THE PERFORMANCE OF A HORIZONTAL FLOW ROUGHING FILTER/SLOW SAND FILTER WATER TREATMENT PLANT IN TANZANIA.

By

MBWETTE ,T.S.A. ; B.Sc.,Dip. S.E.,M.Sc.,DIC,Ph.D.,MIET*
and
KARIUKI ,A.W, ; B.Sc., M.Sc.**

ABSTRACT

The performance of a water treatment plant comprising of the Horizontal flow Roughing Filter (HRF) / Slow Sand Filter (SSF) system was evaluated by monitoring the water quality of the inlet water and the plant filtrates for a period of two months. Improper operational procedures and the absence of adequate maintenance of the plant was found to have resulted to relatively low removal efficiency. This subsequently improved as a result of plant rehabilitation and introduction of new operational procedures and became comparable to the performance of HRF/SSF plants documented in literature. For example, as a result of the changes introduced, the mean overall plant removal efficiency of apparent colour, turbidity and *Faecal Coliforms* increased from 23.1, 43.1 and 79.7 %, respectively to 58.7, 69.3 and 97.8 %.

The increase in the total hardness of the HRF filtrate observed was possibly caused by the partial dissolution of the filter media in the HRF. The authors recommend that careful selection of the filter media for HRF is necessary in order to avoid or minimize such incidences. This study also showed that adequate knowledge and skills of the plant caretaker is crucial to the successful operation of HRF/SSF plants especially those operating at declining rate of filtration.

**Senior Lecturer in Environmental Engineering, University of Dar-es-Salaam, Department of Civil Engineering, P.O. Box 35131, Dar-es-Salaam, TANZANIA.*

***Current Adress: P.O. Box 488, Gatundu, KENYA .*

INTRODUCTION

The use of modern gravel roughing filters and Slow Sand Filter (SSF) systems for water treatment in rural areas is a fairly recent development. Horizontal flow Roughing Filters (HRF) / Slow Sand Filters (SSF) systems have been used since the mid 1970's in Thailand[1], early 1980's in Tanzania[2] and mid 1980's in S.America[3]. However, coarse media roughing filters have been used in groundwater recharge in the 1960's in Germany[4]. The other two types of roughing filters that have been used in rural areas in conjunction with SSF are upflow and downflow roughing filters.

HRF were primarily developed as a simpler alternative to conventional coagulation/clarification systems to reduce impurities in turbid water prior to Slow Sand Filtration[5,6]. The subsequent application of HRF as pre-filters has been found to prolong the SSF filter run time substantially[7,8]. A typical HRF is a box consisting of three compartments separated by perforated walls. These contain graded gravel decreasing in size from 25 to 4 mm [9] sequentially in the direction of water flow. Filtration velocities applied are in the range of 0.5 to 2.0 m/h and mean turbidity removals of at least 50% can be achieved in HRF[8,10,11].

The efficacy of the use of SSF in potable water treatment is well documented in literature[7,8,10,12,13]. SSF can be operated at either constant or declining rate of filtration[14,15]. The former is favoured due to the better and more uniform performance expected, smaller filtration area requirements and simpler operational procedures. In both cases, the filtration velocities should lie in the range of 0.1 - 0.2 m/h [14-16]. In literature, 80-90 and 90-99% reduction in turbidity and *Faecal Coliforms*, respectively have been reported[7,8,10,16]. The sand characteristics is also crucial to the performance of SSF. The sand effective size (d_{10}) should lie between 0.15 to 0.35mm and the coefficient of uniformity (d_{10}/d_{60}) should generally be less than 3. However, its useful to note that the control of the latter is not very crucial in practise if the former is observed[2,16]. This paper presents a summary of the findings of a recent evaluation of the Tanzania National Electricity Supply Company (TANESCO) Tagamenda HRF/SSF water treatment plant. The plant is located some 500 Km. South West of Dar-es-Salaam in Tanzania (see Fig.1) . It treats water for the electricity sub-station cooling and for domestic use of the small community working and living at the TANESCO sub-station. The water treatment plant is the only HRF/SSF system in Tanzania whose mode of operation of the HRF is intermittent and that of the SSF is of declining rate type.

OBJECTIVES

The overall objective was to evaluate the performance of the treatment plant mainly on the basis of the improvement of the water quality. The specific objectives of the study

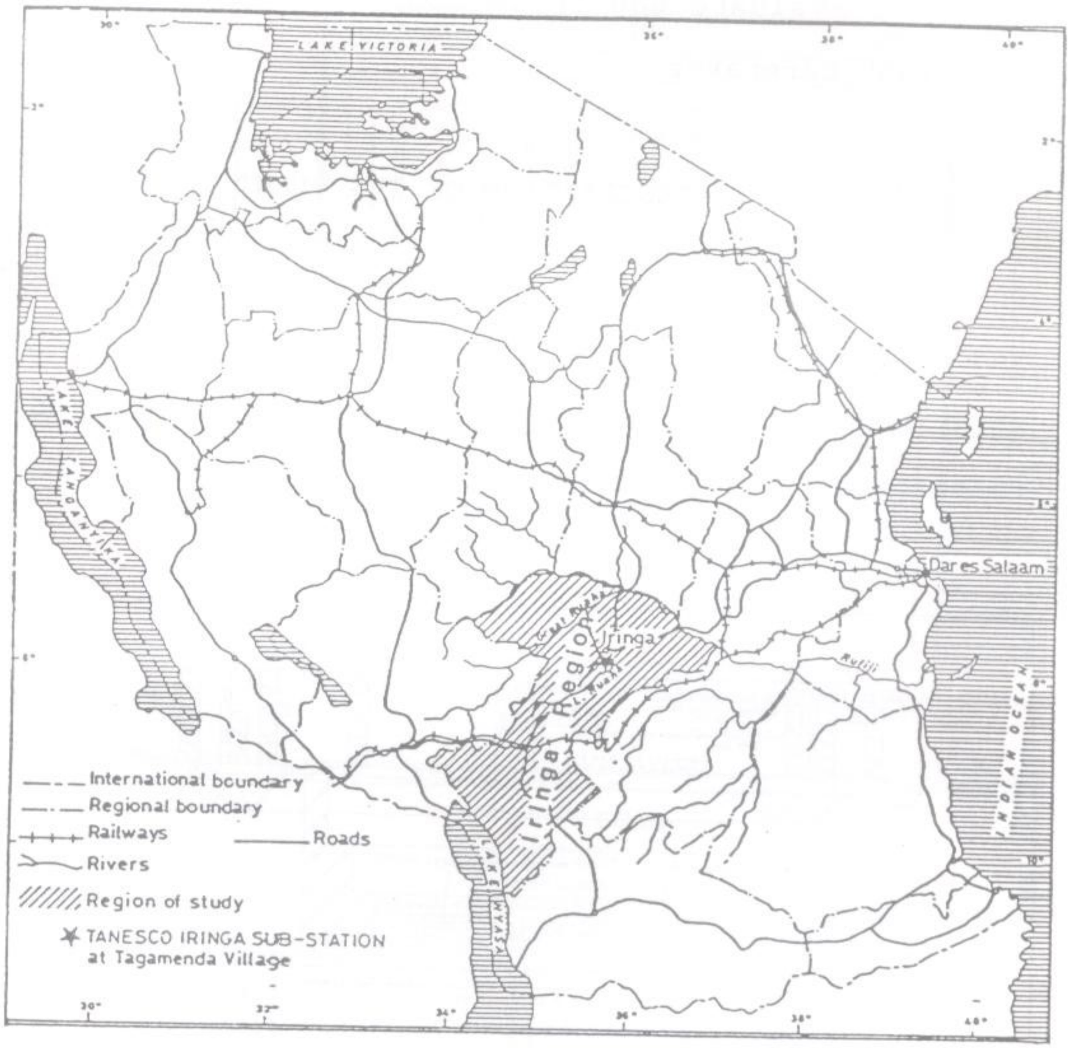

Fig.1 The Location Map of The TANESCO Tagamenda Plant.

were as follows:

(i) To analyze the water quality of the inlet water and the filtrates.

(ii) To assess the filter media characteristics and grain composition of both the HRF and SSF units.

(iii) To evaluate the operational procedures followed by the plant caretaker.

DESCRIPTION OF THE PLANT

The treatment plant consists of a single HRF and SSF unit and a 30 m^3 capacity clear water reservoir. Figs. 2 and 3 show the layout plan and section of the HRF and SSF, respectively. The inlet water is pumped from the river

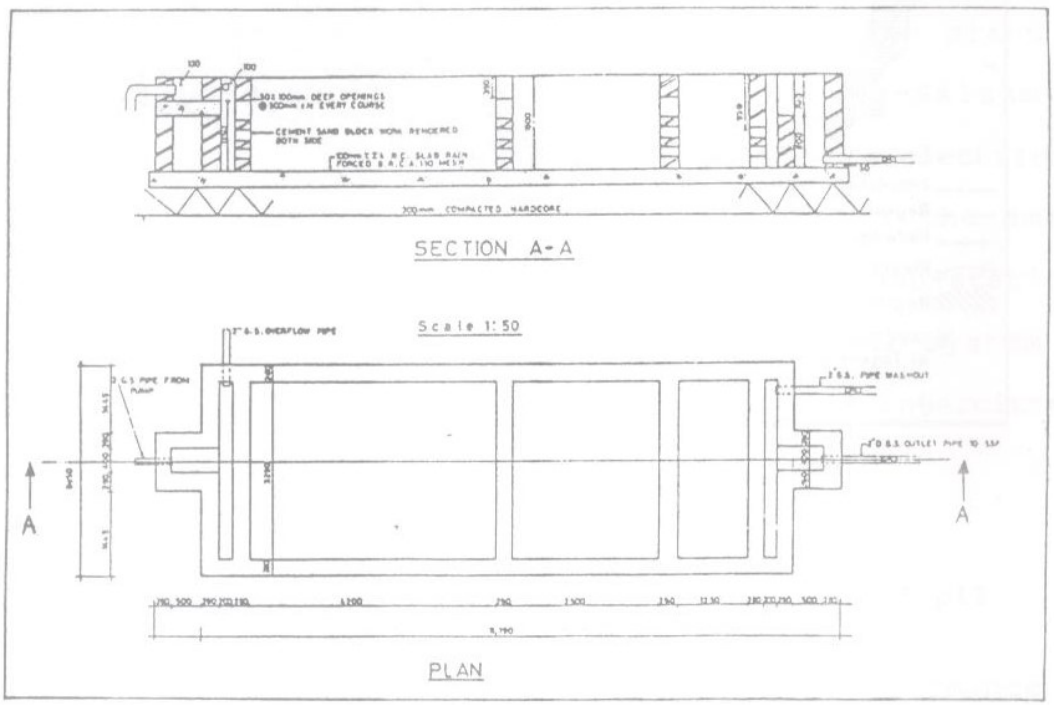

Fig.2 The Layout Plan and Section of the HRF unit .

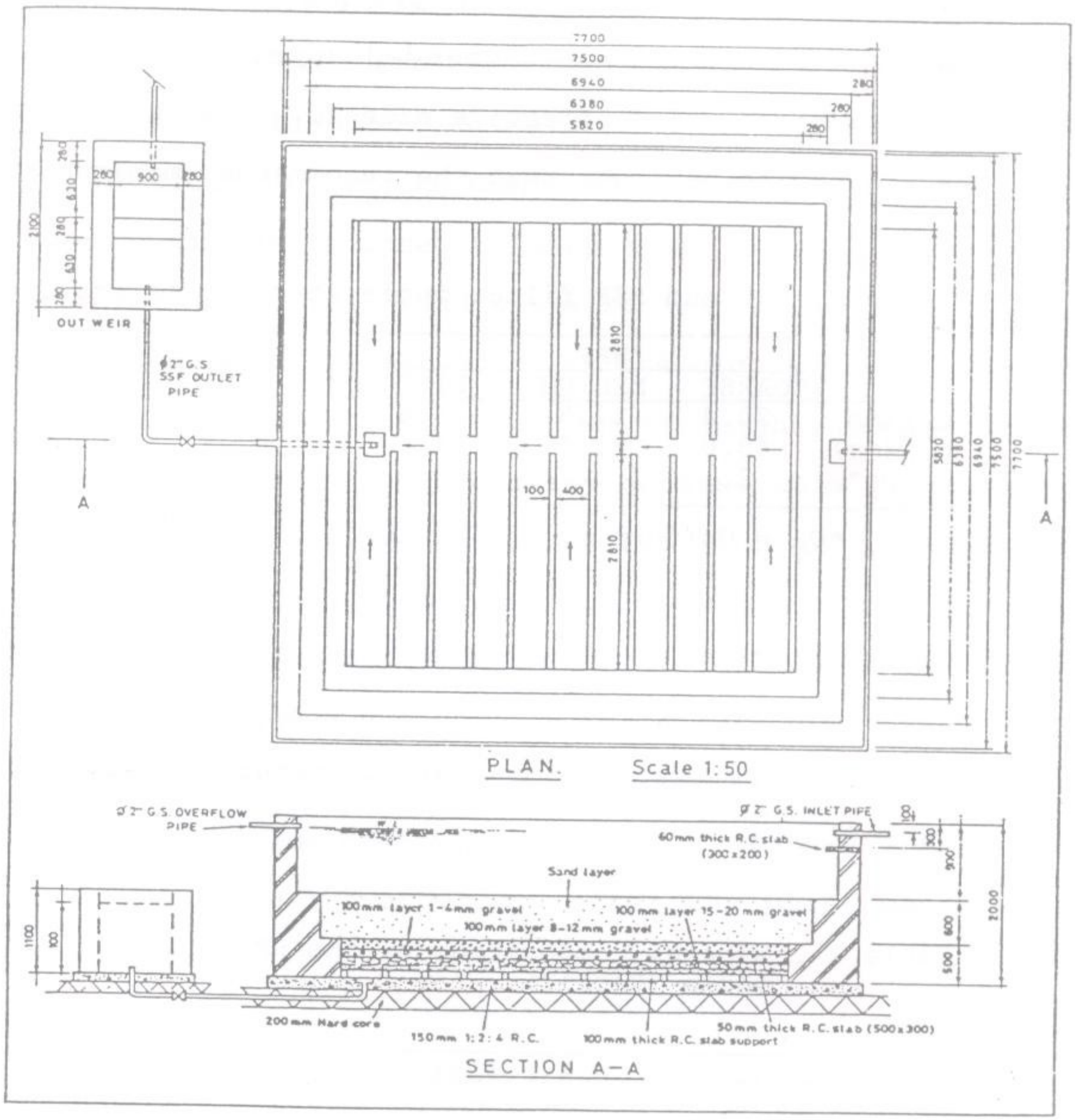

Fig.3 The Layout Plan and Cross Section of The TANESCO Tagamenda plant SSF Unit.

Little Ruaha directly into the HRF inlet structure. Flow through the plant units to the clear water reservoir and the distribution system is by gravity. The sieve analyses of the HRF and SSF media are given in Table 1 . The upper limit of the gravel size for the HRF was not in conformity with the currently recommended upper limit of about 25 millimetres[9]. The effective size (d_{10}) of the old SSF sand was found to be finer than the recommended minimum size.

Table 1. HRF and SSF filter media characteristics (Ref.17)

	HRF			SSF	
	COARSE	MEDIUM	FINE	OLD	NEW
d_{10} (mm)	20.4	17.5	4.6	0.129	0.260
d_{60} (mm)	43.0	29.6	11.2	0.321	0.742
U_c*	2.1	1.7	2.5	2.5	2.85

*U_c = Uniformity Coefficient.

The evaluation of the mineral composition of the HRF and SSF media from X-ray diffraction analysis and observation of thin rock sections in the Laboratory is summarized in Table 2.

Table 2 . Mineral composition of the HRF and SSF media (Ref.17)

Unit	Media	Classification	Major Minerals
HRF	Coarse & Medium	Gravel	Quartz, Feldspar, Plagioclase,Calcite Dolomite(Calcium Alkaline rock)
	Fine	Gravel	Hornblende, Quartz, Biotite,Garnet & Feldspar.
SSF	Fine	Sand	Quartz, Plagioclase, Haematite,Feldspar.

CONDUCT OF FIELD TESTS

The field tests were carried out between mid-February and mid-April 1991 in two phases. The first phase was the period prior to the plant rehabilitation while the second phase comprised of the period after subsequent plant rehabilitation. During plant rehabilitation, the SSF walls were repaired in order to stop some leakages observed in the SSF unit. New sand was also introduced into the SSF after scraping the top 20 mm of the old sand. In the HRF, the fine fraction was removed and thoroughly cleaned before refilling. This was necessary because this fraction was only partially filled initially and a lot of deposits were collected on top of the gravel as a result of sedimentation of suspended matter. The other two fractions were cleaned within the filter bed by flushing from the top. It is useful to note that the HRF in this plant has no provision for fast routine drainage of the water which was adopted as a standard design accessory after the plant was already constructed.

The water quality parameters were monitored according to the standard methods[18]. Table 3 summarizes the parameters analyzed and the methods of analysis used. Detailed procedures of analysis can be found elsewhere[17]. The filtration velocities and daily operation of the HRF and SSF were also recorded.

Table 3 . Water quality parameters monitored and analysis methods.(Ref. 17)

Classification	Parameter	Methods of analysis
Physical	.Turbidity	Paqualab EL430-257 meter
	. Apparent colour	Hellige Neo-comparator with two 250 mm Nessler tubes.
	. Filterability	By filtration of water through Schleicher &Schull paper No.595 /604 .
Chemical	. pH	Paqualab EL 430-010 meter
	. Total Hardness(mg/l)	Analytical, EDTA soln.
	. Total Alkalinity(mg/l)	Analytical, titration with 0.02 N HCl soln.
Bacteriological	.*Faecal Coliforms*	Membrane Filtration

RESULTS

PLANT OPERATION

The average daily HRF and SSF operation times and filtration rates before and after rehabilitation are given in Table 4 .

Table 4. Average HRF/SSF operation times and filtration rates.

	Before Rehabilitation		After Rehabilitation	
	HRF	SSF	HRF	SSF
Operation time (Hours)	3.5	3.0*	4.2	24.0**
Filtration rate (m/h)	1.59	0.16	1.69	0.06-0.01

* Intermittent ** Declining rate

Thus, before rehabilitation of the plant the caretaker was operating the SSF intermittently contrary to the recommended operation procedures[14,16]. Due to this, the average SSF filtration rate was higher . After rehabilitation, the filtration rates were kept below the allowable upper limits. The HRF average filtration rate increased slightly after rehabilitation but still remained well below the recommended upper limit of 2.0 m/h.

TURBIDITY

Fig.4 shows the variation of turbidity in the plant while Tables 5 and 6 give a summary of the turbidity data and the percentage removals, respectively at the different treatment stages. From the data, it can be observed that

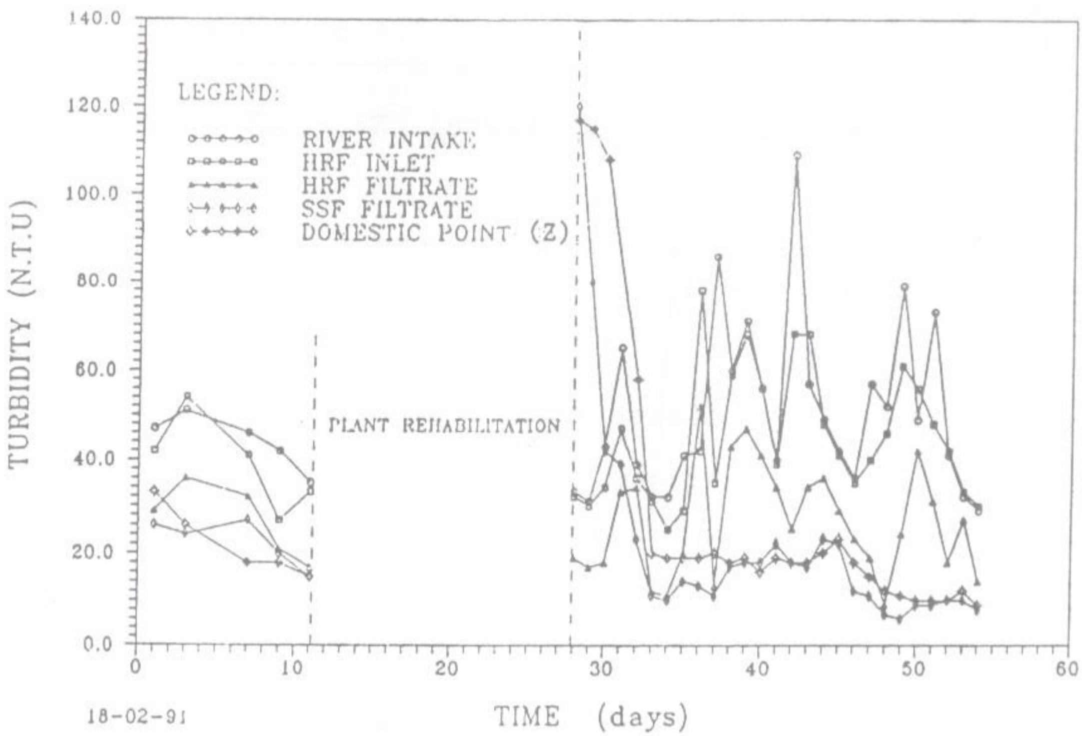

Fig.4 Turbidity Changes At Different Treatment Stages.

the mean removal efficiencies of the individual units and the plant as a whole improved substantially after rehabilitation, especially the SSF unit (Table 6). Immediately after rehabilitation, the SSF filtrate turbidity was higher than the HRF filtrate (see Fig.4) due to the residual dust in the new sand introduced in the SSF.

Table 5. Summary of Turbidity and Apparent colour

Parameter	Level	Before Rehabilitat.			After Rehabilitat.		
		HI	HF	SF	HI	HF	SF
Turbidity (NTU)	Min.	27	17	15	25	9	6
	Max.	54	32	27	78	52	23
	Mean	39.4	25	22.4	45.4	26.9	13.9
Apparent colour (mg Pt/l)	Min.	100	80	80	125	80	40
	Max.	125	90	80	>150	150	90
	Mean	105	82	80	126.3	100.2	62.2

HI = HRF inlet, HF = HRF filtrate, SF = SSF filtrate.

APPARENT COLOUR

Fig.5 and Table 6 indicate that there was a considerable improvement in apparent colour removal after plant rehabilitation. Again the biggest improvement in performance was by the SSF unit. As with turbidity, immediately after rehabilitation the SSF filtrate apparent colour was higher than the same for the HRF filtrate because of the residual impurities in the new sand.

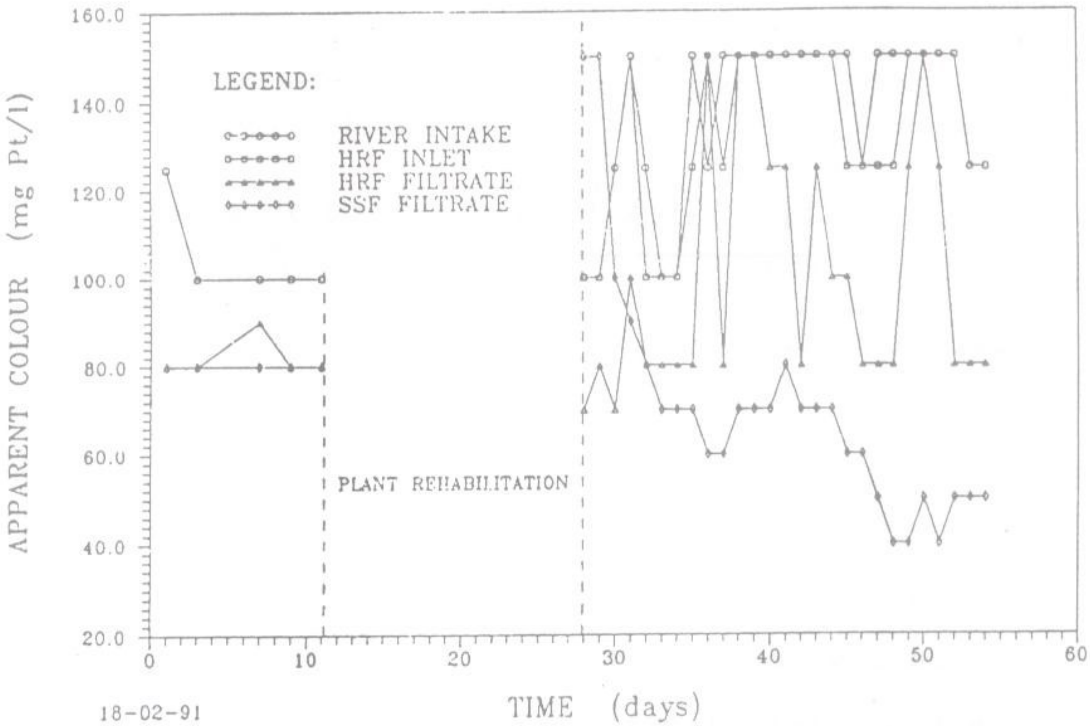

Fig.5 The Apparent Colour Changes At Different Stages.

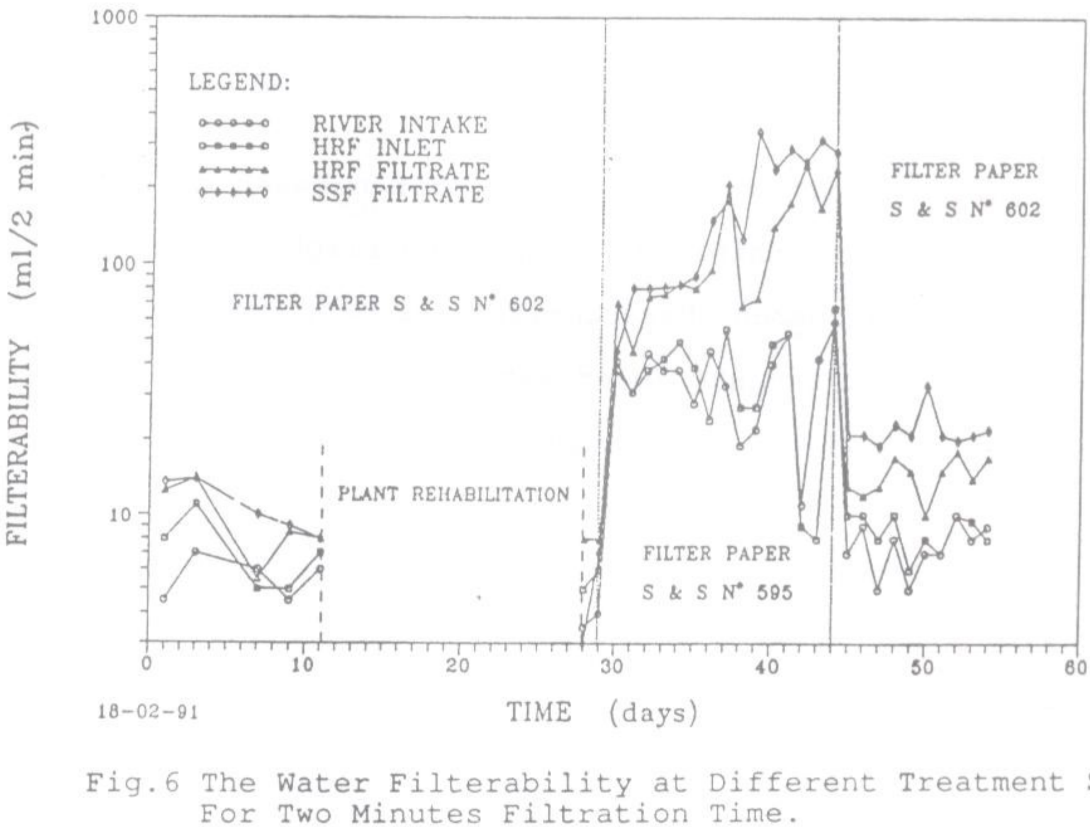

Fig.6 The Water Filterability at Different Treatment Stages For Two Minutes Filtration Time.

Table 6. Mean percentage removal of Turbidity and Apparent colour.

Parameter	Before Rehabilitation			After Rehabilitation		
	HRF	SSF	Overall	HRF	SSF	Overall
Turbidity	36.5	6.6	43.1	40.7	28.6	69.3
Apparent colour	21.2	1.9	23.1	20.7	38.0	58.7

FILTERABILITY

From Fig.6, the filterability curves for two minutes filtration time generally showed a trend of increase along the treatment plant. Moreover, this became even more distinct with increased filtration time especially after the plant rehabilitation for the HRF and SSF filtrates. Note that two different types of filter papers were used.

pH

From Fig.7 it can be observed that between days 40 and 51 the filtrate exhibited an enhanced slightly alkaline trend which is a common characteristic of most mature SSF[10]. The mean pH for the HRF inlet water, HRF and SSF filtrates was 7.5, 7.5 and 7.7, respectively.

TOTAL HARDNESS

From Fig.8 and Table 7 it can be observed that there was some increase in the total hardness of the water after passage through the HRF. The mean removal by the HRF, SSF and the whole plant were -56.9, 37.9 and -19 %,

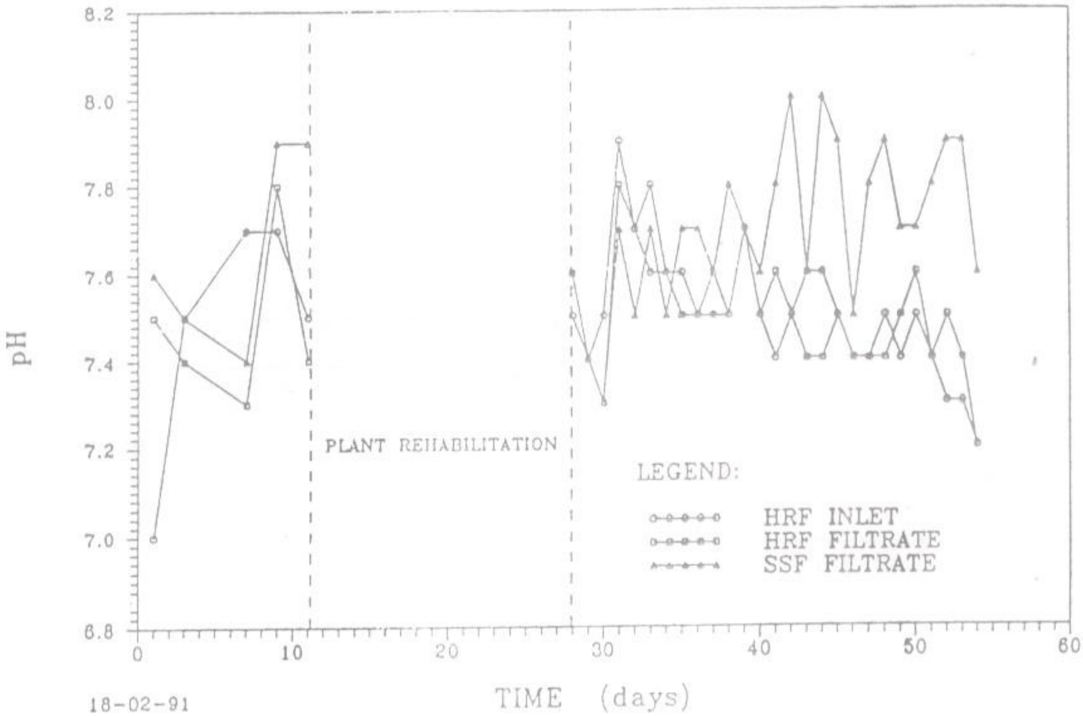

Fig. 7 pH Changes At Different Treatment Stages .

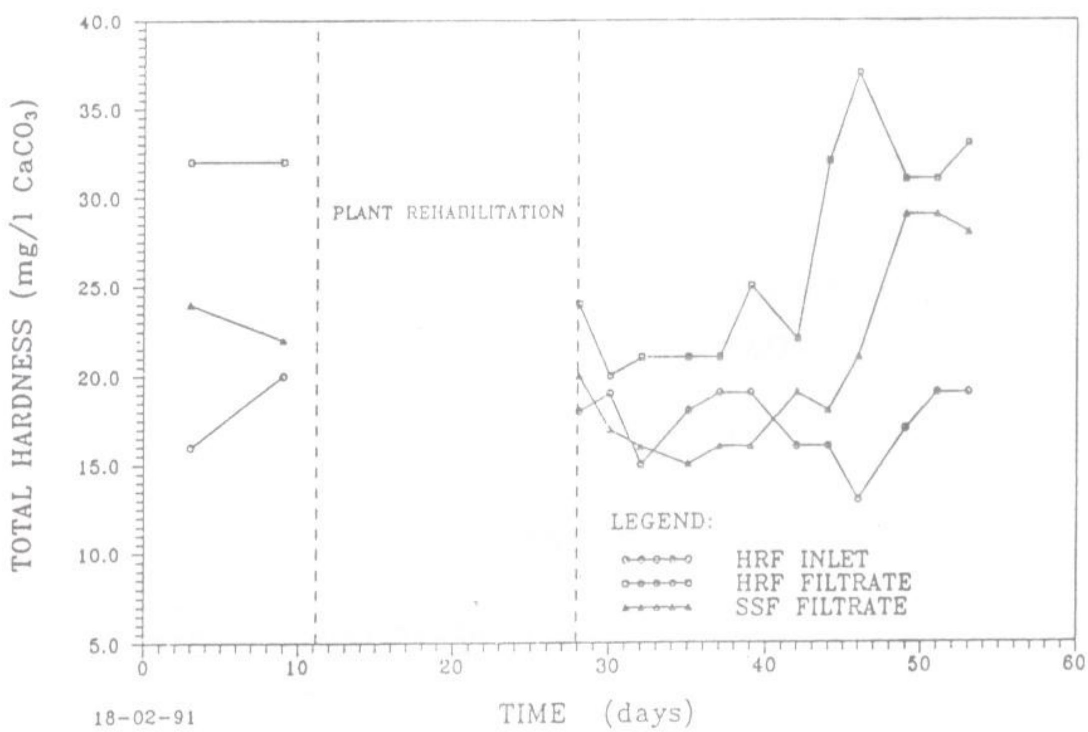

Fig. 8 Total Hardness Changes At Different Treatment Stages.

respectively . Thus there was a net increase in total hardness of the plant filtrate although it still remained soft (i.e < 50 mg $CaCO_3$/l) and potable.

Table.7 Summary of Total Hardness data mg$CaCO_3$/l

	HRF Inlet	HRF Filtrate	SSF Filtrate
Min.	13	21	15
Max.	20	37	29
Mean	17.4	27.3	20.7

FAECAL COLIFORMS

From Fig.9 and Table 8, it can be observed that there was a general trend of reduction in *Faecal Coliform* levels in the different treatment stages. However, from Table 8 it is evident that there was a significant improvement in bacteriological removals after plant rehabilitation . While before rehabilitation, the HRF and SSF filtrate bacteriological removal efficiencies were 43.1 and 79.7 %, respectively, after rehabilitation the same were 69.3 and 97.8 % .

Table 8. *Faecal Coliforms* removal No./100 ml

	Before Rehabilitation			After Rehabilitation		
	HI	HF	SF	HI	HF	SF
Min.	145	44	26	150	26	0
Max.	420	310	82	3300	760	70
Mean	290	165	59	711	220	15

HI= HRF Inlet, HF= HRF Filtrate, SF= SSF Filtrate.

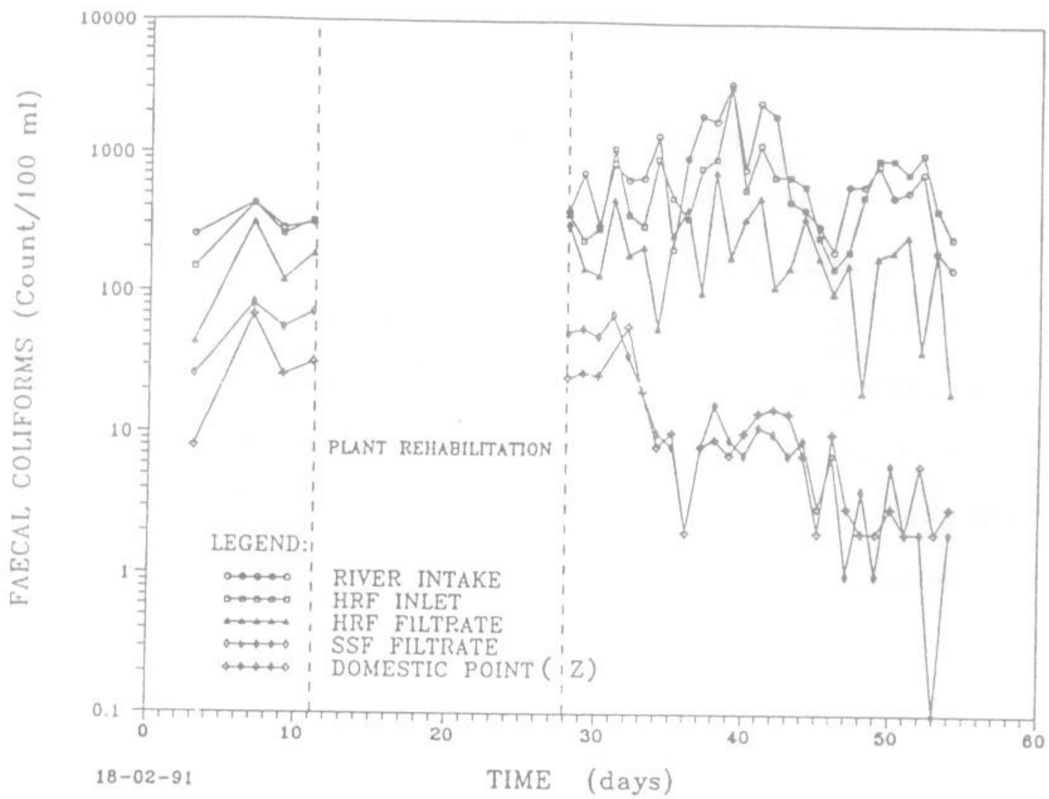

Fig.9 Faecal Coliform counts at different stages.

DISCUSSION OF THE RESULTS

Improper operational procedures of the SSF and the absence of adeaquate maintenance of the plant contributed to the low levels of removal of turbidity, apparent colour and *Faecal Coliforms* before rehabilitation of the plant. This resulted in production of a lower quality of the plant filtrate.

After rehabilitation, there was a significant improvement in the levels of removal of the impurities. The filtrate produced approached WHO quality guidelines[19] and the performance of the plant was comparable to that of constant rate filtration plants elsewhere[7,8,10,11,12]. Prior to the plant rehabilitation, the mean overall apparent colour, turbidity and *Faecal Coliforms* removals were 23.2, 43.1 and 79.3 %, respectively . However, after plant rehabilitation, the removals increased to 58.7, 69.3 and 97.8 % thus proving the importance of proper operation and maintenance of HRF/SSF systems . In addition, there was considerable improvement in filterability which indirectly reflects an increase in removal of the suspended matter from water.

The filtrate produced immediately after rehabilitation was of unsatisfactory quality for two main reasons; the first was the effect of residual impurities in the newly washed sand and the second was the fact that the top filter skin (Schmutzdecke) had not properly developed on the SSF. The increase in the total hardness of the HRF filtrate was most probably caused by the partial dissolution of the Calcium alkaline rock found in the coarse and medium fractions of the HRF as supported by the mineralogical identification (see Table 2) . The plant caretaker was found to be deficient in the knowledge of operational procedures of declining rate SSF which resulted in its being intermittently operated . Such procedures disturb the biological processes in the SSF bed and can create anaerobic conditions inside.

CONCLUSIONS AND RECOMMENDATIONS

As a result of the reported study, the following conclusions and recommendations can be made:

1. To achieve water quality which is safe for human consumption and in accordance to the WHO guidelines, terminal disinfection of the plant filtrate is necessary.

2. Careful selection of gravel used in HRF is necessary where relatively high levels of hardness are found in raw water. This will preclude the occurrence of unacceptable increases of hardness of water caused by partial dissolution of the filter media.

3. Satisfactory performance of HRF/SSF is dependent upon proper operational procedures and existence of adequate maintenance schemes. It is therefore imperative that the plant caretakers are properly trained in both aspects of the HRF/SSF plants.

4. A feeder tank/reservoir should be constructed upstream of the HRF unit in order to store suufficient water which can allow continuous operation of the plant at a constant filtration rate.

5. The introduction of an underdrainage system of pipes and the application of contact coagulation in the HRF unit coupled with fabric protection of the SSF unit can improve the performance of this plant especially during the rainy seasons.

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