Water Quality Improvement in the Inner Murchison Bay, Lake Victoria: A Case Study of Algal Removal at Gaba II Water Treatment Plant

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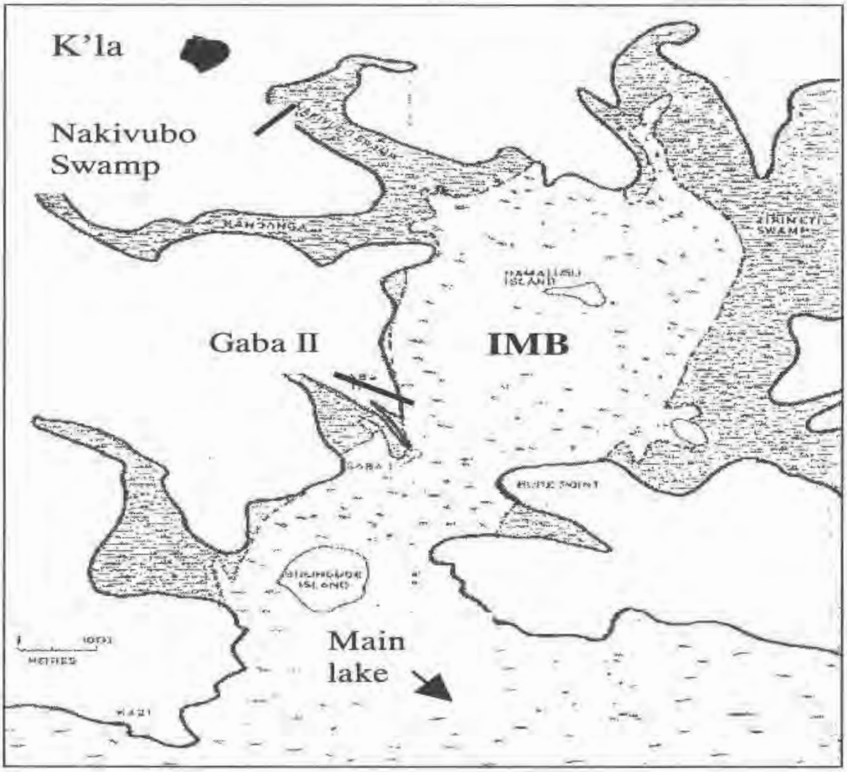
ABSTRACT

Gaba II, a conventional water treatment plant in Uganda, draws its raw water from the Inner Murchison Bay of Lake Victoria. Over the last six years (1995-2000), the water quality has changed as evidenced by increase in colour, turbidity and algae (chlorophyll-*a*) concentrations. Increased algal blooms in the Bay have had negative effects on the water treatment especially the clarification and filtration processes. In this paper, the performance of the treatment plant in terms of organic matter and algae removal was assessed using colour, turbidity, permanganate value and chlorophyll-*a* as indicator parameters. Identification and quantification of the dominant algae groups in the treatment process was done, and pilot clarification tests were carried out to identify options for algal removal. The removal of the colour, turbidity, permanganate value and chlorophyll-*a* to the levels of 88%, 71%, 65% and 85% respectively was found to take place mostly at the clarification stage. The results show that Gaba II water treatment plant does not perform well in terms of chlorophyll-*a* removal, especially at the filtration stage. At all the treatment stages, green and blue-green algae were found to be the dominant algal groups. The clarification efficiencies achieved in the pilot tests were 60-80% when using alum alone, 45-50% for alum with lime, 45-75% for alum with copper sulphate and 50-75% for alum with chlorine. This showed that none of the combinations was a better algae removal option than the presently practised clarification using alum alone.

Keywords: Inner Murchison Bay, Algal blooms, Algae removal, Clarification, Filtration

INTRODUCTION

Gaba II water treatment plant is found at the shores of the Inner Murchison Bay (Fig. 1) of Lake Victoria, which is the source of the raw water. It is a conventional water treatment plant, commissioned in December 1992, and supplies water to Kampala City, the capital of Uganda. The water treatment process involves clarification, rapid sand filtration, disinfection (using chlorine gas and High Test Hypochlorite (HTH)) and pH correction (using soda ash). Clarification is done using alum as the coagulant in flat-bottomed clarifiers.



(adapted from Gauff, 1988) **K'la** - Kampala City Centre

Figure 1: Map of the Inner Murchison Bay (IMB) showing the location of Gaba I and Gaba II, and the swamps in the catchment (semi-shaded)

The quality of the raw water at Gaba II water treatment plant has changed over the last five to six years (Tibatemwa, 2000). Colour and turbidity have increased at least two-fold, from an average of 35 to 74 PtCo for colour, and from an average of 2.7 to 6.3 NTU for turbidity (National Water and Sewerage Corporation (NWSC) Water Quality Database, (Tibatemwa, 2000)). Chlorophyll-*a* levels have also risen compared to the values obtained in 1988 (GAUFF, 1988). According to Palmer (1980), algae are known to change the pH, dissolved oxygen, alkalinity, hardness, colour, turbidity, and the organic matter content of water. The increase of colour, turbidity and chlorophyll-*a* of Gaba II raw water may, in part, be a result of increased algal concentrations.

Gaba II water treatment plant has over the years experienced increased algal invasion. Problems cited as a result of this include: intense clogging of raw water screens, algal growth on clarifier and filter walls, formation of lighter and smaller flocs during clarification, increased floc carry-over during clarification, increased chlorine demand for disinfection and more often objectionable odour of the treated water.

The problems highlighted above have caused operational setbacks e.g. frequent interruption of operation to scrape off the attached algae from the walls, abrupt changes in alum dose rate and clogging of filters, hence the need for more frequent backwashing and replacement of the fine sand media.

A number of studies had been carried out, prior to the construction of Gaba II, to assess the suitability of the Inner Murchison Bay (IMB) as a raw water source for Kampala City. These include: WHO/Resources Group (1969-1970), design studies for Gaba II by the EEC team (1982-1983), and Kampala water quality supply expansion project by Gauff Engineers (1987-1988). All the studies recommended the Bay as a suitable source of drinking water with no major changes since 1969. Later reports and research publications, however, indicate that the IMB and indeed the entire Lake Victoria ecosystem has undergone substantial changes over the last three decades (Chege, 1995; Hecky, 1993). The eutrophication of the IMB resulted from increased nutrient loads, due to the rapid increase of the population of Kampala City, coupled with rapid increase in industrial activity but without a corresponding waste management plan, leading to increase in discharge of semi-treated municipal and industrial effluents (COWI / VKI, 1998; Tibatemwa, 2000). The IMB also receives the surface run-off from the catchment where subsistence agriculture takes place and much of the forest cover has been indiscriminately harvested.

The IMB, therefore, may be looked at as a place where wastes of diverse kinds are deposited while at the same time serving as a source of raw water for Kampala City.

The aim of this research was to assess the plant performance in removal of organic matter and algae, given the changed water quality. Quantification of the algae is necessary because the success of any removal option depends on, among other factors, the concentration of the algae. The research aims at identifying options for the removal of the algae entering the treatment plant.

MATERIALS AND METHODS

Gaba II water treatment plant is located about 13 km South East of Kampala City centre. It is built at the shores of the Inner Murchison Bay (Fig. 1). The immediate catchment of the IMB is characterised by some areas of bare ground arising from deforestation and diminishing wetlands due to human encroachment (mainly for farming and housing construction). There is also poor sanitation in fish landing sites and villages, discharge of semi-treated municipal and industrial wastes and urban run-off, soil erosion and run-off from agricultural areas around the shores of the Bay and from earth surfaced roads in and around Kampala (COWI / VKI 1998).

Fig. 2 shows the location of the sampling points in Gaba II water treatment plant, used in this research. Plant performance at the different treatment stages was assessed based on organic matter and algae removal.

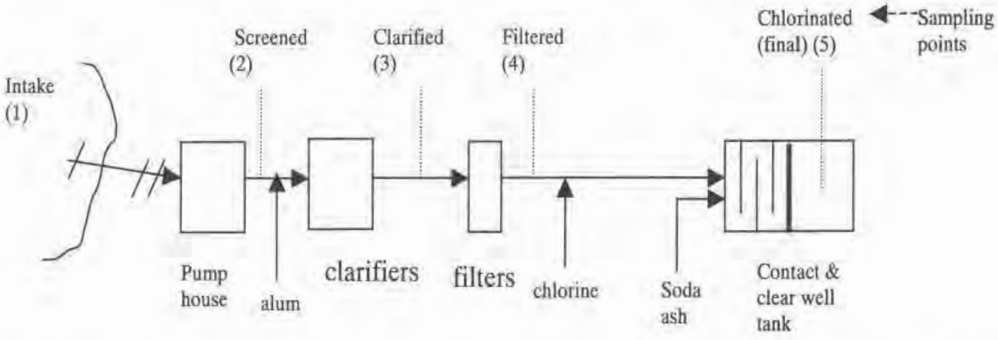


Figure 2: Simplified scheme of Gaba II water treatment plant showing the location of the sampling points used in this research (numbered 1 to 5)

Colour (apparent) was determined colorimetrically using a DR 2000 spectrophotometer. Turbidity was determined using the nephelometric method using a Laboratory Turbidimeter Model 2001A. Chlorophyll-*a* was determined using a solvent extraction method and readings taken using CECIL 1010 spectrophometer. All the methods are discussed in the Standard methods (APHA, 1989). Permanganate value was determined using a titrimetric method adapted by NWSC from IWE (1964) where 125 ml instead of 300 ml of sample was used and 5 ml instead 10 ml of 3.6M sulphuric acid added. The changes did not affect the results obtained.

At each sampling point, a 20 ml sample was taken into a screw-capped bottle and 4 drops of Lugol's solution added immediately and the sample was kept in an ice cooled dark box and transported to the laboratory. The sample was kept for at least 24 hours to allow for killing, staining, preserving and weighting of the algae. Algae genera identification and quantification was done using the Wilovert Wetzlar inverted microscope, model Z 10282, at magnification 100x. The method used was adapted from Wetzel and Likens, (1991). Identification and quantification of the algae was done by reference to the identification keys, plates (drawings), and index of algae from APHA (1989); Palmer (1980); Wetzel and Likens (1991).

Various options were tried as possibilities for improvement in algae removal in the clarification and filtration stages. The options were based on the selection criteria designed for this research, given in Table I.

Two concepts of algae removal were considered:

1. Coagulation-flocculation with sedimentation, followed by filtration (using rapid sand filters). Two conditions were considered: Clarification using alum alone and alum in combination with lime.

2. Algae conditioning prior to coagulation-flocculation with sedimentation followed by filtration. Two conditioners were used: chlorine, as an oxidant, in the form of High Test Hypochlorite (HTH) and copper sulphate as an algaecide.

Table I: Selection criteria for the appropriate algae removal method

				Pre-conditioning using						
	Direct filtration	Direct Coagulation-Flocculation	DAF	Cl_2	ClO_2	Ozone	$KMnO_4$	$CuSO_4$	UV	Microstraining
Oxidising ability	NA	NA	NA	++	+	++	++	+	-	NA
Cost	++	++	+	+	+	+	-	-	-	-
Availability	++	++	--	++	-	-	-	+	-	--
Side effects	+	+	++	--	+	-	+	+	++	++
Application operation	+	+	-	+	+	+	+	+	++	++
Aids coagulatn-flocculation	NA	+	++	-	-	-	+	+	-	+
Algae type, size, form dependance	--	--	++	+	+	++	+	+	++	++
Score	**4**	**5**	**4**	**4**	**3**	**2**	**4**	**5**	**2**	**1**

(All the pre-conditioning methods are followed by coagulation-flocculation sedimentation and rapid sand filtration; Dissolved air flotation (DAF) replaces sedimentation; side effects include trihalomethanes (THMs), bromate formation and toxicity).

Key: NA (Not applicable), + (1 point), ++ (2 points), - (1 minus point), — (2 minus points)

Pilot test 1 –Clarification with alum

One – litre samples were dosed with 1% w/v alum solution with concentrations ranging from 25 to 35 mg/L alum. The optimum dose was determined which was used for the application of lime, copper sulphate and chlorine in pilot tests 2 – 4. Replicates of 4 were used.

Pilot test 2 – Alum in combination with lime

The optimum alum dose found in pilot test 1 was used. 1% w/v lime dose was then added in concentrations of 0, 20, 40, 60, 80 and 120 mg/L. Replicates of 4 were used. The optimum lime dose was then determined using the jar test.

Pilot test 3 – Application of copper sulphate, then alum

Copper sulphate solution of 0.1% w/v was added, followed by the optimum dose found in pilot test 1. The copper sulphate was added in increasing amounts of 0, 0.25, 0.5, 1, 2 and 3 mg/L., allowing a reaction time of 15 minutes before addition of the alum. The optimum alum dose was then determined using a jar test.

Pilot test 4 – Pre-chlorination followed by alum dosing

Chlorine solution of 0.1% w/v was added, followed by the optimum dose found in pilot test 1. The chlorine was added in increasing amounts of 0, 0.25, 0.5, 0.75, 1.0 and 1.25 mg/L. Replicates of 5 used. A reaction time of 15 minutes was allowed before addition of the alum, and then the jar test runs were done.

Statistical data analysis was done using one-way ANOVA. The mean and standard error of replicate samples were determined. ANOVA: two-factor with replication, was used for the comparison of the variances of the algae abundance between the water treatment stages. A T-test for the comparison of means was used for the confirmation of the significance of the relative abundance of algae groups between the treatment stages. The differences between the four pilot algae removal tests were also compared using the T-test. Any statistical probability ≤ 0.05 was considered significant.

RESULTS AND DISCUSSION

The performance of the plant was assessed in terms of colour, turbidity, permanganate value (PV) and chlorophyll-*a* removal, in the period October 2000 to January 2001.

The clarification stage was found to remove up to 88% colour (Table II). It was however, noted that persistent colour remained after filtration depending on the raw water quality. The filtration stage was found to remove an additional 4% of the colour (Fig. 3). The chlorinated (final) water colour was 5.9 ± 0.8 PtCo which is within the national standard for piped water (15 PtCo).

Table II: Gaba II colour, turbidity, PV and chlorophyll-*a* removal through the treatment stages (mean ± se, n = 14 for colour and turbidity, 8 for PV and 6 for Chlorophyll-*a*)

	Raw water	Clarified water	Filtered water	Chlorinated (Final) water
Colour [PtCo]	104 ± 4.7	12.5 ± 1.0 (88%)	8.2 ± 0.6 (92%)	5.9 ± 0.8 94%)
Turbidity [NTU]	7.7 ± 2.1	2.2 ± 0.6 (71%)	1.9 ± 0.5 (75%)	1.8 ± 0.5 (77%)
PV [mg/L] Chlorophyll-*a*	2.3 ± 0.5	0.8 ± 0.2 (65%)	0.7 ± 0.2 (70%)	0.5 ± 0.2 (78%)
[μg/L]	64.5 ±15.1	9.5 ± 3.3 (85%)	8.2 ± 2.4 (87%)	7.2 ± 2.0 (89%)

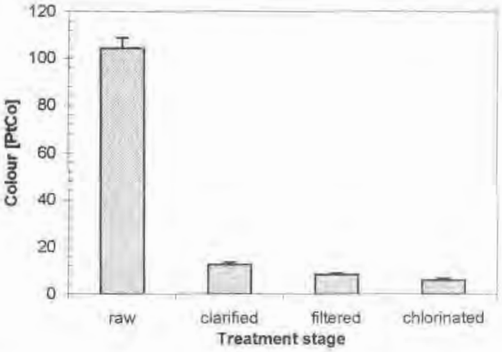


Figure 3: Gaba II stagewise colour removal, sampling period Oct. 2000 – Jan. 2001 Mean ± se,n = per 14 per treatment stage)

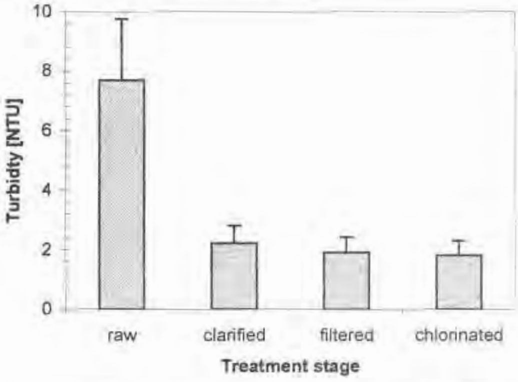


Figure 4: Gaba II stagewise turbidity removal, sampling period Oct. 2000 – Jan. 2001 (Mean ± se se,n = per 14 per treatment stage)

Turbidity reduction during the study period was found mainly to take place at the clarification stage, i.e. about 71 % was achieved (Table II) with a slight reduction at the filtration stage and no significant turbidity reduction. Twort *et al.* (1985) states that rapid sand filters are designed to reduce turbidity to less than 0.4 FTU (the same as NTU), and in the United States to less than 0.1 FTU, at the time of his publication. The mean turbidity of the filtered water obtained in this research was 1.9 ± 0.5 NTU implying unsatisfactory performance. Occasional increase of turbidity in the final water, may be attributed to resuspension of settled matter in the clear water well due to turbulence caused by continuous draw off by the high lift pumps. The final water turbidity (1.8 ± 0.5 NTU) is, however, within the national standard (5 NTU) for piped water (Fig. 4)

PV refers to the amount of oxygen absorbed when a strongly acidified water sample containing organic matter is mixed with potassium permanganate. The level of organic matter contained determines the PV (Holden, 1970). PV reduction mainly takes place in the clarification stage, i.e. about 65% was achieved (Table II). No significant reduction in PV by the filtration and chlorination stage was noted. Since the PV of a water sample is a measure of the oxygen absorbed by the sample, mainly as a result of its organic matter content (Holden, 1970; IWE, 1964), it implies that most of the organic matter is removed at the clarification stage. An average final water PV of 0.5 ± 0.2 mg/L was obtained (Fig.5). Water with a PV of 0.1 mg/L is ranked as very pure while piped water with a PV of 0.5 is of good quality (Holden, 1970). Neither the Uganda National Bureau of Standards (UNBS) nor WHO gives a guideline for PV in piped water.

Chlorophyll-*a* trends during the sampling period showed that most, i.e. about 85%, of removal took place at the clarification stage (Table II). The filtration stage only reduced chlorophyll-*a* concentration to an average of 7.2 ± 2.0 μg/L in the chlorinated water (Fig. 6). This concentration of chlorophyll-*a* may be considered high based on the MAC of 0.1 μg/L, set by the German association of drinking water reservoirs (Petrusevski, 1996). According to Steynberg *et al.*, (1996), the same standard (0.1 μg/L) is used as the guideline for potable water by the Rahnbach Reservoir Association in South Africa while Rand Water Company (South Africa) uses 1 μg/L as the standard.

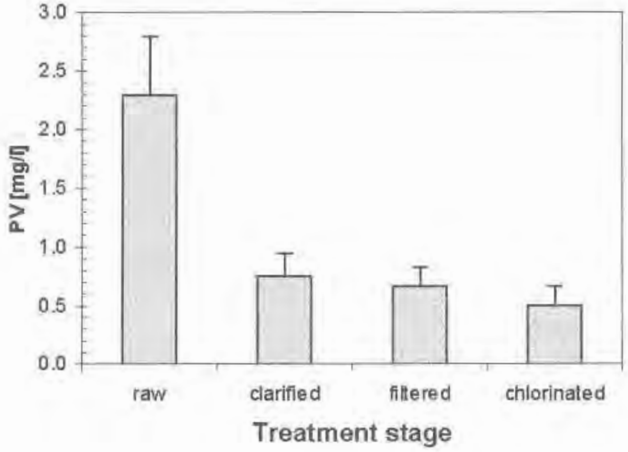


Figure 5: Gaba II stagewise PV removal, sampling period Oct. 2000 – Dec. 2000 (Mean ± se, n = 8 per treatment stage)

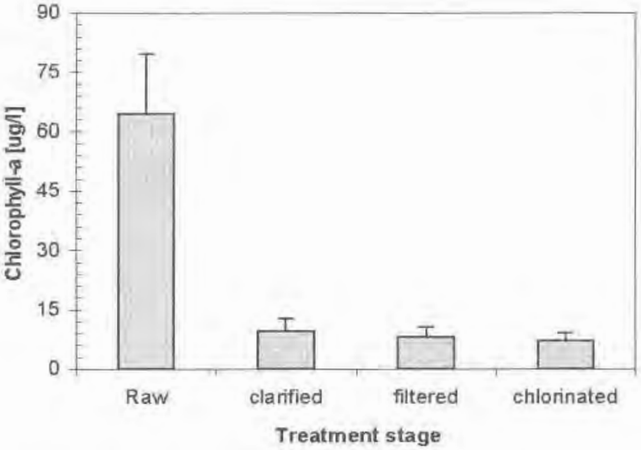


Figure 6: Gaba II stagewise Chlorophyll-*a* removal, sampling period Nov. 2000 – Jan. 2001 (Mean ± se, n = 8 per treatment stage)

The results of colour, turbidity, PV and chlorophyll-*a* show that the performance of Gaba II filtration system was below that reported by other authors (Twort *et al.,* 1985). Turbidity, for example should be less than 0.4 NTU in final water but was 1.9 NTU. This poor performance could be attributed to the loss of the fine sand media in the filters at the time.

Identifcation and quantification of algae

Table III shows the types of algae (genera) identified in the water treatment system. The total number of genera identified was 40 distributed among the groups as follows: 17 were green algae, 14 were diatoms, 5 were blue-greens, 3 were flagellates and only 1 belonged to the red algae group.

Table III: The algae types identified at the different water treatment stages at Gaba II

Genera	Group	Treatment stage				
		Raw water	Screened Water	Clarified Water	Filtered water	Chlorinated (Final) water
Agmenellum	BG	P	P	P	P	P
Anacystis	BG	P	P	P	P	P
Anabaena	BG	P	P	P	P	P
Arthrospira	BG	P	P	-	-	-
Gomphosphaeria	BG	-	-	-	P	-
Synedra	D	P	P	P	P	P
Gomphonema	D	P	P	-	-	-
Cymbella	D	P	P	P	-	P
Asterionella	D	P	P	-	P	P
Fragilaria	D	P	-	-	P	-
Nitzschia	D	-	P	-	-	-
Ulothrix	D	-	P	-	P	P
Navicula	D	-	-	P	P	P
Cyclotella	D	-	P	-	P	-
Tabellaria	D	-	P	-	-	-
Aragilaria	D	-	-	-	-	-
Melosira	D	-	P	-	-	-
Asterionella	D	-	P	-	-	-
Navicula	D	-	P	-	-	-
Ankistrodesmus	G	P	P	P	P	P
Oocystis	G	P	P	P	P	-
Scenedesmus	G	P	P	P	-	-
Spirogyra	G	P	P	-	-	-
Palmera	G	P	P	-	-	-
Phytoconis	G	P	P	P	P	P
Gonium coccus	G	P	P	-	-	-
Urothrix	G	P	-	P	-	P
Nitera	G	P	P	-	-	-
Padiastrum	G	P	P	P	-	P
Tetraspora	G	P	P	P	P	P
Chlorella	G		P	-	-	- -
Phacotus	G		P	-	-	- -
Zygnema	G		P	-	-	- P
Closteriam	G		-	-	-	- -
Oedogonium	G		-	-	P	P P
Tetraedron	G		-	-	-	- -
Euglena	F		P	P	P	- -

Volvox	F	P	P	-	-	-
Clorogonium	F	P	P	P	P	-
Hildenbrandia	R	P	P	P	P	-

BG = Bluegreen, D = Diatoms, G = Green, F = Flagellates, R = Red algae; p = Present, - = Absent.

Fig. 7 shows the relative algae group abundance as found in the successive treatment stages. According to Palmer, (1980) and APHA (1989), the genera identified in the raw water and at all the treatment stages were, as expected, those commonly found in fresh water, those associated with filter clogging and the attached algae.

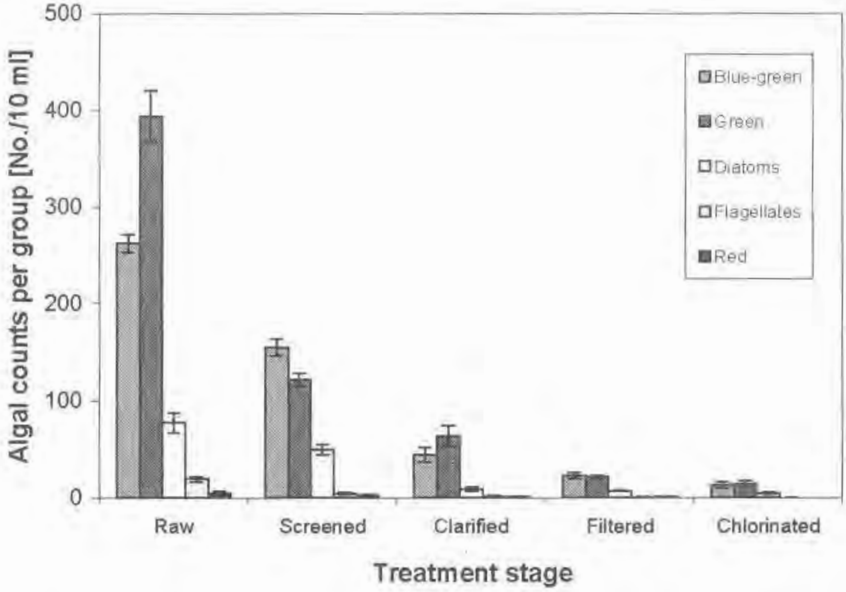


Figure 7: Algae abundance per group per treatment stage (Mean ± se, n = 6 per treatment stage)

Raw water

The most abundant of the algae groups found in the raw water were the green algae followed by the blue-green algae. The diatoms were next in abundance followed by the flagellates. The red algae were the least represented group in terms of abundance. The most dominant genera within the groups were as follows: *Ankistrodesmus, Scenedesmus* and *Nitera* for the green algae, *Agmenellum, Anacystis* and *Anabaena* for the blue-greens and *Synedra, Nitzschia* and *Gomphonema* for the diatoms.

Screened water

In the screened water, there was a shift in relative group abundance from the green to the blue-green algae. This implies that green algae are more effectively removed by the screening system than the blue-greens. The relative abundance for the diatoms, flagellates and the red algae remained the same as in the raw water. The dominant genera found at this stage were *Agmenellum, Anacystis,, Anabaena, Arthrospira,* and *Gomphospharia* for the blue-greens; *Synedra* and *Navicula* for the diatoms; and *Ankistrodesmus, Oocystis, Scenedesmus, Spirogyra* and *Palmera* for the green algae.

Clarified water

The dominant algae group found in the clarified water were the green algae followed by the blue-green algae. This implies that the clarification process was more efficient in removal of the blue-greens than the green algae. The next in abundance were the diatoms, followed by the flagellates and the red algae. The abundant genera found at this stage were *Agmenellum, Anacystis* and *Anabaena* for the Blue greens; *Synedra, Navicula* and *Cymbella* for the diatoms; and *Ankistrodesmus, Phytoconis, Scenedesmus* and *Tetraspora* for the Green algae. Various authors including APHA, (1989), Palmer, (1980), Lembi and Waaland, (1988) state that *Anacystis, Anabaena, Synedra, Cymbella* and *Navicula* are among the notorious filter clogging algae. The same authors report that *Phytocnis* and *Tetraspora* cause problems by attachment on tank walls. Gaba II clarifier and filter walls bear marks of attached algae and there is evidence of filter clogging, confirming the views of the same authors.

Filtered and chlorinated water

There was no significant difference in abundance between the green algae and the blue-green algae in the filtered and chlorinated water. The diatoms represented a smaller abundance compared to the blue-greens and the green algae while the flagellates and the red algae were not found in the chlorinated water. Some of the algae at this stage, namely *Anacystis, Anabaena, Asterionella* and *Synedra* are known to cause taste and odour in drinking water while *Anacystis* and *Anabaena* produce toxins (APHA, 1989; Palmer, 1980; Lembi and Waaland, 1988).

The plant performance in algae removal per group is illustrated in Figure 7 and Table III. Most of the algae (about 56%) are removed at the screening and clarification stage, but a significant fraction (about 7 %) remains and persists through the filtration stage and chlorination stage (about 4 %). The immediate effect of algae passing through the rapid filter media is shielding of pathogenic bacteria from disinfection, hence the increased chlorine demand of the water. Problems caused by algae presence in the distribution system are: taste and odour, corrosion of water mains (iron) and discolouration of water, after growth of bacteria, zooplankton and higher organisms in the mains and release of toxins (Petrusevski, 1996; Vlaski, 1998).

The algae removal efficiency for the filtration stage was about 56 % (Table IV), which is within the range reported by Mouchet and Bonnelye, (1998), *i.e.* 10% to 75% with an average of 50% efficiency, depending on the dominant algae species. Palmer, (1990), on the other hand, reports that an efficiently run rapid filtration system can achieve 90% algae removal efficiency, implying that Gaba II filtration system achieves slightly more than half the expected efficiency.

Table IV: Gaba II algae removal efficiency per group and per treatment stage (mean ± se, n = 6 per treatment stage)

Algae group	Raw water	Screened water	Clarified water	Filtered water	Chlorinated (final) water
Blue greens	262 ± 8.8	155 ± 8.9 (37%)	44 ± 7.7 (83%)	23 ± 3.3 (91%)	13 ± 2.8 (95)
Green	394 ± 26.2	122 ± 6.5 (69%)	64 ± 10.7 (84%)	21 ± 1.4 (95%)	14 ± 3.0(96%)
Diatoms	77 ± 10.3	50 ± 5.3 (35%)	9 ± 2.0 (88%)	7 ± 0.6 (91%)	4 ± 1.0 (95%)
Flagellates	19 ± 2.5	5 ± 1.2 (76%)	2 ± 0.3 (92%)	1 ± 0.2 (97%)	0 (100%)
Red algae	4 ± 2.5	2 ± 0.7 (50%)	1 ± 0.5 (75%)	1 ± 0.2 (75%)	0 (100%)
Total	756 ± 26.9	334 ± 11.5 (56%)	120 ± 19.2 (84%)	53 ±4.7 (93%)	31 ± 5.4 (96%)

Table IV shows the algae removal efficiency per group, of each of the treatment processes. Less than 45 % of the diatoms and the blue-greens are removed by the screening process, while over 60 % of each of the other groups, except the red algae, are removed. The graph shows no difference in the removal efficiency of the clarification-sedimentation process for the green algae, blue-green algae and the diatoms. A statistical analysis of their relative abundance, however, shows that the difference is significant. Steynberg, *et al.* (1996) states that the efficiency of algae removal by unit treatment processes depends on size, shape, presence of spines and on motility. According to Lembi and Waaland, (1988), diatoms have no flagella and many are non-motile. According to Dokulil, (2000) blue greens are able to float using their gas vesicles. This could be the mechanism that makes them difficult to sediment during the clarification process.

An average of 3 % of the diatoms, which escape the clarification stage, are retained by the filters. On the other hand, the filters are able to retain about 11% and about 9% of the green algae and blue-green algae respectively. One hundred percent overall removal efficiency is achieved for the red algae and the flagellates. The overall algae removal efficiency of the plant was, on average 96%.

Algae removal pilot experiments

The results of the pilot experiments to determine the best option for algae removal are presented in the following sections. The percentage removal of colour and turbidity was used to determine the clarification efficiency.

The samples were taken from the supernatant (settled), and filtered product of the jar tests, apart from the experiment with alum alone, in which only the supernatant was analysed.

Based on colour and turbidity removal at the settlement stage (supernatant), results of the experiments show that the change in alum dose rate from 25 mg/L through to 35mg/L caused no significant difference in the clarification efficiency. The flocs formed at a dose of 29 mg/L were slightly bigger and settled faster than at the lower and higher doses but the settled water colour and turbidity was no better than for the other doses. Both colour and turbidity removal efficiency ranged from 60 to 75% (Fig. 8 and 9).

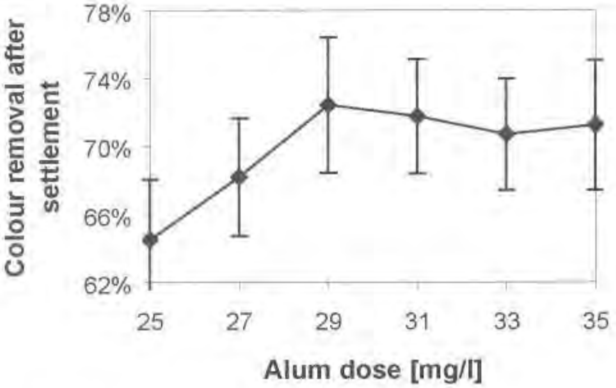


Figure 8: Colour removal (%) after settlement as a function of alum dose (Mean ± se, n = 4 for all the doses).

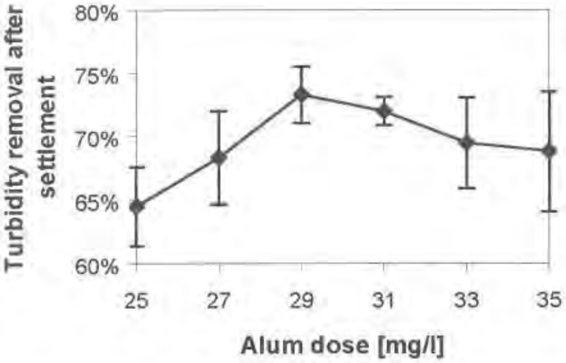


Figure 9: Turbidity removal (%) after settlement as a function of alum dose (Mean ± se, n = 4 for all the doses).

Lime was added to alum with the aim of raising the pH and alkalinity in the coagulation-flocculation process. The pH of the solution rose from an average of 6.6 to 6.7, and alkalinity from an average of 44-73 mg/L as $CaCO_3$. Based on colour and turbidity removal, the four jar test experiments using alum in combination with lime, however, showed that addition of lime caused no improvement of the clarification efficiency. The efficiency achieved was 40–65 % for colour removal and 20–50 % for turbidity removal (Fig. 10 and 11).

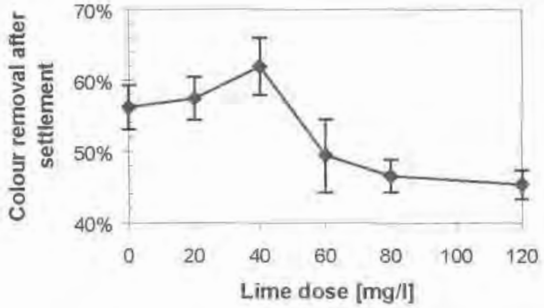


Figure 10: Colour removal (%) after settlement, as a function of lime dose (Mean ± se, n = 4 for all the doses)

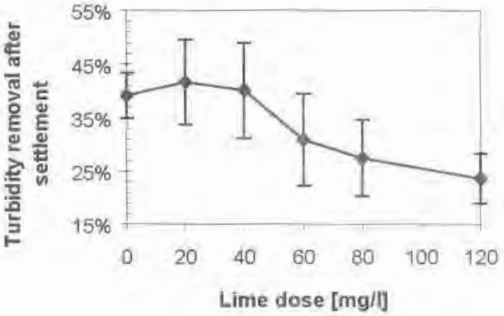


Figure 11: Turbidity removal (%) after settlement, as a function of lime dose (Mean ± se, n = 4 for all the doses)

Four jar test experiments were carried out using copper sulphate prior to clarification with alum. It was expected that the copper sulphate, as an algaecide, would cause immotility or death of the algae, hence rendering them settleable and, therefore, improving the clarification efficiency. Based on colour and turbidity removal, addition of copper sulphate prior to coagulation-flocculation, however, caused no significant improvement in the clarification process. The efficiency achieved was 45–75 % for colour removal and 40–60 % for turbidity removal (Fig. 12 and 13).

Chlorine acts as a strong oxidising agent and has been used as an algae conditioner, enhancing their sedimentation during the clarification process (Palmer, 1980; McGhee, 1991). Five jar test experiments were carried out using chlorine prior to clarification with alum. Based on colour and turbidity removal, addition of chlorine prior to coagulation-flocculation, however, caused no significant improvement in the clarification process. The efficiency achieved

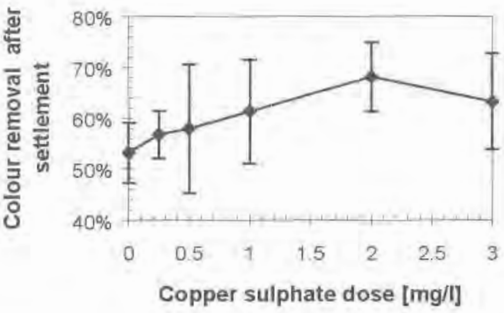


Figure 12: Colour removal (%) after settlement, as a function of copper sulphate dose (Mean ± se, n = 4 for all the doses)

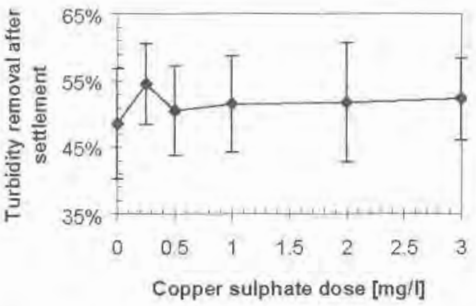


Figure 13: Turbidity removal (%) after settlement, as a function of copper sulphate dose (Mean ± se, n = 4 for all doses)

was 50–75 % for colour removal and 40–65 % for turbidity removal (Fig. 14 and 15). Besides the low efficiency obtained, chlorine is known to react with organic matter in the water producing THMs, which are carcinogenic. Chlorine also causes algal cell damage (lysis) releasing even smaller particles in the water. The damaged cells release dissolved organic carbon and metabolites leading to toxicity, taste and odour (McGhee, 1991; Mouchet and Bonnelye, 1998).

Statistical analysis showed that there was a significant difference in clarification efficiency between the jar test experiments (options tried) except for the combinations of alum with lime and with copper sulphate, and alum with chlorine and with copper sulphate. None of the options produced better clarification efficiency than alum alone.

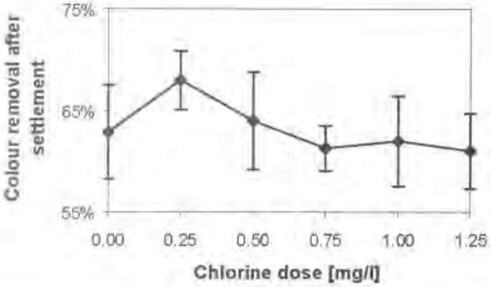


Figure 14: Colour removal (%) after settlement, as a function of chlorine (Mean ± se, n = 5 for dose all the doses)

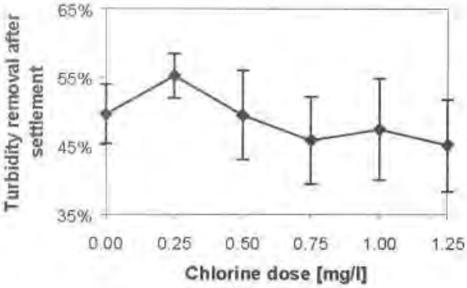


Figure 15: Turbidity removal (%) after settlement, as a function of chlorine dose (Mean ± se, n = 5 for all the doses)

The clarification efficiencies achieved by the four different options are given in Table V.

Table V: Clarification efficiencies achieved by the four pilot jar test experiments

Treatment option	Clarification efficiency	
	Colour removal (%)	Turbidity removal (%)
Alum alone	60-80	60-80
Alum with lime	45-50	20-50
Alum with $CuSO_4$	45-75	40-60
Alum with chlorine	50-75	40-60

CONCLUSIONS

- The change of water quality in the Inner Murchison Bay, marked by increased algal blooms, has had a negative effect on the efficiency of Gaba II water treatment plant, especially the filtration stage.

- Green algae, blue-green algae and the diatoms are the most common algal groups affecting the water quality of Gaba II. Most of the dominant genera identified at all the treatment stages are those associated with filter clogging, production of taste and odour and release of toxins.

- The use of alum in combination with lime, alum after application of copper sulphate and after application of chlorine in the pilot jar test clarification experiments did not produce better clarification efficiency than the use of alum alone.

RECOMMENDATIONS

- A detailed study of the cause of poor performance of the filtration stage of the treatment plant should be carried out.

- Further research should be carried on the species dominant at all the treatment stages, and their physical and physiological characteristics, which could explain their dominance. This would help to design appropriate removal methods.

- Optimization of the clarification process should be done by controlling the pH and use of coagulant aids, such as cationic polymers.

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