean inadequate, ideal and overfeed of coagulant respectively. At Gaba, jar tests and plant experience were practiced in arriving at an optimum coagulant dosage.

The coagulation process is notably affected by factors such as process pH, alkalinity and nature and characteristics NOM and particles (Tseng et al. 2000). The efficiency of coagulation in removing turbidity depends largely on the control of coagulation pH and the coagulant dose (Koohestanian et al. 2008). Their study revealed that high pH favoured turbidity reduction due to the shift in conditions to alkaline basic, suitable for sedimentation. From the above literature, the goal of this study was to investigate the impact of daily and seasonal variations of raw water quality on treatability, using alum as the coagulant.

MATERIALS AND METHODS

Study area

This study was done at NWSC, Gaba water treatment complex located about 7 km east of Kampala at the shores of IMB, Lake Victoria. At IMB, water pumps installed in the lake pump the raw water into the water balance tank located at Gaba I treatment plant. From the water balance tank, water is then distributed by gravity to each of the three plants, Gaba I, II and III via ground installed pipes for treatment.

Sampling and testing

Experiments were done in a dry and wet period to take into account the seasons. The dry period sampling and testing were done between January and February, generally dry months whereas the wet periods were done in April and May. Table 1 presents equipment and material used in the study.

Table 1: Equipment and instruments Used

No.	Equipment/Instrument (E/I)	Quantity	Model	Accuracy	Manufacturing company
1.	Six paddle Flocculator	1	SW 1	N/A	Bibby Scientific Ltd.,

					Staffordshire, UK
2.	pH meter	1	MM 374	0.002 pH	Hach Company, Colorado, USA
3.	Turbidity meter	1	2100Q	±2%	Hach Company, Colorado, USA
4.	Colour meter	1	DR 1900	±0.003 Abs	Hach Company, Colorado, USA
5.	8 L HDPE plastic bottle	1	-	-	N/A
6.	1 L glass beakers (Jars)	6	-	-	Pyrex, Fisher Scientific UK Ltd
7.	250 ml volumetric flask (with cock)	1	-	-	Pyrex, Fisher Scientific UK Ltd
8.	1 L graduated measuring cylinder	1	-	5.0 ml tol.	Pyrex, Fisher Scientific UK Ltd
9.	25 ml Class A Volumetric pipette	1	-	+ 0.03 mL	Pyrex, Fisher Scientific UK Ltd
10.	Electronic Balance	1	A 250	0.1 mg	Fisher Scientific Company, Ontaria, Canada

On each day of sampling and testing, two grab water samples were collected at 9:00 h and 14: 00 h from the water balance tank using an 8 L HDPE sampling container. On each sample, physical-chemical tests including water pH, turbidity, colour, and temperature were measured using E/I No. 2, 3, 4, and 2 respectively in Table 1. The time between sampling and testing was less than 30 minutes in all the tests and therefore no samples preservation were done. After the physical-chemical tests, subsequent jar tests were ran at room temperature (25°C) to establish an optimum alum dose for each sample. Optimum alum dose was defined as one that yielded the least turbidity and colour (adopted jar test criteria) in the supernatant.

Jar tests

A Jar test is a test that simulates the full scale water treatment process. This aids water treatment plant operators to have an insight in the way a coagulant will perform with a certain raw water quality. The jar tests were done as described. Using E/I No. 10 in Table 1, 2.5 g of granular alum was weighed and transferred into E/I No. 7 and 250 ml of distilled water added to the mark and the cock fixed. The mixture in E/I No. 7 was shook until all the granules were completely dissolved forming a solution. The result was a 1% alum solution used for coagulant. The reason for using such a concentration was anchored on; minimization of residual aluminium concentration and a past study by Jeffcoat and Singley (1975). By using alum concentrations between 0.01 – 100 % this study reported better turbidity removal at relatively dilute concentrations due to envisaged rapid alum dispersion. After preparing the alum solution, E/I No.1 capable of speeds between 0 and 260 revolutions per minute (rpm) was turned on (illumination switch). Each of the six paddles were submerged in 1 L of raw water in jars measured using E/I No. 8. The alum solution was added in to E/I No. 5 in the pattern; 5.0, 5.5, 6.0, 6.5, 7.0 and 7.5 ml L^{-1} using E/I No. 9 . To arrive at this dosing pattern, preliminary jar tests were ran using 1 % alum at doses between 4 - 10 ml L^{-1} and the results showed an existence of an optimum dose in the chosen pattern. This pattern was maintained in all the jar tests. With the rpm dial on E/I No. 1 set to 200 rpm, it was turned on for 1 minute followed by 60 rpm for 15 minutes while observing and noting the speed of floc formation in the six samples in E/I No. 6. To allow for settling of the floc formed, E/I No. 1 was turned off for 30 minutes. Finally, the samples in E/I No. 6 were decanted carefully (no filtration was done) and the supernatant tested for turbidity, pH, colour and residual aluminium.

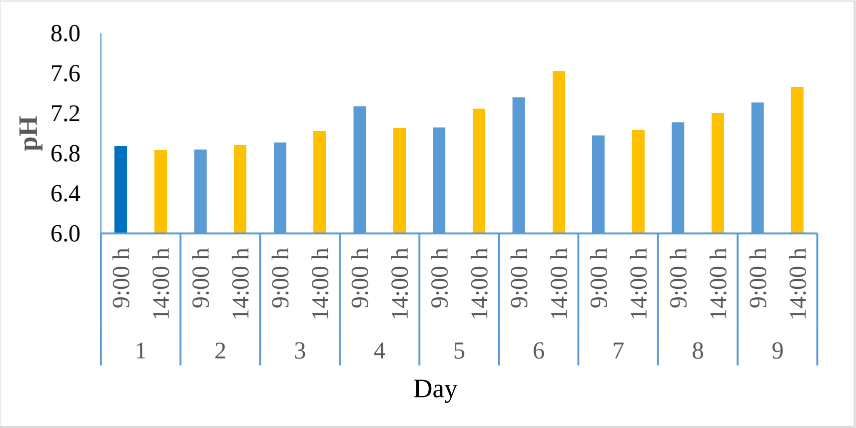
RESULTS AND DISCUSSION

A total of 34 raw water samples, 18 in the dry and 16 in the wet period were collected. On each sample, parameters such as pH, turbidity, colour and temperature were measured. Subsequent jar tests were carried out for each sample to determine the optimum alum dose. Table 2 emphasises the concept of optimum alum dose. The variation of the four raw water quality parameters pH, turbidity, colour and temperature are depicted graphically in Figures 1, 2, 3 and 4 respectively. Statistical analysis was done (Tables 3 and 4) to explore variations between the values that were obtained in the dry and wet periods.

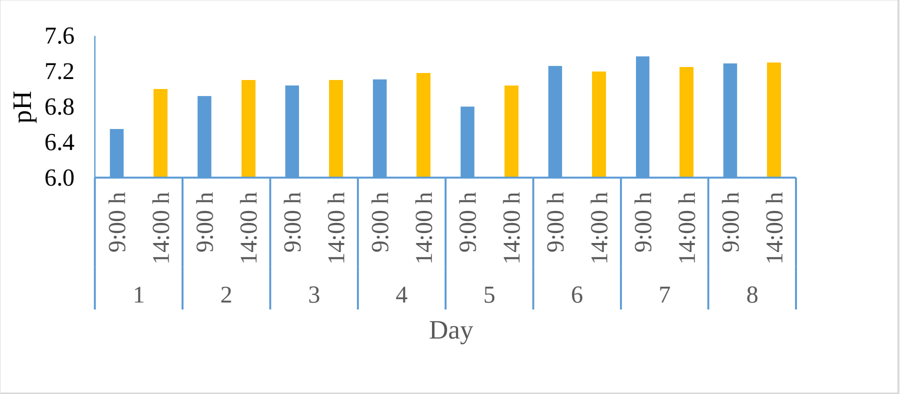
Table 2: Typical result for the Jar tests (guide to choosing optimum alum dose).

Jar No.	**1.**	**2.**	**3.**	**4.**	**5.**	**6.**
Alum dose, ml L^{-1}	5.0	5.5	6.0	6.5	7.0	7.5
Alum dose, mg L^{-1}	50	55	60	65	70	75
Order of Floc formation	6	5	4	2	1	3
Floc Size	Medium	Medium	Large	Large	Large	Large
Order of Floc settlement	6	5	4	3	1	2
Supernatant Turbidity, NTU	1.15	0.86	0.68	0.57	0.50	0.66
Supernatant pH	6.1	6.06	5.95	5.90	5.82	5.67
Supernatant colour, Pt/ Co	10	0	0	0	0	0

With the order of floc formation, floc size, order of floc settlement, and the criteria of least turbidity and colour in the supernatant into play, Jar No. 5, alum dose, 70 mg L^{-1} in Table 2 is the optimum dose for the specific raw water sample with an initial pH, turbidity, colour, and temperature of 7.27, 7.46 NTU, 130 Pt/Co and 26.7 ^{o}C respectively. The optimum coagulant dosage were between 60 – 70 and 65 -70 mg L^{-1} for the 9:00 h and 14: 00 h samples respectively. An analysis of residual aluminium for the jar with the optimum coagulant dose ranged from 0.06 to 0.16 mg L^{-1} and 0.02 to 0.11 mg L^{-1} in the dry and wet seasons respectively.

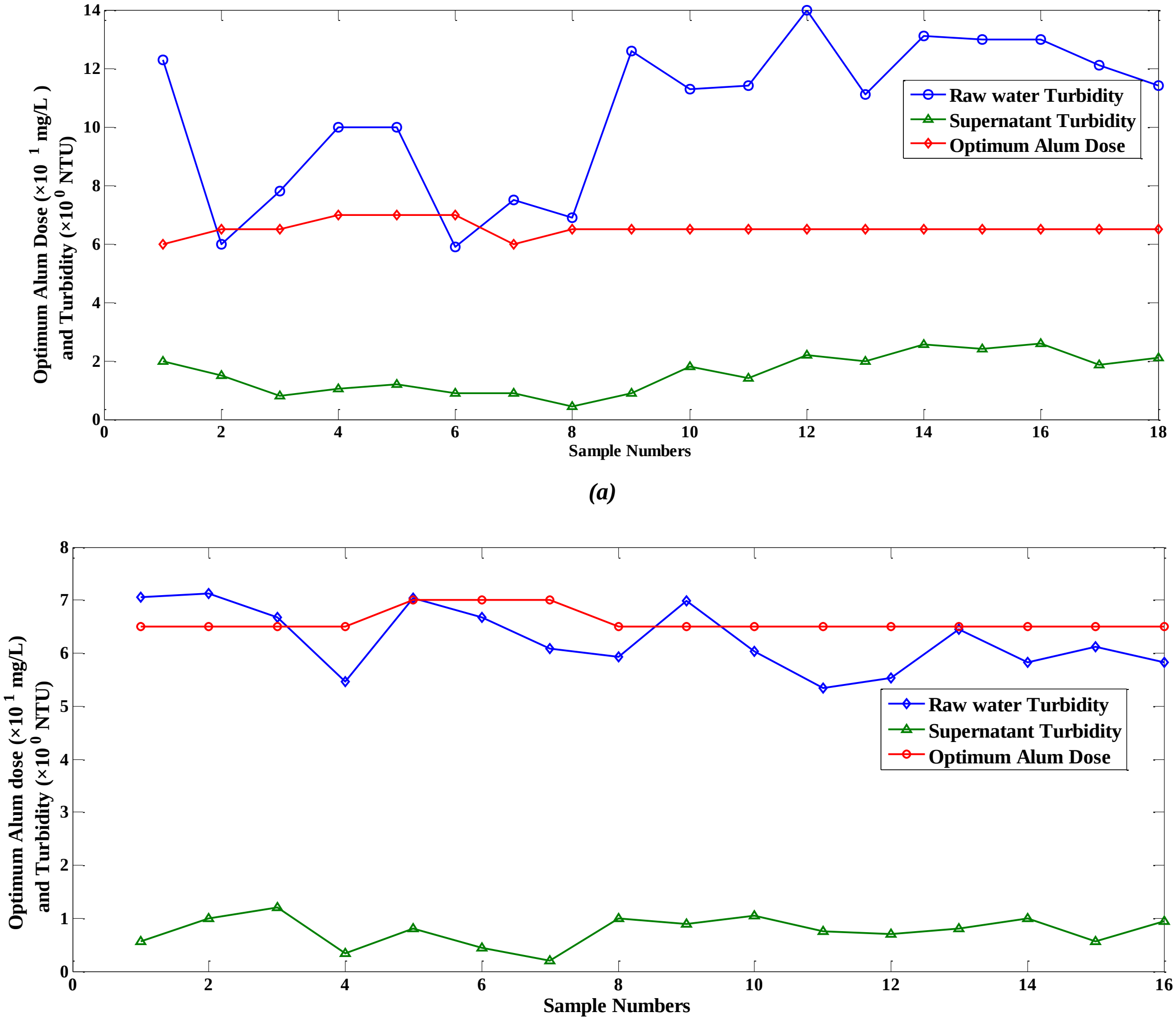


(a)



(b)

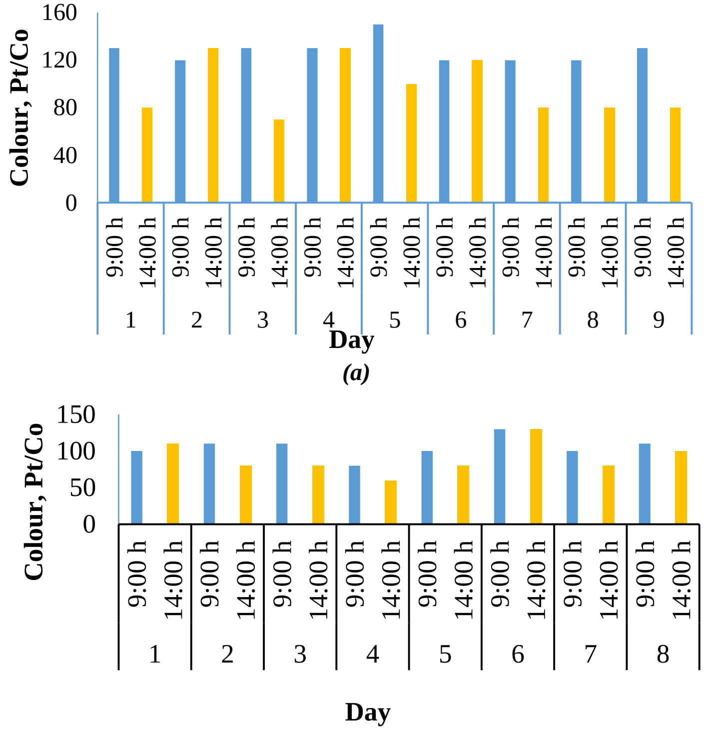
Figure 1: pH variation (a) in the dry period; (b) in the wet period



(a)

(b)

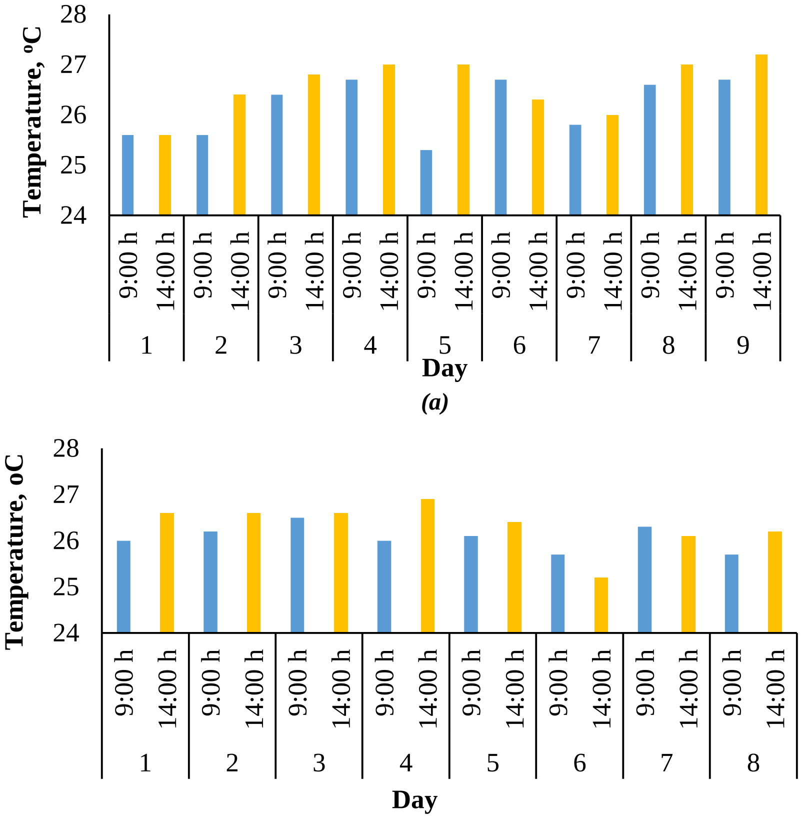
Figure 2: Relationship between water turbidity and optimum alum dose (a) in the dry period (b) in the wet period



(a)

(b)

Figure 3: Water colour variation (a) in the dry period; (b) in the wet period



(a)

(b)

Figure 4: Temperature variation (a) in the dry period; (b) in the wet period

Table 3: Statistical analysis of the raw water parameters in the dry period

	Range		**Average**		**Standard Deviation**		**Statistical Inference**
Parameter	**9:00 h**	**14:00 h**	**9:00 h**	**14:00 h**	**9:00 h**	**14:00 h**	**At p=0.05**
pH	6.84 - 7.36	6.83 -7.62	7.08	7.15	0.20	0.26	$p > 0.05$
Temperature, °C	25.3 - 26.7	25.6 - 27.2	26.16	26.59	0.57	0.54	$p > 0.05$
Colour, Pt/Co	120 - 150	70 - 130	128.00	97.00	9.72	23.98	$p < 0.05$
Turbidity, NTU	7.5 - 13	5.9 - 14	10.90	10.2.0	2.03	3.17	$p < 0.05$

Table 4: Statistical analysis of raw water variation in the wet period

	Range		**Average**		**Standard Deviation**		**Statistical inference**
Parameter	**9:00 h**	**14:00 h**	**9:00 h**	**14:00 h**	**9:00 h**	**14:00 h**	**At p =0.05**
pH	6.55 - 7.37	7 - 7.3	7.04	7.15	0.28	0.1	$p>0.05$
Temperature, °C	25.7 - 26.5	25.2-26.9	26.06	26.33	0.28	0.52	$p>0.05$
Colour, Pt/Co	80 - 130	60 -130	105	90	14.14	22.04	$p<0.05$
Turbidity, NTU	5.34 - 7.05	5.47 -7.13	6.47	6.05	0.6	0.57	$p>0.05$

Water pH

From Figure 1, it is observed from the relative heights of the bars that the 14:00 h samples had a higher pH than 9:00 h samples. However, statistical analysis in Tables 3 and 4 showed no significant ($p>0.05$) difference in pH for the daily and seasonal findings. It is known that pH has a pronounced impact on the electrical charge of organic and inorganic compounds and a profound role in the hydrolysis of alum (Letterman and Vanderbrook, 1983, Chow et al. 1999). Whereas alum is least soluble at pH 6 and 6.2 at temperatures of 5°C and 20°C, respectively according to Pernitsky and Edzwald (2003), the raw water pH, 6.83-7.62, Table 3, in the dry period, and 6.55-7.37, Table 4, in the wet period were within the alum working range of 6-7 (Gregor et al. 1997). The supernatant water pH from the jar test reduced to between 5.0 and 6.2. This showed that addition of alum lowers the raw water pH, and hence pH correction using suitable bases was necessary in order to raise the pH to neutral. However, laboratory pH correction was not within the scope of the study.

Water turbidity

In Table 3, a significant ($p<0.05$) difference in the turbidity of the 9:00 h and 14:00 h samples was obtained. However, there was no significant ($p<0.05$) difference in the optimum alum dose from the jar tests. The dry period turbidity, Figure 2, significantly ($p<0.05$) higher than the wet periods was not expected due to the increased run off into the lake in the wet period as a result of precipitation. However, dilution as result of precipitation could explain this phenomenon. The lowering of the raw water turbidity to the supernatant turbidity , Figure 2, with an optimum alum dose, 60-70 mgL^{-1} was more than 92 %. A similar result with turbidity removal of greater 90 % has been reported by Yang et al. (2010) at 10 mg L^{-1} (Al_2O_3). The observed variation of raw water turbidity, Figure 2, produced no linear effect in the coagulant dose. According to Edzwald and Kaminski (2009), while considering two parameters , raw water turbidity and UV_{254}, alum dosing changed with changing UV_{254} and not with turbidity. This agrees with turbidity findings in this study.

Water colour

The water colour for the 9:00 h samples were significantly ($p<0.05$) higher than the 14:00 h samples in the dry and wet periods as presented in Tables 3 and 4, whereas the 14:00 h samples in the dry and wet periods were not significantly ($p>0.05$) different (Tables 3 and 4). Despite the observed variation in water colour, Figure 3, the optimum alum dose yielded complete colour removal. However, alum doses below and above the optimum showed ± 5% unremoved colour. Stephenson and Duff (1996) reported a similar finding. It is therefore possible that for coagulant doses above optimum, residual colour after coagulation, flocculation, and sedimentation processes may not be necessarily be due to unremoved raw water colour but due to coagulant effect.

Water temperature

Water temperatures were relatively warm and stable as shown in Figure 4. Compared to polyaluminium chloride, alum is adversely affected by low water temperatures (Van Benschoten and Edzwald, 1990). Their study found out that, at cold temperatures of about 4^{o}C, an increase in the water pH by about 0.8 pH units mitigated the cold effects. From this study, the average water temperatures in Tables 3 and 4 did not show noticeable effects on coagulation from the jar tests. However, water temperature among other factors has been found to have a more pronounced impact on the formation of disinfection by-products (DBPs) (Delpla et al. 2009). Water temperatures between 5-30^{o}C were found to elevate the formation of DBPs therefore, the temperatures, 25.2 – 27.2^{o}C from this study were within temperatures for forming DBPs. However, the formation of DBPs was not within the scope of this study. In summary, Matilainen et al. (2002) in Finland found that raw water quality does not significantly affect the water treatment process, however, the treated water quality was affected more by the functioning of the treatment process, and this largely are confirmed by the findings in this study.

CONCLUSION

The hypothesis (basis) for this study that daily and seasonally variations in raw water quality affects the treatment process, specifically, the short filter run time that was experienced at Gaba was proven otherwise. The results from the series of jar tests indicated an efficient alum performance within the recorded variations in the measured parameters. However, a number of factors including; mixing condition, mixing time and velocity gradient affect alum dose determination. These factors need an investigation in order to narrow down the fault scope or better, solve the fault at Gaba. Other areas requiring further studies include; efficiency of the backwashing process and effective size of the granular sand used as these factors affect the functioning of the filtration process. As demonstrated by Gaba III, an auto coagulant dispensing plant, with an online monitoring of the raw water treatment process, a shift from manual plant types, Gaba I and II could prove to be a long term solution to the mishaps associated with manual plants. For example, the tedious process of frequently checking manually the raw water parameters such as colour and turbidity are lessened in auto plants.

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