Evaluation of Performance of Conventional Water Treatment System: A Case Study

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Abstract: ***Most urban centres of the world are already limited by the amount and quality of available water. According to World Health Organization (WHO, 2002), in the next 30 years alone, accessible water is unlikely to increase more than 10 percent but the earth's population is projected to rise by approximately one-third. One of the millennium development goals is to provide access to safe drinking water to all. The existing main water supply system for Kakamega town comprises surface water abstraction from River Isiukhu, located on the south-eastern boundary of the Municipality. The water supply relies on a two stage pumping regime from the abstraction to treatment works and thereafter to the town's main storage tanks in Milimani area. This paper presents findings of a study carried out to determine performance of Kakamega water treatment plant. Samples of water were taken from the source and the treated water and were analyzed for physical, chemical and bacteriological parameters of water quality. Kakamega treatment plant employs rapid sand filters that utilize a bed of silica sand and graded gravel of 0.6 m and 0.4 m deep respectively. The sand has effective sizes of 0.66 mm and uniformity coefficient of 1.82, it as well has porosity of 56.1%. While the graded gravel has specific gravity of 2.56 and porosity of 38.1%. This indicates that the filter sand used as filter media fails to comply with most of the requirements of a rapid sand filter.***

Keywords: Water treatment, contaminant levels, water quality, water production, Filter media

1. Introduction

Human activities like industrialization, urbanization as well as rapid population growth [1] gives increasing to water demand and distribution challenges along with increased wastewater production. Thus the process of sustainability and sustainable sanitation is coming in front to adjust the economic, social and environmental conditions [2]. Research has been carried out on Performance of Water Treatment Plants [3, 4]

According to [5] it is now clear that future water demands cannot be met unless wastewater management is efficient. According to [6] mentioned in Bhusal (n.d.), "lots of cases have occurred in the world due to unsafe drinking water for example: 1.6 million people die each year due to diarrhea, 160 million people are infected with Schistosomiasis, around 1.5 million cases of clinical hepatitis each year and intestinal helminthes

The Treatment Works in Kakamega has two raw water abstraction intakes on the Isiukhu River. The raw water from both intakes is pumped separately by low lift pumps to the treatment works. The treatment works consists of a combination of Conventional Treatment Units and Package Treatment Units in four partly independent production line systems with a combined total design capacity of 8240 m^3/day.

The existing water treatment systems comprise the following:

- *Phase I treatment line constructed in 1956*. These are Old Conventional Treatment Units with a design capacity of 1680 m^3/day.
- *Phase II treatment line constructed in 1972*. These are New Conventional Treatment Units with a design capacity of 2880 m^3/day.
- *Phase III treatment line constructed in 1985*. These are the Struja Package Treatment Units with a design capacity of 800 m^3/day.
- *Phase IV treatment line constructed in 1992*. These are Newer Conventional Treatment Units with a design capacity of 2880 m^3/day.

(i) Purpose of Water Treatment

The purpose of water treatment is to condition, modify and/or remove undesirable impurities, to provide water that is safe, palatable, and acceptable to users. While this is the obvious, expected purpose of treating water, various regulations also require water treatment. Some regulations state that if the contaminants listed under the various regulations are found in excess of maximum contaminant levels (MCLs), the water must be treated to reduce the levels [7]. If a well or spring source is surface influenced, treatment is required, regardless of the actual presence of contamination. Water is mixed with air to increase dissolved oxygen through aeration which removes dissolved gases such as carbon dioxide and oxidizes dissolved metals such as iron, hydrogen sulfide, manganese and volatile organic chemicals

(ii) Stages of Water Treatment

Water treatment is made up of various stages or unit processes combined to form one treatment system. Note that a given waterworks may contain the entire unit processes discussed in the following or any combination of them. One or more of these stages/structures may be used to treat any one or more of the source water problems. Also note that the model discussed here may not necessarily apply to very small water systems. In some small systems, water treatment may consist of nothing more than removal of water via pumping from a groundwater source to storage to distribution. In some small water supply operations, disinfection may be added because it is required.

The stages in a water treatment plant include, Pretreatment which include screening, Mixing Chamber (Hydraulic and Mechanical Rapid Mixing), Coagulation, Flocculation, Sedimentation, Filtration and Disinfection.

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(iii) Sedimentation and settling

After flocculation basin, water entered into the sedimentation basin also called clarifier or settling basin which allows floc to settle to the bottom. The amount of floc that settles out of the water is dependent on the time and depth of the basin. Normally detention time for settling basin is 2 to 4 hours (WHO 1996). During storage, about 90% of suspended solids settle down within 24 hours and water become clear and clean and certain heavier chemicals also settle down during storage [8]

2. Materials and Methods

The study was carried out using both qualitative and quantitative methods of data collection. These methods were laboratory tests (physiochemical and bacteriological), interviews questionnaires and field observations. Documentary data was obtained from the records of Water Resource Management Authority, Lake Victoria North Water Services Board and Western Water Services

A. Laboratory tests

A total number of 24 samples were collected for full physiochemical and bacteriological analysis. More minor samples were also collected in which the analysis was done in the treatment plant. In each sample a number of perimeters have been analyzed. Laboratory tests that have been carried out were grouped in to the following categories: Physical analysis, Chemical analysis and, Bacteriological analysis and Sieve analysis of filter media.

B. Interviews

A total number of 60 interviews were carried out guided by pre-structured interview sheet. Answers were mainly recorded. This was made up of:

a) Key informer interviews

To gain some insight in the topic, 10 selected personnel were interviewed made up of 2 members from Lake Victoria North Water Services Board and 8 members from Western Water Services Company.

b) Customers

Total number of 50 customers were selected for the interview. The size was based on the assumption that at least 4 people from each main zone of the 12 water distribution zones of Kakamega municipality will represent a fair representation of opinion of the problem. 50 people, all adults, made up of 29 females and 21 males from 50 houses were selected randomly for interview.

3. Results and Discussions

a) Interviews

A total number of 60 interviews were carried out, 50 of which were customers while the remaining 10 was drawn from Lake Victoria North Water Services Board and Western Water Services Company. The results of the interview is shown in table 1

Table 1: Water supply Sources

Source of water	Number of respondents	Respondents of each source in %
House connection	41	68.3 %
Stand pipe	12	20 %
Borehole	5	8.3 %
Other sources	2	3.3 %
Total	**60**	**100 %**

From table 1 above the total number of respondents who receive water from either house connection or stand pipe is 53. Customers are capable of detecting only some physical parameters such as colour and it is that observation they use to choose whether the water supplied to them at particular time is clean or dirty. This however, is not enough to give judgment that the water is contaminated because the water may be coloured yet is clean from any harmful substance. The details of respondents in water quality is shown in the figure 1

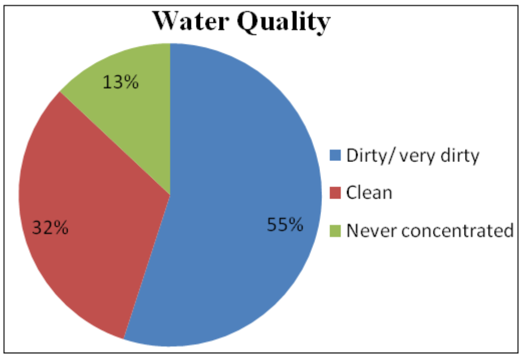

Figure 1: Aesthetic water quality

From Figure 1 above, it is clear that large percentage of respondents reported receiving water that is not clean according to their observations. The respondents cited receiving dirty water mostly during rainy season. The term water quality in the figure refers to the physical observations only. This, however, doesn't mean the water is not safe for consumption. To assess the quality of the water a full physical, chemical and bacteriological analysis was carried out and that is the only way of making judgment about the water quality.

b) Determination of Water Quality Parameters

In this research a total number of 24 samples were taken for full physical, chemical and bacteriological analysis of water quality. Half of the samples collected was used for physiochemical analysis while the other half was used for bacteriological analysis. The point of extraction was taken as the point of sampling in the river and in the treated water the samples were taken from the clear water tanks (storage tanks). To avoid changes in quality that may occur between the actual point of extraction and the inlet to the treatment plant, an additional sampling location upstream of the extraction point was chosen. Only minor samples that were analyzed in the treatment plant were collected from this upstream point.

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Table 2: water quality analysis results

a) January

Parameter	Unit	Analytical Value			WHO Guide
		Raw Water	Treated Water		
			Old plant	New plant	
Dissolved oxygen	Mg/l	10.1	9.3	9.6	> 4
Temperature	^{0}C	24.2	24.7	24.5	-
E. Conductivity	µS/cm	89	110.3	109.1	1000
TDS	mg/l	59	65	67.3	500
pH		7.7	6.8	6.8	6.5–8.5
Colour	mgPtCo/l	**63**	8	14	15
Turbidity	NTU	**71**	3.8	**6.2**	5
Iron	mgFe/l	**0.43**	0.24	0.23	0.3
Total Hardness	mgCaCO$_3$/l	254	349	325	500
Total Alkalinity	mgCaCO$_3$/l	367	251	301	500
Chloride	mgCl/l	< 1	4.2	3.7	250
Nitrite	mgNO$_2$/l	0.36	0.34	0.37	3
Ammonia	mgNH$_3$/l	0.91	0.12	0.22	1.5
Total Coliforms	MPN/100mls	≥1600	0	0	0
Feacal Coliforms	MPN/100mls	200	0	0	

b) February

Parameter	Unit	Analytical Value			WHO Guide
		Raw Water	TreatedWater		
			Old plant	New plant	
Dissolved oxygen	Mg/l	9.6	8.67	8.9	> 4
Temperature	^{0}C	26.3	26.4	26.4	-
E. Conductivity	µS/cm	92	116.7	127.3	1000
TDS	mg/l	46.1	58	61.5	500
pH		7.43	**6.12**	**6.10**	6.5 – 8.5
Colour	mgPtCo/l	**70**	10	**16**	15
Turbidity	NTU	**58**	4.01	**5.7**	5
Iron	mgFe/l	**0.37**	0.08	0.19	0.3
Total Hardness	mgCaCO$_3$/l	280	370	360	500
Total Alkalinity	mgCaCO$_3$/l	410	280	330	500
Chloride	mgCl/l	0	3.4	2.9	250
Nitrite	mgNO$_2$/l	0.3	0.3	0.3	3
Ammonia	mgNH$_3$/l	0.79	0.01	0.31	1.5
Total Coliforms	MPN/100ml	≥1600	0	0	0
Feacal Coliforms	MPN /100ml	280	0	0	0

c) March

Parameter	Unit	Analytical Value			Who Guide
		Raw Water	Treated Water		
			Old Plant	New Plant	
Dissolved Oxygen	Mg/L	6.2	7.4	6.9	> 4
Temperature	^{0}c	24.5	25.2	24.8	-
E. Conductivity	µs/Cm	91.4	105.8	109	1000
Tds	Mg/L	46.3	52.3	51.8	500
Tss	Mg/L	39	10	17	30
Ph		**6.16**	7.2	7.6	6.5–8.5
Colour	Mgptco/L	**59**	4	**18**	15
Turbidity	Ntu	**68**	4.9	**7.1**	5
Iron	Mgfe/L	**0.8**	**0.43**	**0.51**	0.3
Total Hardness	Mgcaco$_3$/L	59	61	58	500
Total Alkalinity	Mgcaco$_3$/L	290	261	246	500
Chloride	Mgcl/L	1.2	5.7	4.2	250
Nitrite	Mgno$_2$/L	2.3	2.3	2.1	3
Ammonia	Mgnh$_3$/L	**1.6**	0.76	0.90	1.5
Total Coliforms	Mpn/100mls	≥ 1600	0	0	0
Faecal Coliforms	Mpn/100mls	150	0	0	0

Source: Water Resources Management Authority- Lake Victoria North Catchment Area

From tables 2 a, b and c above the concentration of most elements and compounds in finished water was lower than that in source water. Only very few parameters showed an increase of concentration from source water to treated water; these include chloride, total hardness and total dissolved solids. This may be the result of treatment chemicals used for coagulation and disinfection. In raw water some parameters are higher than the guideline values. In all samples that were analyzed turbidity, colour, TSS and Iron remained very high. In the treated water these values have been reduced lower than the guideline values; except turbidity which in most cases remains higher than the required value especially when you consider the new treatment plant. This is due to structural problems of filter media. pH of both raw and treated water fluctuates and in most samples it is lower than the required range. This can easily be adjusted using Soda ash for preconditioning and post-conditioning of raw and treated water respectively.

Chemically, both raw and treated water are clean and suitable for human consumption. Except Iron and Ammonia all the other chemical parameters in raw water have values lower than required; the higher values of Iron and Ammonia may not impose any immediate health problem if the water is used for drinking.

In treated water all parameters are lower than the guideline values meaning that the treatment is performing effectively in chemical removal. This may not, however, be the case if some elements shout up during rainy seasons; these include Nitrites which remains the same both in source and finished waters. Any increase of Nitrites can be problem because the treatment plant was not designed to remove such elements from water.

Isiukhu River is highly contaminated and is not totally suitable for drinking; thus requiring maximum treatment of disinfection. In all samples that have been analyzed, bacteriological trend remains the same. This may be due to animal wastes or any other source of contamination. Treated water is clean and is suitable for drinking or any other use since both total coliform and fecal coliforms are zero. This is mainly due to the disinfection effect of chlorine because rapid sand filters, the treatment plant is equipped with, are not capable of removing any bacteria from the water. Though treated water in the clear water tanks is bacteriologically clean, care has to be exercise in application of chlorine. If there is no enough residual chlorine in water in the reservoir tanks as well as in distribution systems it can lead contamination of water in the distribution systems.

c) Water Production

Daily records of water produced in the first three months was obtained and from the daily production, the monthly water production was computed and recorded as indicated in the table 3. The monthly water production was obtained and is presented in figure 2

Table 3: Water production

Month	Jan	Feb	Mar	Apr	May	Jun
Production m^3	132,671	174,808	135,961	92,738	106,036	143,747

Month	Jul	Aug	Sep	Oct	Nov	Dec	Average
Production m^3	118,299	147,715	148,396	136,344	145,812	143,602	135,511

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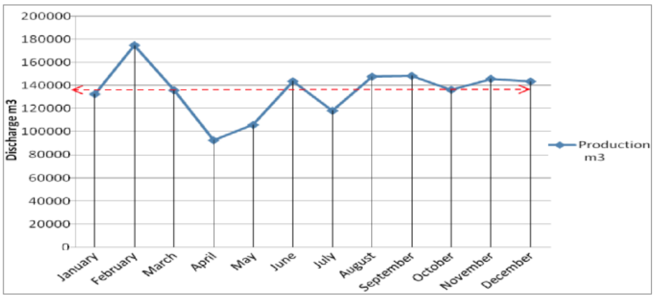

Figure 2: Water production

In the month of January, a total amount of 139,582 m^3 of water was produced with a maximum and minimum production of 6,370 m^3/day and 3,750m^3/day respectively. The average water production in January was 4,503 m^3/day. In February, total amount of 128,540 m^3 was produced with a maximum and minimum of 6,150 m^3/day and 3,510 m^3/day respectively and an average production of 4,432 m^3/day. And in March, a total amount of 151,612 m^3 was achieved with a maximum and minimum production of 5,980 m^3/day and 3,500 m3/day respectively. In this month the average production was 4,890 m^3/day. The monthly water production of the treatment plant from January to December and January to March is shown in tables3 and 34 respectively.

Production pattern of the year is shown in Figure 2. The production pattern for this year is also expected to flow the same trend since there is no change that has been made to the treatment units as from last year. The treatment plant has a design capacity of 247,200 m^3/month. However, as it can be seen from the production data the average monthly production of the treatment plant is about 138,000 m^3/month. This is far less than the design capacity of the treatment plant by 45%. That is to say the existing treatment plant is operating half of its design capacity.

d) Filter media performance

Kakamega treatment plant employs rapid sand filters that utilize a bed of silica sand and graded gravel of 0.6 m and 0.4 m deep respectively. Tests were carried out to determine the particle size distribution of the filter media. The results are indicated in the figure 3

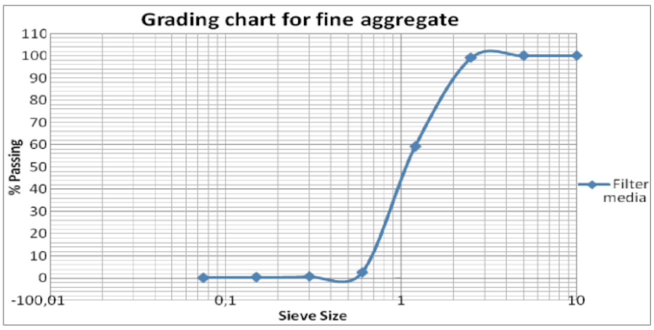

Figure 3: Sieve analysis results for fine aggregates from rapid sand filters

Table 4: Filter media material- fine aggregates

Parameter	Level
Effective size, ES (mm)	0.66
Uniform Coefficient, UC	1.82
Bulk Density (Kg/m^3)	1470
Specific Gravity, GS	2.90
Magnesium as carbonates (%)	0.32
Lime as $CaCO_3$ (%)	0.01
Solubility in 10% HCl (%)	0.5
Porosity (%)	56.1

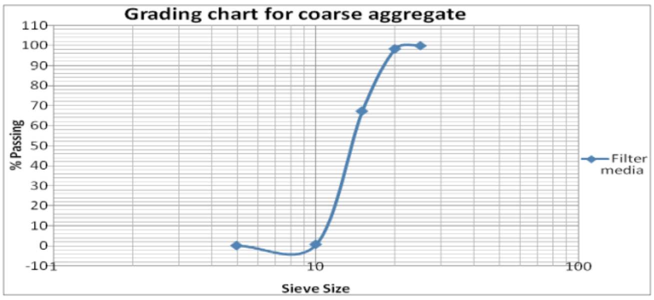

Figure 4: Graphical representation of percentage of passing material versus sieve size for coarse aggregates

Table 5: Filter media material-coarse aggregates

Parameter	Level
Effective size, ES (mm)	11.5
Uniform Coefficient, UC	1.30
Bulk Density (Kg/m^3)	1632
Specific Gravity, GS	2.56
Magnesium as carbonates (%)	0.96
Lime as $CaCO_3$ (%)	0.01
Solubility in 10% HCl (%)	0.2
Porosity (%)	38.1

From table 4 above the sand has uniformity coefficient (UC) of 1.82 and effective size (ES) of 0.66. both of these values are above the recommended levels of 0.35 – 0.5 mm for ES and UC of 1.6 .The porosity of the sand sample was 56.1 which is not within the recommended range of 40 – 43 percent. The bulk density of sand obtained from the sample of sand was 1.47 g/ml which is less than required value of 2.65g/ml.

From table 5 the specific gravity obtained from the gravel sample gave a value of 2.56 which is within the acceptable range. Porosity of the sample was 38.1% which is also within the acceptable range. The depth of the graded gravel layer of the filter media in the existing treatment plant has been found to be 0.40 m deep.

4. Conclusions and Recommendations

(i) Conclusion

From the tests carried out the results and analysis manifest that the raw water from R. Isiukhu is highly contaminated and calls for maximum treatment prior to consumption. In treated water all chemical and bacteriological analysis that have been carried out shows that the water is clean and safe for drinking. However, some of the physical parameters are higher than the acceptable limits; these include turbidity and colour while the pH remained lower than the acceptable range in most case. Though aesthetically unpleasant the treated water is both chemically and bacteriologically safe

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for drinking. High turbidity and colour in treated water seem to be due to defects in both flocculation and filtration basins. In the new treatment plant some of the mechanical rapid mixers have been disabled because of their high power consumption. This has reduced mixing efficiency of coagulants thus affecting floc formation. In filters, the depth of filter media employed is so shallow to combat with high suspended solids in the pre-filtered water.

The sand used as filter media has also failed to comply with the standard specifications of rapid sand filter media.

(ii) Recommendations

The following are proposed recommendations that need to be implemented at the treatment plant so as to improve its efficiency

- Proper maintenance of the treatment plant units should be carried out as necessary.
- The filter media of the rapid sand filters need to be replaced.
- There should be adequate backwash water capacity available for proper backwashing.
- Flocs breakthrough can be avoided by use of mixed-media filter unit. Mixed–media has much greater surface area of grains as compared to sand and dual-media.
- Monitoring and evaluation of the water quality should be improved through training of the plant operators and provision of enough laboratory equipments for daily routine tests.
- The use of a polymer instead of Alum should be evaluated to determine its efficiency.

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