CRITICAL EVALUATION OF THE EFFECTS OF CHANGES MADE TO ROUGHING FILTERS OF MPIRA-BALAKA PLANT ON ITS TREATMENT AND OPERATIONAL PERFORMANCE

By

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ABSTRACT

Mpira Balaka, a full scale rural water supply project was constructed in Ntcheu, Malawi, in 1988 utilising Slow Sand Filtration (SSF) as the main treatment process and roughing filtration as the pretreatment method, following the promotion of this technology by various international institutions.

During the rainy seasons, the treatment plant for Mpira Balaka failed to cope with the high raw water turbidity, resulting into very short filter run times and hence also to unavoidable distribution of very turbid water to the rural communities as a result of by-passing the filters.

Of the fifty or so existing rural projects in Malawi, Mpira-Balaka, the biggest rural project until then, was beset with unforeseen design, treatment and operational problems. In an attempt to rectify the situation, a number of consultants were called to advise the Water Department, eventually resulting in the modification of the existing roughing filters to Downflow type.

Since the suggestions put forward by the consultants and the manner in which the modifications were implemented was rather adhoc in nature, this paper scientifically establishes the efficacy of the modifications made to the roughing filters, and evaluates the treatment performance prior to, during and after the modification of the roughing filters. The study was conducted at the University of Dar es Salaam using data collected in Malawi. Notable improvements in some water quality parameters have been observed. The mean monthly turbidity removals through the system prior to, during and after the modifications were 37%, 54%

and 88%, respectively. During the same period the mean monthly faecal coliform percentage removals observed were 77.8%, 80% and 90%, respectively.

Mean SSF run times increased from 23 days prior to the modification to 58 days after. The observed improvements in the overall plant performance are directly related to the modification in the design and construction of the Downflow Roughing Filters.

KEY WORDS

Roughing Filters, Downflow Roughing Filters, Roughing Filtration, Slow Sand Filtration, Treatment Plants, Filtration.

INTRODUCTION

With an average density of 67 inhabitants per square kilometre, Malawi's population is very unevenly distributed with the Southern Region possessing over half the population (Hutcheson *et al*, 1993). Pressure on agricultural land has tended to have a strong influence on the quality of the surface run-off to the rivers, accounting for high turbidities during the rainy season due to erosion of the cultivated hilly areas (Lewis, 1984). Development of rural piped water supply projects in areas where perennial protected streams and rivers are either not adequate or not present at all has necessitated the abstraction of surface water which seasonally would have some water quality parameters above the Malawi Temporary Rural Water standards. In such cases an appropriate and sustainable treatment option has to be sought.

In 1984, Malawi commissioned it first rural water supply project utilizing Slow Sand Filtration (SSF) at Dombole and three years later, the Mwanza Rural Project, the first project to incorporate a pre-treatment unit (roughing filter) upstream of SSFs (Chaya, 1992).

The performance of these two projects as regards operation, maintenance and treatment paved way for the implementation and development of Mpira-Balaka Rural Water Supply Project, also utilizing Slow Sand Filtration preceded by Roughing Filters (RF).

The Mpira-Balaka Project covers an area of 1900 km^2 astride the M1 road 200km Southeast of Lilongwe (see Fig. 1). The overall Mpira-Balaka project design population to be served has been based on the agricultural carrying capacity of the land rather than census data (Kumwenda, 1992). The project comprises of three parts, namely; The Dam, the Treatment Plant, and the Distribution System.

The Mpira Dam has been constructed across the Mpira River, an upland river in Ntcheu District in Central Malawi. With a 42 km^2 catchment area, the dam has a live storage of 3.72 million m^3 of water.

At completion, the distribution system will serve a rural population of 300,000 and an urban population of 27,000 through 1800 tap points. Per capital consumption for the rural population by the year 2005 is estimated to be 27 l/c/d. At completion there will be 1800 tap points and 38 storage and break pressure tanks have been strategically located throughout the project area (Kumwenda, 1992).

The reported study was mainly centred on the evaluation of the performance of the Downflow Roughing Filters (DRF) at the main water treatment works. However, the performance of the SSF has also been evaluated as an indicator of the performance of the DRF. The performance considerations made were both of operational and treatment nature.

OBJECTIVES

The specific objectives of this study, centred on the main treatment works out of the three existing plants of Mpira-Balaka scheme were:

1. To determine the efficacy of the modifications made to the Downflow Roughing Filters of Mpira Balaka Water Supply Project to date.

2. To evaluate the plant treatment performance before, during and after completion of the modifications.

3. To assess the operation and maintenance of the plant after modification of the RF. The filter run times of DRF and SSF and the cleaning efficiency were considered for this purpose.

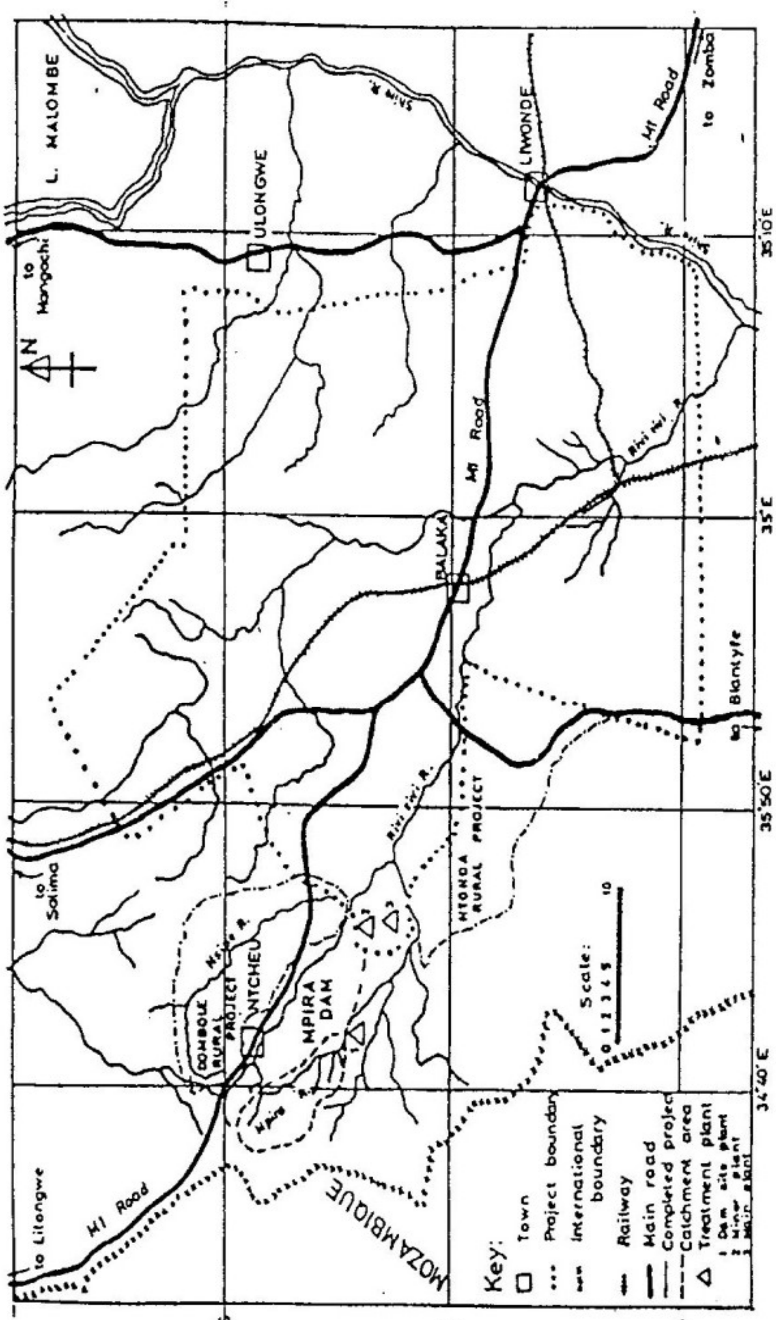

Fig.1 The geographical location of Mpira Balaka water supply project (Zulu,1993).

REVIEW OF THE PERFORMANCE OF ROUGHING FILTERS

Roughing Filtration (RF) is a process in which grains with a diameter of more than 1 mm are used to filter water in order to reduce the suspended solids quantity (Mbwette, 1986).

The theories of filtration in general, filtration mechanisms and purification processes involved are well documented in a number of literature (Amirtharajah, 1988; Bauman, 1988; Culp, 1974; Mbwette, 1991; Tebbutt, 1983).

On maintenance of RF, the importance of an efficient cleaning mechanism has been highlighted. According to literature (Pardon, 1989; Bauman, 1988; Amirtharajah, 1988 and Wegelin, 1988,), the hydraulic cleaning operation encompasses three stages

1. Destabilisation of the deposited solids from their resting positions in the filter bed.

2. Transport of the dislodged deposits through the porous bed to the underdrains.

3. Evacuation of the solids through the underdrains.

The destabilisation is a function of the scouring forces due to the cleaning velocity (V_c), the discharge flow (Q_d), the filter media size (d_g), the porosity of the bed (P_s) and the cohesion of the deposits (C_s). The volume of water available for the process is also important in that it can influence the duration of the cleaning process.

The transport of the re-suspended solids through the bed depends on the discharge flow (Q_d), the volume of water available (V_w), the vertical and horizontal distance to the underdrains, and the viscosity of the solids deposited at the bottom of the filter. The evacuation rate of the solids is dependent on the characteristics of the underdrainage system and the discharge rate.

Roughing Filters are classified according to the direction of flow, their location within the water supply scheme and to their main purpose of application (IRC, 1989). The main categories are:

a) Intake Filters
b) Dynamic Filters
c) Horizontal flow Roughing Filters (HRF)
d) Upflow Roughing Filters (URF)
e) Downflow Roughing Filters (DRF)

Intake filters are installed directly in small and narrow river beds (Wegelin, 1986). They consist of a small weir and different gravel layers installed upstream of the weir. For filter operation, the river is impounded at the weir. Part of the river flows through the filter into the intake pipe, the remaining water falls over the weir into the downstream river bed. For filter cleaning, the entire river flow is discharged through the bottom outlet downstream the river bed. The drained filter is cleaned manually. Its application is limited to small rivers discharging turbid waters only for short durations of time.

Dynamic filters are installed in canal beds for the purpose of capturing heavy silt loads. During filter operation, part of the canal water is filtered through a series of sand and gravel layers, the remaining water is returned to the river. Filter cleaning is carried out when the filter surface is sealed with deposited solids. The filter is cleaned by stirring the filter material. The accumulated solids are thereby re-suspended and washed back to the river, (Wegelin, 1991 and Galvis *et al*, 1992).

In Horizontal flow Roughing Filters (HRF), water runs from the inlet compartment in a horizontal direction through a series of differently graded filter material separated by perforated walls (Wegelin, 1991).
Upflow Roughing Filters (URF) are supplied with raw water at the filter bottom. Pre-filtered water collected at the top is brought to the bottom of the next filter compartment. For filter cleaning, raw water is stopped and each filter compartment undergoes individual filter flush.

Downflow Roughing Filters (DRF) are supplied with raw water at the top of the filter media. This then flows through the filter material to the under drain system. There, the pre-filtered water is collected and sent to the second, thereafter to the third filter compartment containing finer material. Filter cleaning is carried out hydraulically. Each filter section can be drained separately thus flushing out the accumulated solids by high velocity drainage.

RESEARCH AND FIELD EXPERIENCES

A vertical roughing filtration experimental rig was constructed and ran at Atarjea, Peru, between 1984 and 1985 and useful operational experiences were reported by Pardon, 1989.

A comparative study of different pretreatment (RF) options was reported to be under way in Cali, Columbia (Galvis *et al*, 1992). The experimental lines operated under similar conditions fed the different pretreatment alternatives. Downflow Roughing Filtration was among the alternatives being investigated. The water source was a polluted low-land river (Galvis, *et al*, 1992).

Further experiences in operation of RF have been reported from Peru (Wheeler *et al*, 1985 & Lloyd *et al*, 1986); Thailand in the early and mid 70's (Thanh *et al*, 1977); Scotland as early as 1804 and France as early as 1899 (Baker, 1981).

Literature on the general guidelines for the design of both pretreatment units and Slow Sand Filters (SSF) is readily available from different sources, (Graham, 1988; Huisman *et al*, 1974; Mbwette, 1986; Pardon, 1989; Van Dijk, 1982; Pescod, 1986). Parameters for both the design criteria and the design variables of RF have been well exposed (Wegelin, 1986; Wolters et al, 1989; Zulu, 1993).

Nonetheless, these design guidelines, having been the only ready-made solutions to pretreatment problems, have been applied in a number of rural water supplies in developing countries.

DESCRIPTION OF THE MPIRA-BALAKA TREATMENT PLANT

The main treatment works is situated 8 Km downstream of the Mpira Dam at an elevation of 114m below the spillway crest level of the Dam. Fig.2 show the overall layout of the main works while Fig.3 shows the perspective view of a typical modified DRF.

The main works has six Downflow Roughing Filters (DRF) and six Slow Sand Filters. The Design capacity of the SSFs is 128 litres per second.

The main treatment works will eventually have ten Downflow Roughing Filters (DRF) and ten slow sand filter units. Each Roughing filter is 20m long, 10m wide and 2.95m deep while each slow sand filter measures 50m long, 10m wide and 2.95m deep. The additional four filter units (DRF and SSF) were still under construction at the time of writing this paper.

The modifications made to the DRFs included:

a) Compartmentalisation of the filter box
b) Modification of the inlet pipe structure
c) Change of filter media and removal of the fabric originally installed
d) Increase of overall height of filter media
e) Introduction of a hydraulic cleaning mechanism
f) Inclusion of Vee-notch weirs at the inlet of the DRF
g) Removal of the existing underdrainage pipes in the DRF

METHODOLOGY OF DATA COLLECTION

The evaluation of the treatment plant performance is sub-divided into two groups; i.e operational and treatment. The time period over which the data was analysed has also been split into three intervals in relation to the modifications made to the DRF as follows:

Before Modification:	November 1988 to March 1991
During Modification:	April 1991 to March 1992
After Modification :	April 1992 to December 1992

By January 1991, all the six DRFs had already been commissioned and were running. The dates of commission of the modified Downflow Roughing Filters were as follows (Chaya, 1992):

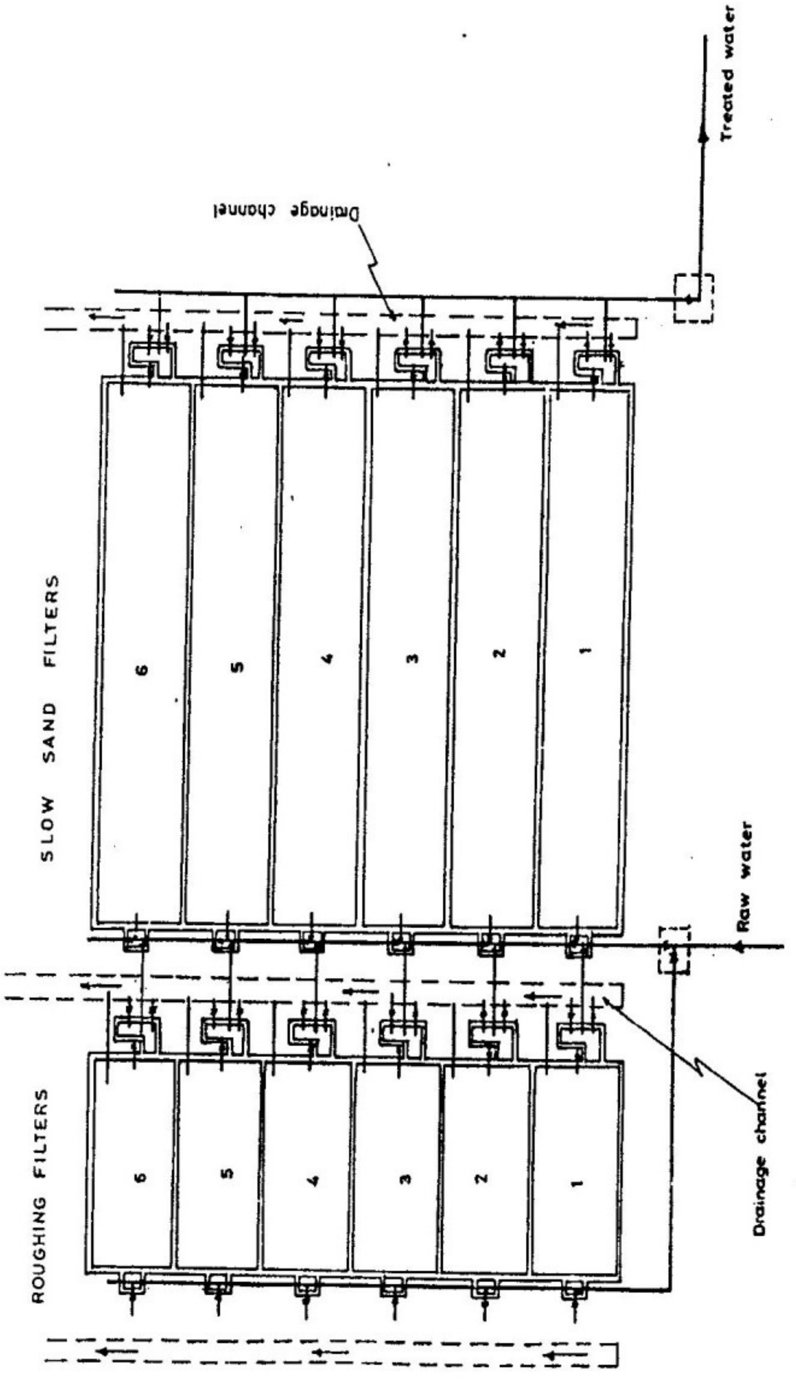

Fig.2 The layout plan of the main treatment plant of Mpira Balaka water supply project.

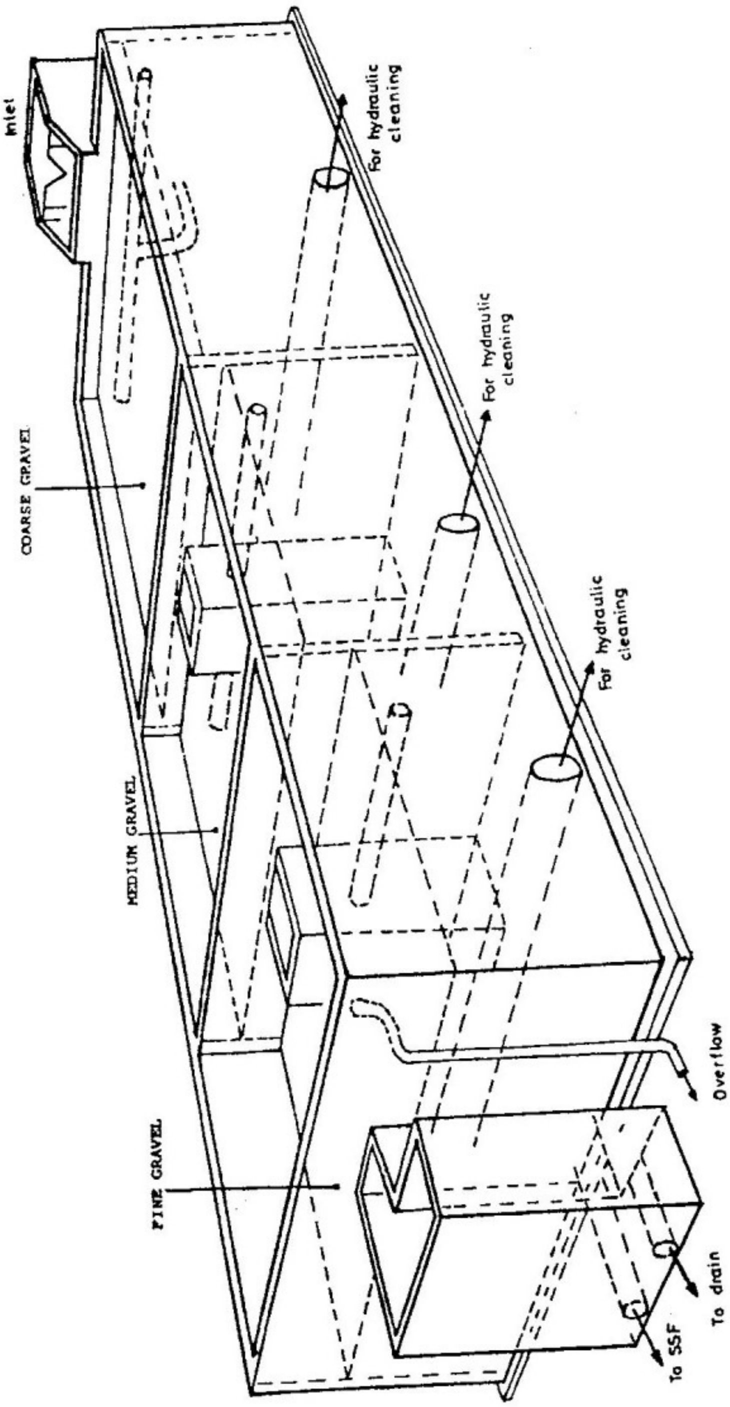

Fig.3 A perspective view of a typical modified DRF unit .

The water quality data reported in this study was obtained from four independent sources. Operational data was obtained from observational records on site (Kumwenda, 1992). The water quality parameters investigated, frequency of investigation and the participating laboratories have been presented in Table 2.

Table 1. Schedule of commissioning of the DRFs.

DRF No.	Date of Commission	DRF No.	Date of Commission
1	25th March, 1992	4	19th March, 1991
2	12th February, 1992	5	9th January, 1991
3	25th May, 1991	6	12th May, 1991

Table 2. Water quality parameters considered

No	PARAMETER	CWL	DKK	ICU	PROJ
1	Turbidity	-	-	-	3
2	Aluminium	1	1	1	-
3	Iron	1	1	1	2
4	Phosphorus	1	1	-	-
5	Sulphate	-	-	-	2
6	pH	-	1	-	3
7	Faecal Coliforms	-	-	-	3
8	Faecal Streptococci	-	-	-	3

Legend:

CWL - Central Water Laboratory, Lilongwe, Malawi
DKK - Koge Water Quality Institute, Denmark
ICU - Industrial Consultancy Unit, Zomba, Malawi
PROJ - Project Laboratory, Mpira-Balaka, Malawi
1 - Once a month
2 - Once a week
3 - Once a day

The standards, procedures and equipment used for the evaluation of the parameters in Table.2 have been elaborated elsewhere (Zulu, 1993).

DISCUSSION OF RESULTS

Operational Performance

The intervals between successive dates of SSF cleanings were determined by subtracting the number of days between the dates on which filter cleaning took place. Allowances were made to take into account the number of days when a slow sand filter was undergoing a long operational stop e.g. re-sanding.

Data on the operation and maintenance of the original roughing filter (only one RF was operational at the time of commissioning) was not available for this study. However it is on record that the RF was completely blocked within two weeks of initial operation (Kumwenda, 1992).

Table.3 shows the number of days between successive SSF cleaning, referred to as filter run times. Operationally, filter run time has increased from an overall mean of about 23 days prior to the modification to a mean of 58 days after the modification of the DRF. Fig.4 illustrates the change in slow sand filter run times prior to, during and after the modification of the DRF. The modification of the DRF was the main reason behind the observed improvement in operational performance of the SSF.

Table.3 Comparison of slow sand filter mean filter run times prior to, during and after modification of the DRF.

Period	Mean filter run time (days)						Overall Mean
	SSF1	SSF2	SSF3	SSF4	SSF5	SSF6	
Prior	16.3	20.7	19.0	-	28.5	28.3	22.6
During	21.4	19.4	25.4	36.5	27.8	38.9	28.2
After	40.4	87.0	48.0	64.3	51.5	58.4	58.3

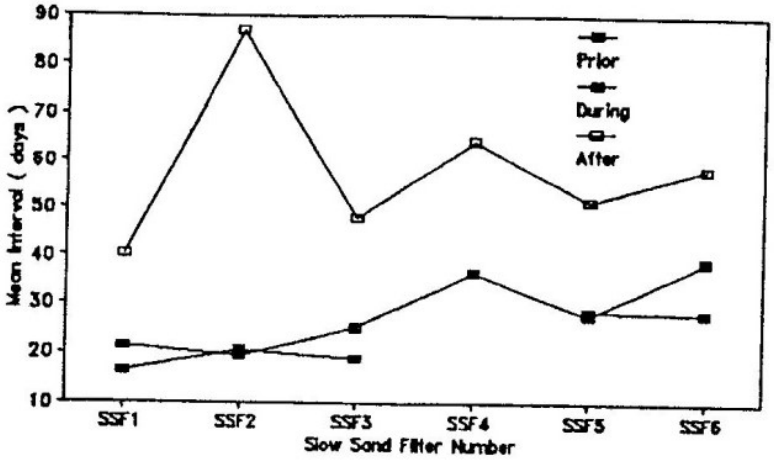

Fig. 4 Frequency of SSF cleaning prior to, during and after the modification of the DRF.

TREATMENT PERFORMANCE

Evaluation of the treatment performance of the plant was based on scrutinization of five chemical water quality parameters, one physical and two bacteriological water quality parameters. Chemical water quality parameters included Iron, Aluminium, Sulphate, Phosphorus and pH, while bacteriological ones consisted of Faecal Coliforms and Faecal Streptococci. Turbidity represented the physical water quality parameters.

Graphs of monthly mean values of the chemical, physical and bacteriological water quality parameters have been plotted following the earlier described manner of sub-division into prior to, during and after DRF modification. A brief comparison of the findings with both the Malawi Rural Drinking Water Standards (Design Manual, 1990) and the WHO guidelines (WHO, 1984) has also been made.

PHYSICAL PARAMETERS

Amongst the physical water quality parameters investigated, turbidity data was the most diverse. Turbidity data was available for the period from January 1991 to December, 1992.

Monthly mean values of turbidity as evaluated at the project laboratory between January 1991 and December 1992 for the period prior to, during and after the modification of the RF are shown in Fig.5. For both Raw and SSF filtrate, one can observe a significant progressive drop from prior to through to after modification of the DRF. The mean raw water turbidity values prior to, during and after the modifications were 196 NTU, 38 NTU and 16 NTU, respectively. Likewise, the mean turbidity of the SSF filtrates showed progressive decrease to 124 NTU, 18 NTU and 2 NTU for the periods prior to, during and after modification of the DRFs, respectively. These values are well within both the WHO guidelines (WHO, 1984) and the Malawi Temporary Rural Water Standards, (see Table.4).

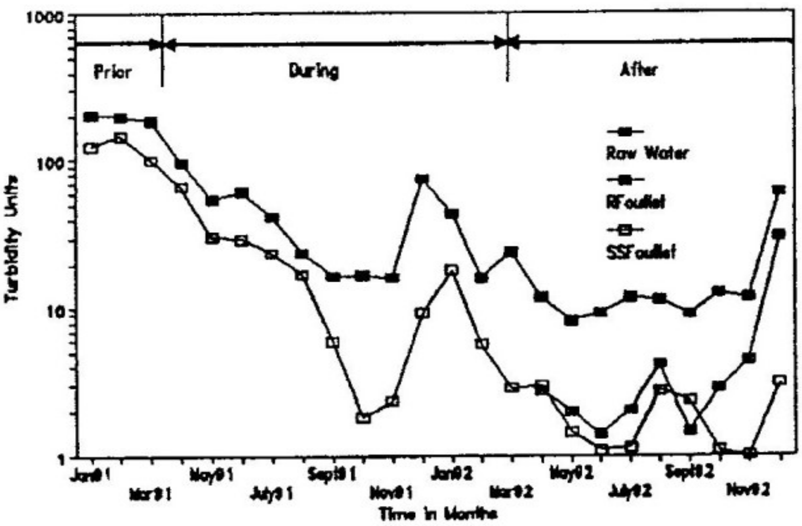

Figure 5 Variation of Turbidity Prior to, During and After the modification of the DRF

Table 4. Overall mean turbidity values and removals

Turbidity			
Period	Raw (NTU)	SSF outlet (NTU)	% Removal
Prior	196.66	123.95	36.97
During	38.51	17.82	53.73
After	16.29	1.89	88.40

Turbidity removals on the other hand give a clearer picture of the effect of the modified DRFs. Table.4 and Fig.6 show the turbidity removals. Mean monthly turbidity removals prior to, during and after modifications to the DRF were 37%, 54% and 88%, respectively.

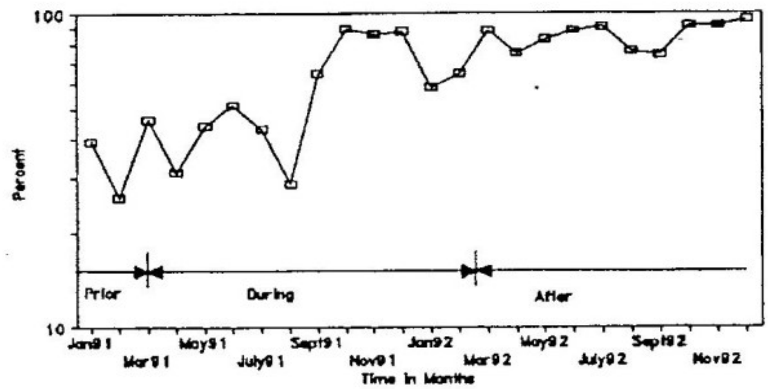

Figure 6 Mean Monthly Overall Turbidity Removal

CHEMICAL PARAMETERS

Table.5 gives a summary of the observed chemical water quality parameters during the three relevant periods. A brief comparison of the mean SSF filtrate values obtained in this study with WHO guidelines for drinking water quality and the Malawi Temporary standards (Design Manual, 1990) indicated in Table.6 leads to the following observations with regard to chemical water quality parameters:

Table.5 Chemical water quality parameters

Period	Iron		Aluminium		Sulphate		Phosphorus		pH	
	Raw	SSF	Raw	SSF	Raw	SSF	Raw	SSF	Raw	SSF
Prior	0.40	0.24	23.48	2.696	8.77	4.57	0.354	0.160	6.75	7.36
During	0.07	0.12	2.29	1.47	3.68	3.51	0.135	0.069	6.70	6.86
After	0.05	0.01			2.63	2.56			7:31	7.06

Chemical Water Quality Parameters

Table 6 Comparison of Mpira-Balaka mean SSF filtrate values with WHO and Malawi temporary rural water standards.

No.	PARAMETER	UNITS	WHO	MALAWI	MPIRA
01.	Turbidity	NTU	5	25	2
02	pH		6.5 - 8.5	6.6 - 9.5	6.6 - 8.36
03	Sulphate	mg/1	400	600	2.67
04	Aluminium	mg/1	0.2	2	4.4
05	Iron	mg/1	0.1	-	0.057
06	Phosphorus	mg/1	-	-	.069

SULPHATE

Overall mean values of Sulphate for the raw water and SSF filtrates as recorded by the project laboratory for the periods prior to, during and after the modification of the Roughing Filters are presented in Table 5. Fig.7 shows the variation of Sulphates during the three periods considered.

The overall mean for Sulphate recorded over the three periods was 2.67 mg/l compared to 400 mg/l and 600 mg/l stipulated by the WHO and the Malawi Rural temporary water quality standards, respectively.

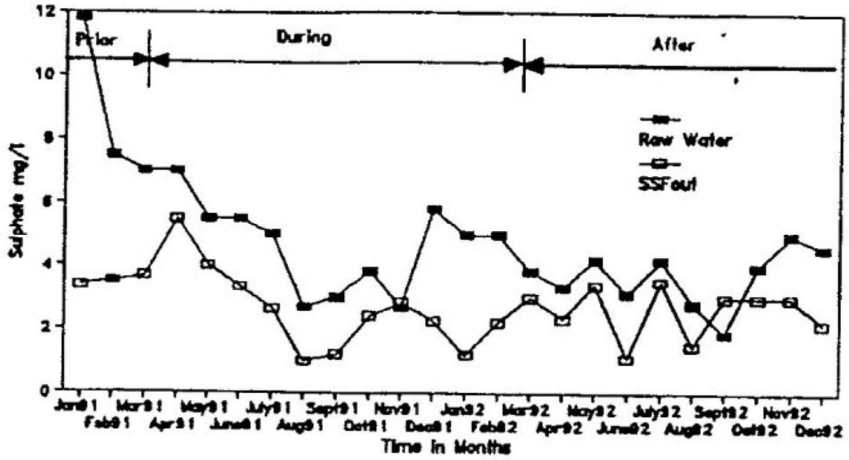

Figure 7 Variation of Sulphate prior to, during and after the modification the DRF (Proj.data)

Throughout the three periods of prior to, during and after the modification of the DRF, the monthly mean value of Sulphate in the SSF filtrate has been consistently lower than in the raw water (Fig.7).

TOTAL IRON

Iron may be present in many waters in varying quantities depending upon the geology of the area and other chemical components along the water course.

Overall mean values of Iron for the periods prior to, during and after the modification of the DRF are presented in Table 5.

The values of Iron from all the four laboratories were not in total agreement with each other for the same samples. This may be partly due to the differences in what was being determined, i.e Fe^{2+}, Fe^{3+} or total Iron.

Fig.8 shows the variation of Iron prior to, during and after the modification of the DRF using data from the project laboratory.

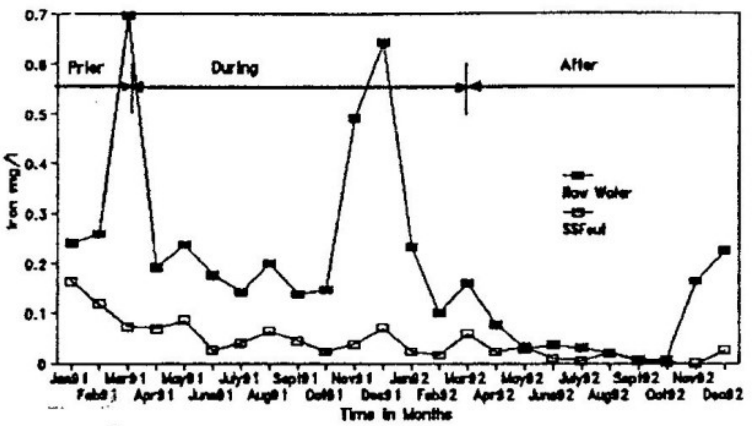

Figure 8 Variation of Iron prior to, during and after the modification of the DRF (Proj- Data)

TOTAL PHOSPHORUS

Table.5 gives the overall mean total Phosphorus content prior to, during and after the modification of the DRF, while Fig.9 shows the mean monthly variation of total Phosphorus as reported by DKK.

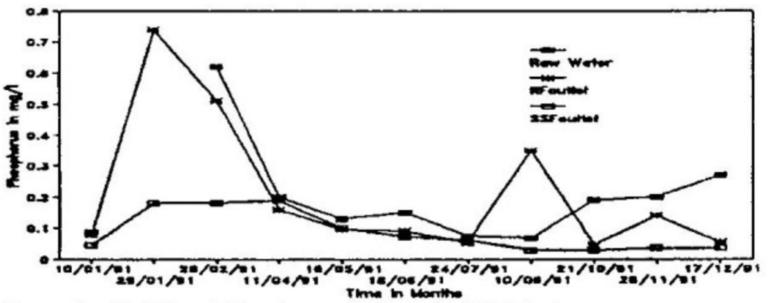

Figure 9 Variation of Phosphorus with Time (DKK Data)

Both the Malawi Temporary Standards and the WHO guidelines have not specified values for Phosphorus. However, the mean of both Iron and total Phosphorus in the SSF filtrate decreased substantially during the period of modification of the DRF when this parameter was monitored. The mean value of total Phosphorus prior to and during the modification of the DRF was about 0.14 mg/1 and 0.07 mg/1, respectively.

ALUMINIUM

Aluminium is the earth's most abundant metal and is present in natural waters from contact with rocks, soil and clay. Table.5 shows the overall means prior to and during the modification of the DRF as analysed by DKK. Fig.10 shows the variation of Aluminium prior to and during the modification of the DRF.

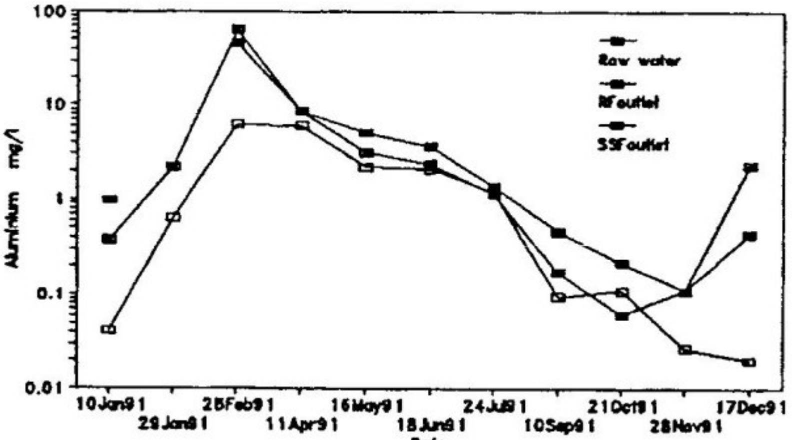

Figure 10 Variation of Aluminium with Time

During the period prior to modification, Aluminum values as high as 63 mg/1 were recorded at the RF outlet on (28/2/91). The SSF filtrate for the same date was only 6.2 mg/1 which happens to be the highest recorded. Despite the 90% reduction by the SSF, 6.2 mg/1 was above both the WHO Guidelines and the Malawi temporary rural water standards of 0.2 mg/1 and 4.4 mg/1, respectively. Prior to modification, the mean of the SSF filtrate was 2.3 mg/1 while during the modification period the same was only 1.48 mg/1 which already indicated some notable improvement in the treatment performance.

pH

pH is an important factor in the chemical and biological systems of natural waters. The degree of dissociation of weak acids or bases is affected by changes in pH.

pH in the Mpira-Balaka water ranged between 6.6 and 8.36 in the 2431 samples analyzed. This range is well within the ranges specified by both the Malawi rural temporary standards and the WHO guidelines.

Overall pH values as recorded by the Project Laboratory during and after modification are recorded in Table 5. Fig. 11 shows the mean monthly variation of pH prior to, during and after the modification to the DRF.

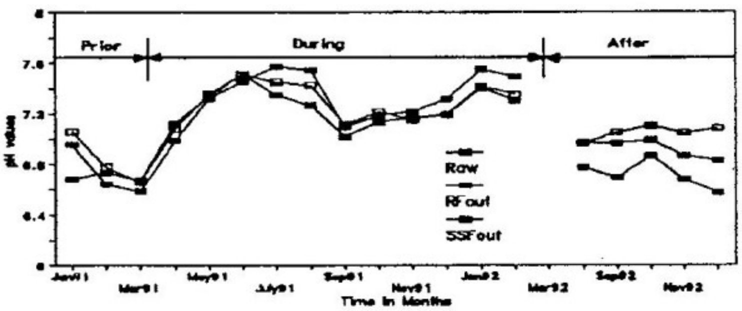

Figure 11 Variation of pH prior to, during and after the modification of the DRF

BACTERIOLOGICAL WATER QUALITY

In conventional water bacteriology, there are three main groups of bacteria used as faecal indicators. These are: (i) coliform bacteria, (ii) the faecal streptococci, (iii) and the aerobe, *Clostridium perfringes.*

Faecal streptococci includes species unique to animals *(Streptococcus bonus* and *S.faecium)*, other species with a wider distribution occurring in both man and animals as well as other types that appear to be ubiquitous occurring in both polluted and unpolluted environments (Feachem *et al*, 1980). The Project Laboratory at Mpira-Balaka uses the first two methods.

FAECAL COLIFORM

Faecal Coliform counts for Raw water, RF outlets and SSF filtrates as recorded at the project laboratory from January 1991 to December 1992 were analysed. Table.7 shows the overall means while Fig.12 shows the trend of Faecal Coliforms prior to, during and after the modification of the prefilters.

Table.7 Overall mean of Faecal Coliform and Faecal Streptococci prior to, during and after the modification of the DRF (No./100 ml)

Period	Faecal Coliforms		Percent Removal	Faecal Streptococci		Percent Removal
	Raw	SSF		Raw	SSF	
Prior	333.9	76.1	77.21	179.2	75.8	57.71
During	33.6	3.5	89.58	31.8	13.9	56.29
After	37.5	7.2	80.8	1.7	1.4	17.65

It can be observed that during the modification, as well as into the first half of the period after the modification of the DRF, the treatment plant produced a filtrate of an acceptable quality i.e. below 1 No./100ml during most of the time (see Fig. 12).

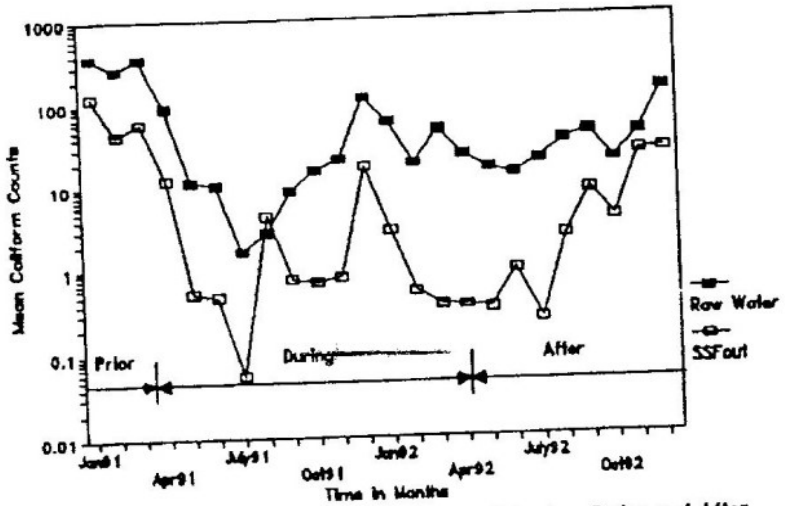

Figure 12 Variation of Faecal Coliform Counts Prior to, During and After the Modification of the DRF (Proj-Data)

FAECAL STREPTOCOCCI

Overall mean values of Faecal Streptococci counts as established by the Project Laboratory from January 1991 to December 1992 for Raw water inlet, RF outlets and SSF filtrates are given in Table 7. Fig.13 shows the variation of Faecal Streptococci prior to, during and after the modification of the pre-filters.

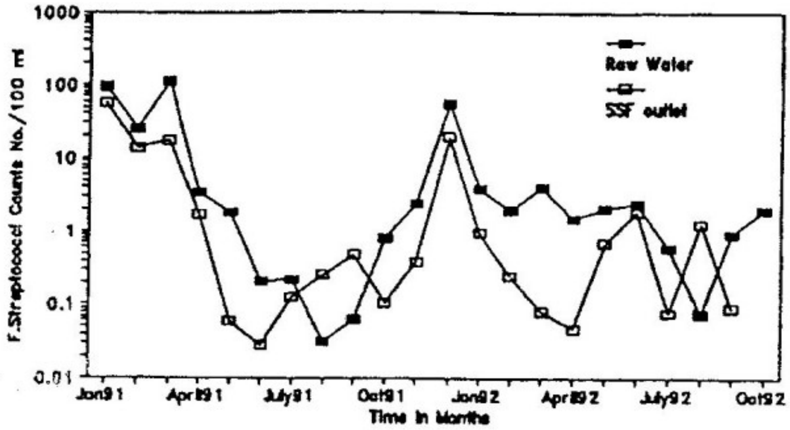

Figure 13 Variation of Mean Monthly Faecal Streptococci Counts Prior to, During and After the modification of the DRF (Proj. Data)

CONCLUSIONS

The following conclusions can be made from this study:

1. The modified DRF have improved the overall treatment performance of the main plant of Mpira-Balaka project.

2. Operationally, SSF run times (days) have increased from a mean of about 23 days prior to the modification of the DRF to a mean of 58 days. This means the operational workload has been more than halved as a result of the modifications to the DRFs.

3. Some bacteriological pollution incidences still occur at the treatment plant.

RECOMMENDATIONS

1. Further study of the performance of the DRF, URF, and HRF systems already constructed at Mpira Balaka is recommended in order to compare their performance directly.

2. Further training of staff in health and hygiene education is necessary to avoid the observed water pollution.

3. The SSF cleaning and sampling procedures should be monitored more closely in order to track the source of the observed apparent post-treatment pollution.

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