# UNIVERSITY OF NAIROBI

## EVALUATION OF PERFORMANCE OF IRON REMOVAL PLANTS FOR GROUNDWATER TREATMENT IN WESTERN KENYA

BY

J. G. MURIUKI

1994

DEPARTMENT OF CIVIL ENGINEERING

# EVALUATION OF PERFORMANCE OF IRON REMOVAL PLANTS
# FOR GROUNDWATER TREATMENT IN WESTERN KENYA

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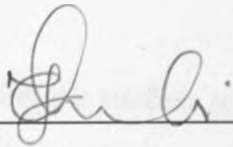
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THE UNIVERSITY OF NAIROBI.

BY

**J.G. MURIUKI**

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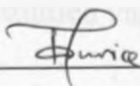
MASTER OF SCIENCE

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# DECLARATION

**THIS THESIS IS MY ORIGINAL WORK AND HAS NOT BEEN PRESENTED FOR DEGREE IN ANY OTHER UNIVERSITY.**

_____

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**THIS THESIS HAS BEEN SUBMITTED FOR EXAMINATION WITH MY APPROVAL AS UNIVERSITY SUPERVISOR.**

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**DR. MAURICE NDEGE**

**SUPERVISOR**

# ABSTRACT

## EVALUATION OF PERFORMANCE OF IRON REMOVAL PLANTS FOR GROUNDWATER TREATMENT IN WESTERN KENYA

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Iron is an important constituent in industrial process and drinking water. However, the presence of Iron in excessive concentrations makes the water objectionable for drinking and other industrial applications. Techniques for Iron removal have therefore been developed and further modified over the years to suit various conditions.

The study aims at assessing the success to the Iron removal project in provision of improved quality water by use of contact filter in the Kenya-Finland western water supply programme.

The study shows that though the technical implementation was carried out successfully, the programme did not adequately train and organise the beneficiary communities to take over the running of the iron removal plants. This very much affected the sustainabilty of these plants.

The result of the various investigations shows that, due to its simple technology, contact filter application for iron removal in western Kenya was a good choice for a rural setting. The three models studied vary in capital, operation and maintenance costs.

The simplest and the cheapest to install was the Khayinga and Siginga model, but as explained below these plants had their own water quality and operational limitations. The major drawback was their tedious backwashing method which resulted in continuos loss of filter media.

In all cases, the construction materials e.g. sand, cement and gravel, piping material, valves and pumps were available in the project area and elsewhere in Kenya. Iron removal efficiencies for the three models were as follows;

| | |
|---|---|
| Siginga and Khayinga | 96 % |
| Shivanga | 94.7 % |
| Lugusi | 85.6 %. |

Despite high iron removal efficiencies at Siginga and Khayinga plants, Iron could not be removed to WHO standard of 0.3 mg/l, due to the high levels of raw water iron concentration of 16.7 mg/l and 14 mg/l respectively. Considering the programme's iron concentration guideline level of 1.0 mg/l, this was a great success. Both Shivanga and Lugusi plants achieved the WHO standard but as indicated by removal efficiencies, this was due to the low concentration of iron in the raw water (0.9 and 0.59 mg/l respectively).

The average treated water Iron concentration (mg/l) from the four Iron removal plants was as follows;

| | |
|---|---|
| Khayinga | 0.58 |
| Siginya | 0.70 |
| Shivanga | 0.19 |
| Lugusi | 0.13 |

As mentioned earlier on, the project was technically very successful but failed due to poor community mobilisation and training approach.

# ACKNOWLEDGEMENTS

# TABLE OF CONTENTS

# LIST OF FIGURES

Page

# LIST OF TABLES

## 1.0    INTRODUCTION

### 1.1    Sources and occurrence of Iron in groundwater

Abundant sources of iron exist in the earth's crust. Iron constitutes five per cent of the earth's crust (Robinson, 1967). In its compounds, iron may exist in ferrous Fe(II) or ferric Fe(III) form.   It is mainly found in form of oxides, carbonates, and less frequently as sulphides. The most common iron oxides are magnetite ($Fe_3O_4$), hematite ($Fe_2O_3$) and limonite ($2Fe_2O.3H_2O$). Siderite ($FeCO_3$) and pyrite ($FeS_2$) are carbonate and sulphide minerals containing iron respectively (Robinson, 1967).

Usually, high concentrations of iron are associated with deep well waters from shale, sandstone etc. (Holden, 1970), where iron mostly occurs in form of ferrous bicarbonate but in some cases, it may be found as higher oxides in complex organic combinations or in rare cases as sulphide (Holden, 1970). The occurrence of iron in groundwater is generally attributed to the action of carbonic acid on higher oxides of iron. Though some carbonic acid could be generated by the action of rain on atmospheric carbon dioxide, most of the acid comes as a result of bacterial action on organic matter.

The dissolution of iron-bearing minerals may take place under aerobic conditions in the presence of reducing agents (organic substances, hydrogen sulphide etc) capable of

reducing the higher oxides of iron to ferrous Fe (II) state. Soluble ferrous iron may enter groundwater through the reaction shown in Equation 1.0 (Engelbrecht et al., 1967).

$$FeCO_3 + CO_2 + H_2O \text{ -------> } Fe(II) + 2HCO_3^{-2} \quad \dots\dots\dots\dots\dots\dots (1.1)$$
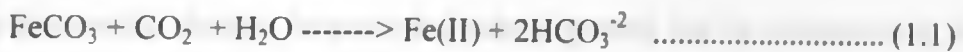
In an aqueous environment, both soluble and insoluble species of hydrolysed iron may be present. The concentration of iron and manganese found in solution in natural waters is frequently limited by the solubility of their carbonates e.g. siderite ($FeCO_3$) and rhodochlosite ($MnCo_3$). Water of high alkalinity often therefore has lower dissolved iron (O'Connor, 1971). For a given pH the solubility of iron carbonate in natural waters is inversely proportional to the bicarbonate ion concentration i.e the alkalinity. The same is true for carbonates of manganese.

**1.2    An overview of problems  of Iron in water and the performance of Iron removal plants in the Kenya-Finland Western Water Supply Programme operation area.**

Iron is an essential element for plant and animal growth, but its occurrence in water in high concentrations makes it objectionable for domestic and industrial uses. Iron occurs in water in dissolved ferrous form which when exposed to air or oxygen tends to oxidize forming brown precipitates which make the water aesthetically objectionable. The deposition of precipitates on plumbing fixtures causes staining and also interfere with laundering operations. The following industries are affected by ironous waters:-

-   Paper making
-   Photography
-   Dying
-   Leather tanning
-   Food processing etc (Weng, 1984)

Water for use in the industries must be treated for iron removal otherwise the quality of the final product will be seriously affected. Deposits of colloidal ferric iron precipitates accumulate in water distribution systems resulting in proliferation of iron bacteria (Crenothrix, Clonothrix) forming masses or slime which can easily block valves and meters as well as reducing the pipe carrying capacity. Sloughing off of the

slime usually causes odour and taste problems. The WHO recommended standard of 0.3 mg/l is based on taste, colour and related nuisance considerations. Tolerable Iron concentration in various areas differ depending on the overall water quality problems experienced in each particular area.

A survey on the existing plants indicated poor maintenance conditions in the majority of the iron removal plants. Details on the causes of negligence will be found in later chapters. In terms of iron removal, the plants were a great benefit to the consumers. The plants were efficiently removing iron down to 1.0 mg/l which was the guideline in the Programme area. Other benefits include reduction of manganese and turbidity further improving taste and colour of the treated water.

The technology level in all the models studied was within the reach of the rural communities. Operation and maintenance costs were affordable and the raw materials were easily available in the Programme area. All these enhanced the sustainability of the iron removal project. Then what caused the failure of the project? The cause of this was found to be poor community participation in the running and maintenance of these plants. The most important finding here is that Siginga and Khayinga plants are among the oldest plants and are still working. This is because the consumers accepted there was a water quality problem and were involved in implementation of iron removal plants. They were well trained in operation and maintenance during and after implementation.

Later, as mentioned in Section 1.3, Iron removal project aroused commercial interests by engaging contractors and the implementation was done hurriedly without consumers' involvement and training. Several Iron removal plants were installed without consumers' approval and in many cases where Iron concentration was as low as 0.3 mg/l. Such installations were hence viewed as a nuisance by the consumers and were later abandoned.

The Iron removal project in Western Kenya was a good solution to the problem in drinking water for the rural communities but was failed by the wrong implementation approach. This is a good example to show the importance of thorough preliminary studies and involvement of project beneficiaries in formulation of solutions not only in water but other development projects. As mentioned earlier, most of the plants are abandoned and the project was a failure.

## 1.3 Advances in Iron Removal, the Western Kenya-FinlandWater Supply Programme

Problems associated with presence of iron in water can only be solved by removing the iron before distribution. Treating for iron removal involves oxidation of dissolved iron which forms filtrable colloidal precipitates. Several treatment methods are available and the choice is mainly dictated by the investment, operation and

maintenance costs and availability of skilled personnel. Conventional treatment techniques which include aeration and chemical oxidation have been applied in several treatment plants in the developed countries. Despite their relatively simple principle of operation, conventional treatment plants have proved unsuitable especially for rural areas in the developing countries. This is due to high construction costs coupled with sophisticated operation and maintenance procedures (Hatva et al., 1973).

In Kenya water treatment for Iron removal by conventional methods is confined to a few groundwater supplies e.g Njoro and Ngong water supplies where aeration is carried out. Chemical oxidation has not been tried in public water supplies in the country. Non - Conventional iron removal treatment techniques have been recently developed and are mainly geared to the reduction of cost and convenience in operation and maintenance. The details of non-conventional treatment methods are given in the literature review.

One of the methods developed recently is the application of the contact filter. The technique utilizes both physico-chemical and biological Iron removal processes where different types of iron bacteria are involved. The filter can be either dry i.e the media not submerged in water or flooded where the media is completely submerged in water. In a contact filter both biological processes and physico-chemical iron removal processes are involved and are complementary to each other.

The method has been tried in the Kenya-Finland Western Water Supply Programme area (which comprises Western Province and a part of Siaya District) since 1985. This is mainly a rural water supply programme. The water sources are shallow wells, borehole wells and protected springs. The groundwater sources are equipped with hand pumps. Each well is supposed to serve about 200-300 consumers in a one Kilometre radius.

The groundwater sources for rural supplies in this area were found to contain iron in excess of WHO recommended level of 0.3 mg/l (WHO, 1984). The most frequently reported quality problem in the programme area has been taste and colour. A study carried out in 1984, by the then project Chemist confirmed the presence of iron and one of his recommendations was the development of iron removal plant suitable for rural areas. Several designs of contact filter were tried culminating in the presently adopted flooded contact filter. The installation of the iron removal plants was mainly done by local contractors who had been trained through the programme in order to enhance the sustainability of the systems. Community beneficiaries had to be adequately trained on operation and maintenance at various stages of construction but it was later found that the contractors were only interested in finishing their work to get their payment. On whether the consumers were given enough training or not is a question to be answered later in this study.

Training on operation and maintenance was carried out together with mobilisation and participation. In most cases construction teams worked ahead and completely independent of the training groups. Thus there lacked co-ordination and continuity. The Iron removal project generated a lot of interest owing to its commercial gains while maintenance was almost forgotten. So many Iron removal plants were constructed but communities continued objecting their quality.

A bacteriological quality survey indicated an increase in contamination in the filtered water in most of the installations. The fact that excessive iron does not cause any serious health problems in humans and that water deteriorated in bacteriological quality after treatment, it was found necessary to slow the rate of construction until the consumers in the existing plants were trained in all aspects of operation and maintenance. It was established that corrosion of borehole casings, galvanised iron rising pipes in borehole and shallow wells contributed a lot to turbidity, colour and taste problems. Most corrosion related problems were later solved by use of plastic casings rising pipes and stainless steel rods.

## 2.0    LITERATURE REVIEW

## 2.1    The chemistry of Iron in groundwater

The chemical reactions involved in the solution and deposition of iron in natural groundwater are readily reversible.   The amount of Fe(II) and Fe(III) present in a given water is dependent on certain conditions of the water such as alkalinity, pH, carbon dioxide, dissolved oxygen content and concentrations of other minerals present (Robinson and Dixon, 1968).

## 2.1.1   Ferrous Iron (Fe(II)) reactions

Fe(II) exists in natural groundwater mostly in anaerobic environment.   In waters devoid of sulphides and carbonates, and when Fe(II) is dissolved under anaerobic conditions, the equilibria equations 1, 2 and 3 in Table 2.1 will take place (Stumm and Lee, 1960).

# Table 2.1     Iron equilibria in water (Stumm and Lee, 1960)

| No. | REACTION | EQUILIBRIUM CONSTANT 1) 25°C | REFERANCE |
|---|---|---|---|
| | **Fe (11) Solubility** | | |
| 1 | $Fe(OH)_2(s) = Fe^{+2} + 2OH-$ | $8 \times 10^{-14}$ | [1] |
| 2 | $Fe(OH)_2(s) = [Fe(OH)]^{+} + OH^{-}$ | $4 \times 10^{-10}$ | [1] |
| 3 | $Fe(OH)_2(s) + OH^{-} = [Fe(OH)_3]^{-}$ | $8.3 \times 10^{-9}$ | [2] |
| 4 | $FeCO_3(s) = Fe^{+2} + CO_3^{-2}$ | $2.1 \times 10^{-11}$ | [10] |
| 5 | $FeCO_3(s) + OH^{-} = [Fe(OH)]^{+} + CO_3^{-2}$ | $1 \times 10^{-2}$ | Computed ) |
| 6 | $HCO_3^{-} = H^{+} + CO_3^{-2}$ | $4.6 \times 10^{-11}$ | [10] |
| 7 | $FeS(s) = Fe^{+2} + S^{-2}$ | $6 \times 10^{-18}$ | [39] |
| 8 | $FeS(s) + OH^{-} = [Fe(OH)]^{+} + S^{-2}$ | $3 \times 10^{-12}$ | Computed |
| 9 | $FeS(s) + 3OH^{-} = [Fe(OH)_2]^{-} + S^{-2}$ | $6.2 \times 10^{-8}$ | Computed |
| 10a | $H_2S(aq) = H^{+} + HS^{-}$ | $1 \times 10^{-7}$ | [39] |
| 10b | $HS^{-} = H^{+} + S^{-2}$ | $1.3 \times 10^{-13}$ | [39] |
| | **Fe (1 H) Solubility** | | |
| 11 | $Fe(OH)_3(S) = Fe^{+3} + 3OH^{-}$ | $\sim 10^{-34}$ | |
| 12 | $Fe(OH)_3(s) = [Fe(OH)_2]^{+} + OH^{-}$ | $1.7 \times 10^{-26}$ | Computed |
| 13 | $Fe(OH)_3(s) = [Fe(OH)]^{+2} + 2OH^{-}$ | $6.8 \times 10^{-22}$ | Computed |
| 14 | $Fe(OH)_3(S) = [Fe(OH)_3](d)^2)$ | $2.9 \times 10^{-7}$ | [2] |
| 15 | $Fe(OH)_3(S) + OH^{-} = [Fe(OH)_4]^{-}$ | $\sim 10^{-8}$ | Estimated |
| | **Complex Formation** | | |
| 16 | $Fe^{+2} + Cl^{-} = [FeCl]^{+}$ | $\sim 2.3$ | [8] |
| 17 | $Fe^{+2} + Cl^{-} = [FeCl_2]^{2-}$ | — | [13] |
| 18 | $Fe^{+2} + Cl^{-} = [FeCl]^{+2}$ | 30 | [40] |
| 19 | $[FeCl]^{+2} + Cl^{-} = [FeCl_2]^{+}$ | 4.5 | [40] |
| 20 | $Fe^{+2} + Cl^{-} = [FeCl]^{+}$ | — | [40] |
| 21 | $Fe^{+3} + SO_4^{-} = [Fe(SO_4)]^{+}$ | $1.5 \times 10$ | [41] |
| 22 | $Fe^{+2} + HCO_4^{-2} = [Fe(HCO_4)]^{+}$ | $4.5 \times 10$ | [42] |
| | **Acidity** | | |
| 23 | $Fe^{+2} + H_2O = [Fe(OH)]^{+} + H^{+}$ | $5 \times 10^{-3}$ | [1] |
| 24 | $Fe^{+3} + H_2O = Fe(OH)^{+2} + H^{+}$ | $6.8 \times 10^{-3}$ | [43] |
| 25 | $[Fe(OH)]^{+2} + H_2O = [Fe(OH)_2]^{+} + H^{+}$ | $2.6 \times 10^{-3}$ | [43] |
| 26 | $[Fe(OH)_2]^{+} + H_2O = Fe(OH)_3(s) + H^{+}$ | 5.8 | Computed |
| | **Polymerization** | | |
| 27 | $2[Fe(OH)]^{+2} = [Fe_2(OH)_2]^{+4}$ | 30 | [43] |
| 28 | $2Fe^{+3} + 2H_2O = [Fe_2(OH)_2]^{+4} + 2H^{+}$ | $1.4 \times 10^{-3}$ | [43] |

1) For most of the reactions listed, different authors have determined equilibrium constants, which differ slightly among each other. Other values may be found in [8]

2) Computed values have been obtained from other equilibrium constant given in this Table. For example, $K_{12}$ can be computed from the equilibrium constants of reactions 11 and 24.

3) [Fe(OH)] (d) is dissolved molcular (undissociated) ferric hydroxide.

Using these equilibria equations and Equation 2.2,

$$H_2O \rightleftharpoons H^+ + OH^- \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2.2)$$

where $Kw = [OH^-][H^+]$

the activities of the different Fe(II) compounds can be plotted as a function of pH by taking the logarithms of Equation 2.1 and the equilibria equations in Table 2.2. Figure 2.1.2 shows the solubility of $Fe(OH)_2(S)$ in waters devoid of any carbonate or sulphur species (Stumm and Lee, 1960).
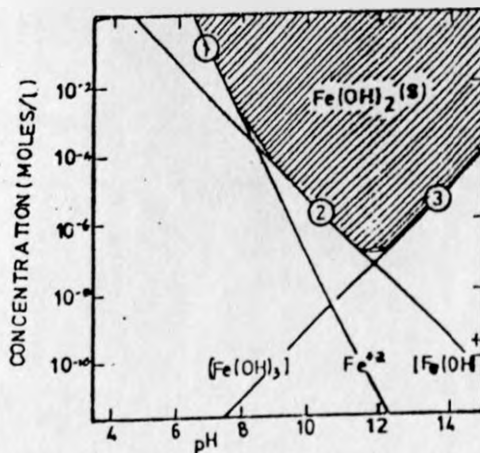


Fig. 2.1.1    Solubility of Fe(OII)$_2$ in a non-carbonate, non-sulphide solution (Stumm and Lee, 1960)

11

The solubility of Fe(II) cannot exceed the limits of the boundary defined by the shaded area in Figure 2.1.1. Figure 2.1.1 however, will not give a correct picture of the conditions in anaerobic groundwater where there are carbonate species and often sulphur compounds. Fe(II) reacts with carbonates and sulphides and form new compounds.

In natural water, where only Fe(II) and carbonates are present the equilibria equations 4, 5 and 6 in Table 2.1 will take place in addition to the equilibria equations 1, 2 and 3. Figure 2.1.2 shows the solubility of Fe(II) in a carbonate containing waters (Stumm and Lee, 1960).
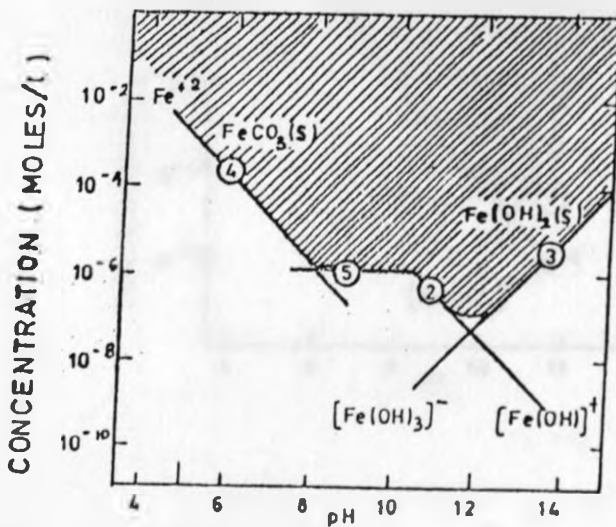


Fig. 2.1.2    Solubility of Fe(II) in a carbonate containing water (alkalinity = $2 \times 10^{-3}$ Eq/l) (Stumm and Lee, 1960)

From Figure 2.1.2, it can be seen that at pH = 10.5, $FeCO_3$ determines the solubility of Fe(II) while $Fe(OH)_2$ determines the solubility of Fe(II) for pH < 10.5 (Snoeyink and Jenkins, 1980). The other principal equilibria associated with Fe(II) in groundwater are sulphur compounds and the formation of complex ions and chelation (Robinson and Dixon, 1968). Equilibria equations 7 to 10 in Table 2.1 will occur between Fe(II) and species of sulphide system if available in groundwater. Figure 2.1.3 shows the solubility of Fe(II) in a carbonate and sulphide bearing water (Stumm and Lee, 1960).
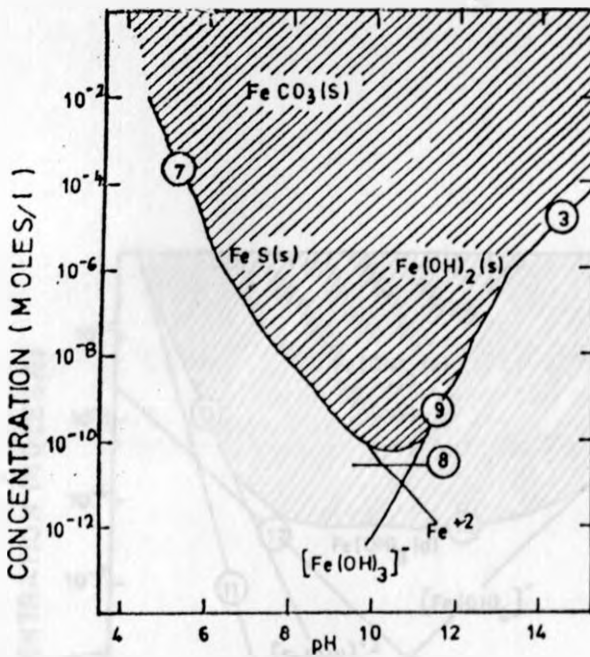


Fig. 2.1.3    Solubility of Fe(II) in a carbonate and sulphide bearing water (Alkalinity = $2 \times 10^{-3}$ Eq/l; S(II) $10^{-4}$ mol/l) (Stumm and Lee, 1960)

13

## 2.1.2  Ferric Iron (Fe(III)) reactions

On aeration or by the addition of oxidising agents Iron Fe(II) oxidizes to Fe(III) form and the Fe(III) form an equilibria with $H_2O$. The most common species in the Fe(II) system is $Fe(OH)_3(S)$ which has a low solubility over pH range of 6 to 9, the most common cases in natural waters. The reactions which Fe(III) forms with $H_2O$ are shown in equilibria equations 11 to 15 in Table 2.1. The solubility curves of Fe(III) in a non-carbonate, non-sulphide solutions is shown in Figure 2.1.4 (Stumm and Lee, 1960).
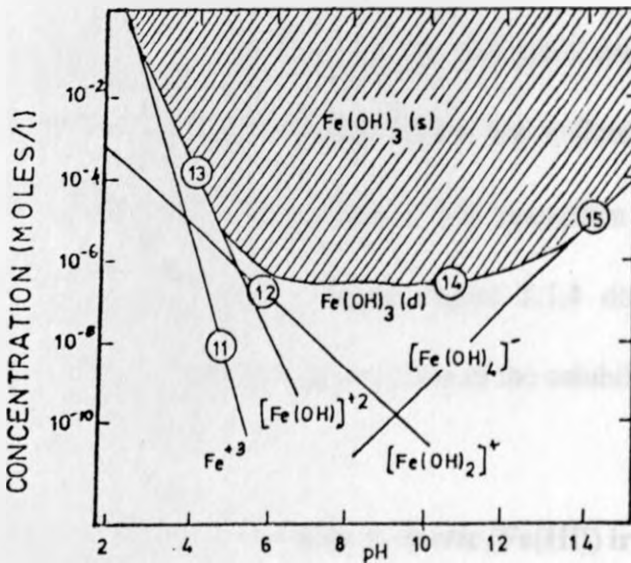


**Fig. 2.1.4**  **Solubility of Fe(II) in a non-carbonate, non-sulphide solution (Stumm and Lee, 1960)**

The low solubility of Fe(OH)$_3$ over the wide range of pH is an advantage in conventional water treatment plants, where the precipitated Fe(OH)$_3$ may be removed by filtration and/or sedimentation. However, Fe(III) can form complex compounds with hydroxides, orthophosphate, many organic bases etc causing iron to remain in solution. The extent of complex formation is pH dependent. Within pH range of natural waters, soluble or insoluble mixed Fe(III) complexes that may contain OH$^-$ ions as well as other ligands can be formed (Stumm and Morgan, 1970). Equilibria equations 16 to 22 in Table 2.1 show some examples of complex formation. The complex formations bring higher concentration of dissolved Fe(III) than indicated in Figure 2.1.4.

The incorporation of coordinating anions into basic precipitates not only alters the solubility relations but also strongly affects the colloid chemical properties of the dispersed phase. The complex formation will strengthen the colloid form, instead of combining as larger particles. Hence Figure 2.1.4 does not precisely show the condition in natural waters but it gives a hint of the solubilities at different pH values.

### 2.1.3 Oxidation of ferrous (Fe(II)) to ferric (Fe(III)) iron

Iron exists in natural groundwater in the soluble Fe(II) state where the water is devoid of oxygen. To remove this form of iron, Fe(II) must be oxidized to Fe(III) form. This phenomenon occurs by a redox process where the oxidizing agents can be oxygen

($O_2$), permanganate ($MnO_4^-$), chlorine ($Cl_2$) or equivalent.  Stoichiometrically, 1 mg/l of oxygen will oxidise 7 mg/l of Fe(II) (Engelbrecht et al., 1967).  The reaction is as follows

$$\frac{1}{4} O_2 + H^+ + e^- \rightleftharpoons \frac{1}{2} H_2O \qquad \text{reduction} \quad ........... (2.2)$$

$$+$$

$$Fe (II) \longrightarrow Fe(III) + e^- \qquad \text{Oxidation} ............ (2.3)$$

$$2.2 + 2.3 = \frac{1}{4}O_2 + Fe(II) + H^+ \rightleftharpoons Fe(III) + \frac{1}{2} H_2O \text{ redox reaction ... (2.4)}$$
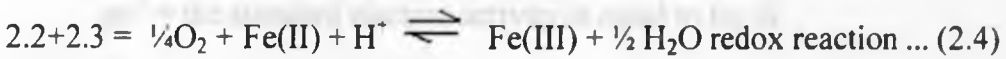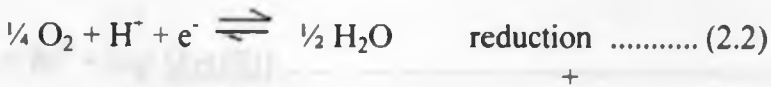
As can be seen from the above reactions, oxygen is reduced while Fe(II) is oxidized. If Equation (2.4) is considered as reduction

$$Fe(III) \rightleftharpoons Fe(II) - e^- .............................................................. (2.5)$$

which by mass action law gives

$$\frac{[Fe(II)] \ [e^-]}{[Fe(III)]} = K .............................................................. (2.6)$$

which is equal to

$$-\log [\, e^{\cdot} \,] = \log K + \log \frac{[Fe\ (III)]}{[Fe(II)]} \quad\text{..........................................................} (2.7)$$

and Equation (2.7) can also be written as

$$Pe = Pe^{0} + \log \frac{[Fe(III)]}{[Fe(II)]} \quad\text{..........................................................} (2.8)$$

where pe = the electron activity and is defined as $-\log [\, e- \,]$

pe° = the standard electron activity is equal to log K.

In order to relate p to log K, K is defined in terms of the equilibrium constant of the reduction reaction (Stumm and Morgan, 1970). Pe is a measure of the oxidizing or reducing intensity of a solution, i.e how strong the solution is to oxidize or reduce other species. For instance, large positive values of pe (low electron activity) represent strongly oxidizing conditions and small or negative values (high electron activity) correspond to strongly reducing condition (Stumm and Morgan, 1970).

Pe° is the electron activity at [ (Fe(II) ] = [ (Fe(III) ] or generally when the activity of the oxidant and the reductant are equal. Therefore, it can be said that Pe° is a comparative expression of the redox properties of the species. However, many redox

17

equilibria are pH dependent as can be seen from the half reaction Equation 2.9 (reduction reaction).

$$FeOH^{2+} + H^+ + e^- \rightleftharpoons Fe^{2+} + H_2O \dots\dots\dots\dots\dots (2.9)$$
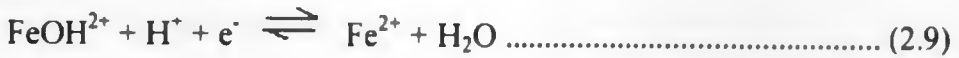
Pe is calculated as

$$Pe = Pe^\circ + \log \frac{[FeOH^{2+}][H^+]}{[Fe^{2+}]} \dots\dots\dots\dots\dots (2.10)$$

Equation 2.10 can be simplified as

$$Pe = Pe^\circ - pH + \log \frac{[FeOH^{2+}]}{[Fe^{2+}]} \dots\dots\dots\dots\dots (2.11)$$

Pe° will not necessarily give a correct expression of the oxidizing or reducing intensities of the single species for most of the reactions in natural waters carried out at pH values around 7. Therefore, a constant Pe° (w) analogous to Pe° is introduced in which $(H^+)$ and $(OH^-)$ in the redox equilibrium equations are assigned their activities in neutral water. Values for Pe° (w) for 25° C thus apply to unit activity of oxidant and reductant at pH = 7 (Stumm and Morgan, 1970).

$$Pe^\circ(w) = P^\circ + nH \log kw \quad\text{...................................................................... (2.12)}$$

where $nH$ = the number of the moles of the protons exchanged per mole of electrons.

$nH = -1$ at $pH = 7$ in Equation (2.12)

$Pe^\circ(w)$ of different species can be compared directly and permits grading of different

species in order of their oxidizing intensity at $pH = 7$. Any species will tend to oxidize

equimolar concentration of any other species having a lower $Pe^\circ(w)$ value. Figure



REDUCED FORM    $HS^-$   $Fe^{++}$    $CH_4$    $Mn^{+2}$    $N_2$   $H_2O$

OXIDISED FORM   $SO_4^{--}$ $Fe^{+++}$   $CH_3OH$   $Mn^{+4}$   $NO_2^-$   $O_2$

$Pe^\circ(w)$
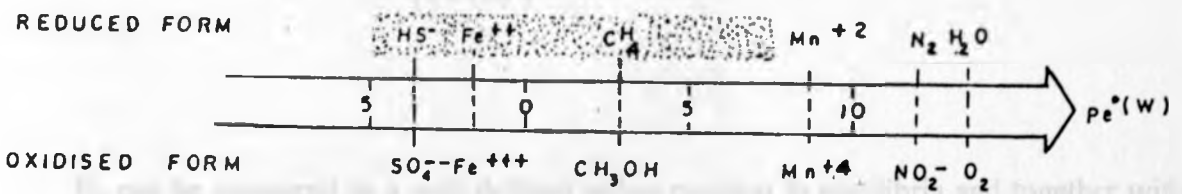
**Fig. 2.1.5**   **Comparison of $Pe^\circ(w)$ of different species. Example; $Fe^{3+}$ can in principle oxidize all the reduced species at left i.e $Hs^-$. $Fe^{2+}$ can in principle reduce all oxidized species at right, i.e $CH_3OH$, $Mn^{4+}$, $NO_3^-$, $O_2$ (Herremöes et al., 1980/cited by Viegand, 1984)**

The quantity of $Pe^\circ(w)$ is a relative expression for the electron activity when all

species other than the electrons are at unit activity. The electron activity can also be

expressed in redox potential $E_h$. Pe is related to $E_h$ by

$$Pe = \frac{F}{2,3RT} E_h \quad\text{.................................................................................. (2.13)}$$

2,3RT

Where F = Faraday's constant

        R = gas constant

        T = temperature is Kelvin scale

By application of the redox potential Equation (2.8) can be written as

$$E_h = E_h^\circ + \frac{2.3RT}{F} \; \log \frac{[\,Fe\,(III)\,]}{[\,Fe\,(II)\,]} \; \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (2.14)$$

$E_h$ can be measured in a well defined redox reaction in equilibria and together within pH give valuable information about the condition of the system. However, difficulties might occur with attempts to measure oxidation-reduction potentials in natural waters, where many redox systems are involved and often the systems are out of equilibria. In this kind of natural waters the measurement of the redox potential must be done with care (Stumm and Morgan, 1970).

A theoretical model useful in illustrating the various redox equilibria for iron is the $E_h$-pH diagram also known as the solubility-field diagram, which is computed from chemical equilibria data (Ghosh et al., 1966). In Table 2.2 the redox reactions of iron in a carbonate water are shown together with the activity equations. The activity equations in Table 2.2 can for a fixed pH be plotted in an activity diagram as shown in Figure 2.1.6 (Stumm an Morgan, 1970).
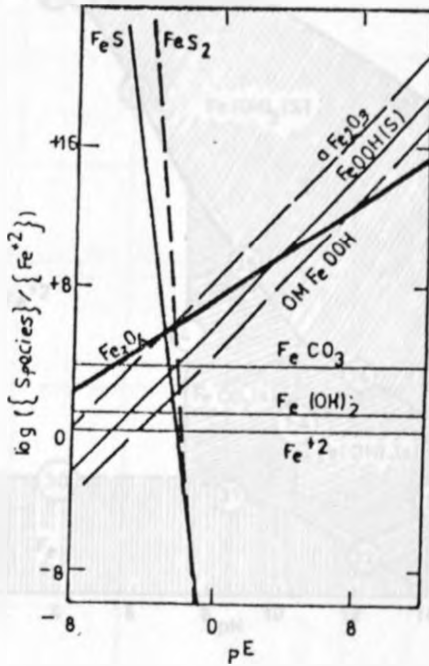


Fig. 2.1.6     Activity diagram for a carbonate and sulphide bearing water. (pH = 7; $CT = 10^{-3}M$, $SO_4^{-2} = 10^{-3}M$) (Stumm and Morgan, 1970)

For a fixed $Fe^{2+}$ activity the equation in Table 2.2 can be plotted in an $E_h$ -pH diagram also known as stability field diagram. Care must be taken in the application of equilibrium data and $E_h$ - pH diagrams for the interpretation of the behaviour of materials like in natural waters due to comments given earlier about $E_h$ measurement. Figure 2.1.7 shows the $E_h$ - pH diagram (Stumm and Lee, 1960).
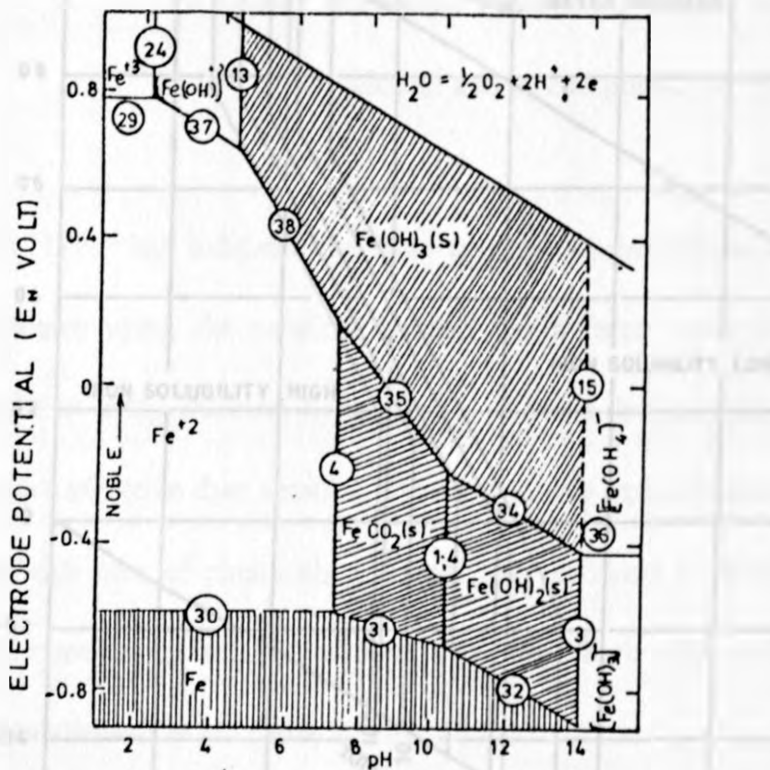


Fig. 2.1.7    $E_h$ - pH diagram.  The shaded areas show the solid Fe - species.  The lines denote the points at which the activities of soluble iron is $10^{-5}$ mol/l; alkalinity = $2x10^{-3}$ mg/l. (Stumm and Lee, 1960).

23

$E_h$ - pH diagram can be made for different activities of $Fe^{2+}$ but the purpose of the diagram is primarily to give a general view of the adjacent relations between iron species. Figure 2.1.8 shows $E_h$ - pH diagram for activities of soluble iron in the presence of carbonate species (Hem, 1961).
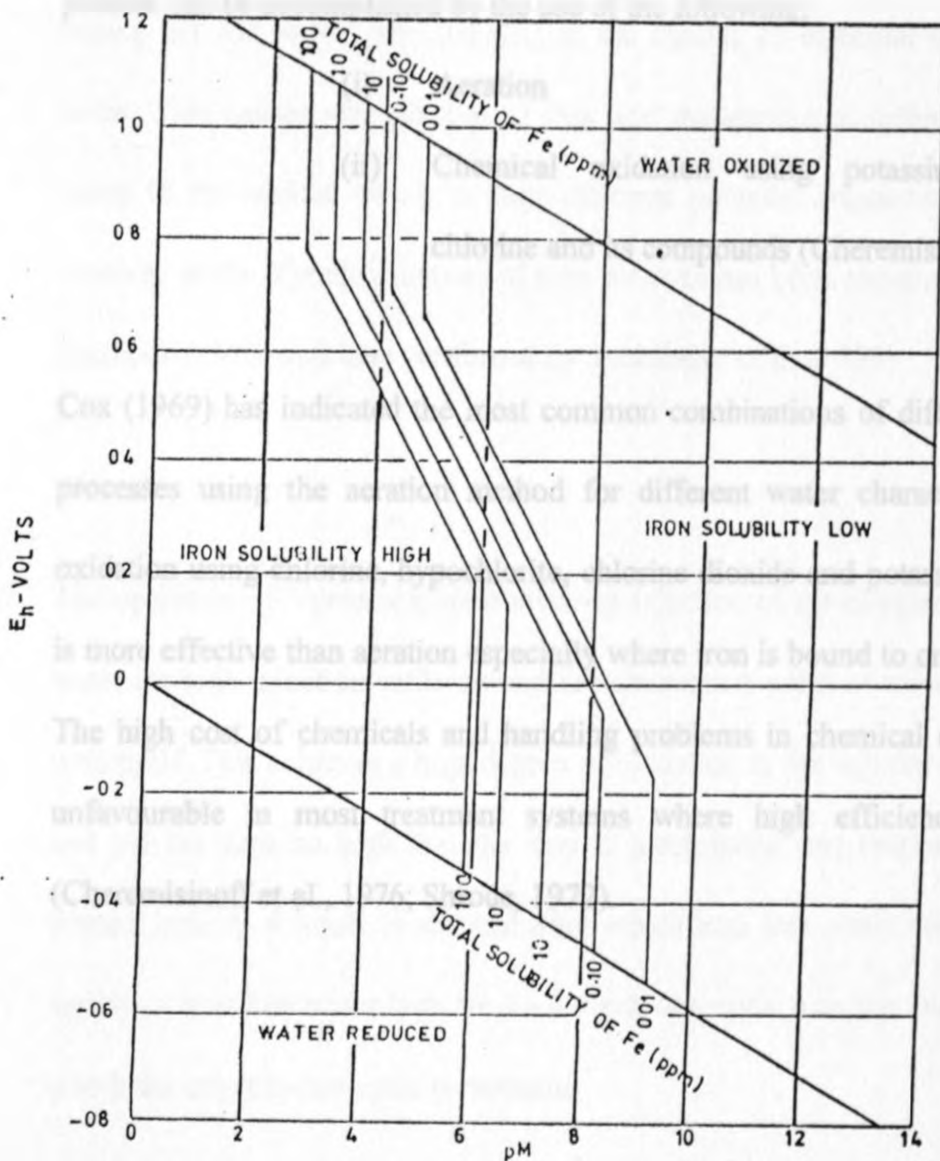


Fig. 2.1.8    $E_h$ - pH for different activities of soluble iron in a carbonate bearing water, $CT = 1.6 \times 10^{-3}M$ (Hem, 1961)

## 2.2    Iron removal using conventional treatment plants

Iron removal by conventional treatment involves oxidation of iron  Fe(II) to iron

Fe(III) which is insoluble followed by sedimentation and filtration.  The oxidation

process can be accomplished by the use of the following;

(i)    Aeration

(ii)   Chemical oxidation using potassium permanganate,
       chlorine and its compounds (Cheremisinoff et al., 1976).

Cox (1969) has indicated the most common combinations of different iron removal

processes using the aeration method for different water characteristics. Chemical

oxidation using chlorine, hypochlorite, chlorine dioxide and potassium permanganate

is more effective than aeration especially where iron is bound to organic compounds.

The high cost of chemicals and handling problems in chemical oxidation makes it

unfavourable in most treatment systems where high efficiency is not desired

(Cheremisinoff et al., 1976; Shrode, 1972).

## 2.3    Iron removal by non conventional methods.

### 2.3.1   Vyredox

This is an underground treatment of water for iron removal. The technique involves raising pH and redox potential ($E_h$) in the aquifer by injection of oxygen saturated water. This causes precipitation of iron and manganese at different redox potential zones in the aquifer owing to their different potential requirement. The principles involved in the Vyredox method of iron removal has been explained by Hallberg and Martinell (1976) and later confirmed by Techlinger et al. (1985).

The operation of Vyredox system involves injection of the oxygen saturated iron free water through injection wells around the abstraction point or through the abstraction well itself. This achieves a high degree of oxidation in the aquifer around the well. $E_h$ and pH are kept so high that the iron is precipitated and retained in the strata. A contact time of 4 hours is allowed after which iron free water can be pumped. The supply of iron free water lasts for 2 - 4 weeks depending on the rate of pumping after which the oxygenation cycle is repeated.

26

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### 2.3.2 Overland flow

Overland flow is normally practised in waste water treatment. The technique has been utilized in iron removal with good removal efficiencies. Overland flow involves application of water containing iron over a vegetated slope where the flow facilitates oxidation of Ferrous to Ferric iron. To maximize iron removal the following conditions must be fulfilled:-

1.   The dissolved oxygen of water must be increased.

2.   The pH must be raised to the appropriate level.

3.   Sedimentation of the resulting iron precipitate.

     (Zirschky and Carlson, 1984)

Overland flow provides a large area through which gas transfer can occur. Therefore there is a large potential for increase in dissolved oxygen and dissolution of carbon dioxide resulting in pH elevation. Due to its shallow depth, overland flow is very effective in clarification. The vegetative cover provides additional suspended solids removal by intercepting many of settling particles.

An example of overland flow treatment for iron removal is Salo treatment plant in Finland. The following removal efficiencies have been achieved for manganese and iron.

Iron - over 97%

Manganese - 92%

Dissolved oxygen increased from 13 to 97% and carbon dioxide decreased from 62 to 13 mg/l. The pH increased from 7.2 to 7.9.

### 2.3.3 Contact beds

Iron oxidation occurs by catalytic oxidation on the surfaces of the bed media. Normally the bed is made of gravel on to which oxides of minerals have previously been precipitated. Pyrolusite is an example of an oxide commonly used in catalytic oxidation. The oxide provides both oxygen and a surface area for the reaction. The function of the bed depend on the catalytic action of the absorbed oxides of manganese and iron and therefore the bed should never be washed clean (Leher et al., 1980). To maintain an adequate supply of the manganese oxides coating on the bed, periodic regeneration using potassium permanganate is necessary (Leher et al., 1980).

### 2.3.4 Ion exchange

This method should be considered for hard waters containing iron or manganese provided that the raw water is devoid of dissolved oxygen as the process removes only soluble iron only or manganese together with calcium and magnesium (Cox, 1969).

The precipitates tend to physically bind to the resin so firmly that regeneration by conventional processes is difficult. Due to this clogging problem, iron and manganese concentration should be 0.5 mg/l for each 17 mg/l of hardness up to a maximum of 10 mg/l. Hence for 10 mg/l, the maximum allowable hardness is 340 mg/l (Cox, 1969). The water should be clear and free of iron bacteria (Leher et al., 1980).

### 2.3.5 Diatomite filter

This filter is mainly used in turbidity removal in potable water treatment. When used for iron and manganese removal, calcined magnesite (MgO) and diatomaceous earth are fed into a rapid mixing tank where manganese (II) and iron (II) are oxidised to Mn(IV) and Fe(III) in a residence time of 5 - 10 minutes. The water is then filtered through a diatomaceous earth filter. Maintenance of the filter consists of adding new diatomaceous earth when the efficiency decreases until that time no improvement is found on further addition. This marks the end of the filter cycle. On exhaustion, the filter cake is removed and cleaning carried out before fresh media recharge (Baumann, 1971).

### 2.3.6    Biologically mediated iron removal

### 2.3.6.1    Contact filters

Both submerged and dry filters are discussed in this topic. Details of reactions involved in iron removal by dry filter were studied in advance of submerged filter but were later found to be similar in mechanism except for maturation period.

**Dry contact filter**

Dry filter is similar to gravity (rapid sand) filter but the filter media is not submerged in water. Removal of iron occurs by oxidation of soluble iron to iron Fe(III) by various types of iron bacteria which develop on the media surface and the precipitate is consequently filtered off (Huisman, 1977).

The principle of iron removal by dry filter was first explained as due to formation of a double ion layer around the media surface with the negative layer formed first. The electric double layer which surrounds every grain may then lose a lot of positive ions as the water trickles through the media bed. According to the rate of flow, an equilibrium is set up between the number of ions carried with the stream and those removed by the double ion layer. Thus, Fe(II) and Mn(II) will be bound more strongly than single charged ions. The higher valency ions will gradually replace the low valency ones. The reaction rate is directly proportional to the concentration of the

32

reacting ions. Reaction at the boundary of solid and liquid phase is higher for turbulent than for laminar flow (Kooijmans, 1955).

Later, iron removal was revealed to be more of a biological nature. Micro-organisms naturally occurring or purposely introduced in the raw water are absorbed on the filter material, where they multiply selectively using available iron and manganese. In dry filter the water is not completely saturated with oxygen, therefore there exists a favourable environment for iron and manganese bacteria (Grombach, 1985). Under conditions of low oxygen concentration, microbes that obtain their metabolic energy from the oxidation of dissolved iron and manganese to insoluble salts develop. It is notorious for clogging of borehole screens and groundwater filters (Grombach, 1985).

Due to presence of air in the filter media voids, the water velocity downward increases thereby increasing the strength of cross-currents. Hence Fe(II), Mn(II) ions and suspended particles come into contact with the filter media where the micro-organisms and catalytic surface action promotes filtration efficiency. This is the reason why dry filtration is preferred when the presence of organic matter presents problems in defferisation (Huisman, 1977).

The biological nature of iron removal by dry filter was confirmed in a pilot plant in Austria (Frischherz et al., 1985). The study revealed that the micro-organisms contained in raw water developed and occupied the void space in the filter bed within

a short time after the start of the operation. Microbiological investigations lead to isolation of extracelluar polymer structures in pure culture. The micro-organisms responsible for extracelluar polymers were found to be time dependent and hence the maturation of the filter.

Manganese oxidizing bacteria were found only sporadically at the beginning of the filtration run. Their number rose along with increasing age of the dry filter to form certain regular percentage (5-12%) of the biological slime (Frischherz et al., 1985). It was felt that the manganese bacteria activity is strongly affected in the upper portions of the filter where heavy iron precipitation occurs.

The iron removal process in the pilot plant was mainly determined by three factors (Frischherz et al., 1985).

- Configuration and area of the filter surface as held fast for a biocenosis.

- residence time of the water

- usable volume of voids for iron removal

The filtration rate applied was 3 - 10 m/hr depending on the concentration of iron in the raw water. In waters with low iron concentrations (eg 0.2 mg/l Fe), matured dry filters can operate at higher filtration rates of up to 60 m/hr without any breakthrough (Frischherz et al., 1985). Frischherz et al. (1985) studied the start up behaviour of the filter and found that at a filtration rate of 3 m/hr, iron removal occurred immediately

after the beginning of the operation. This initial removal was suggested to be of a chemical nature. At the same time micro-aerophilics were found in practically all the samples observed. Manganese removal or ammonium oxidation did not take place at the same time with iron. There was a time lag between ammonium oxidation and manganese removal (See Fig. 2.2.2).

The study on the start up behaviour of the pilot plant by Frischherz et al. (1985) found that:-

- Oxidation of iron started after about a day
- Ammonium oxidation to nitrite and nitrate occurred after six weeks and continued for the next three weeks.
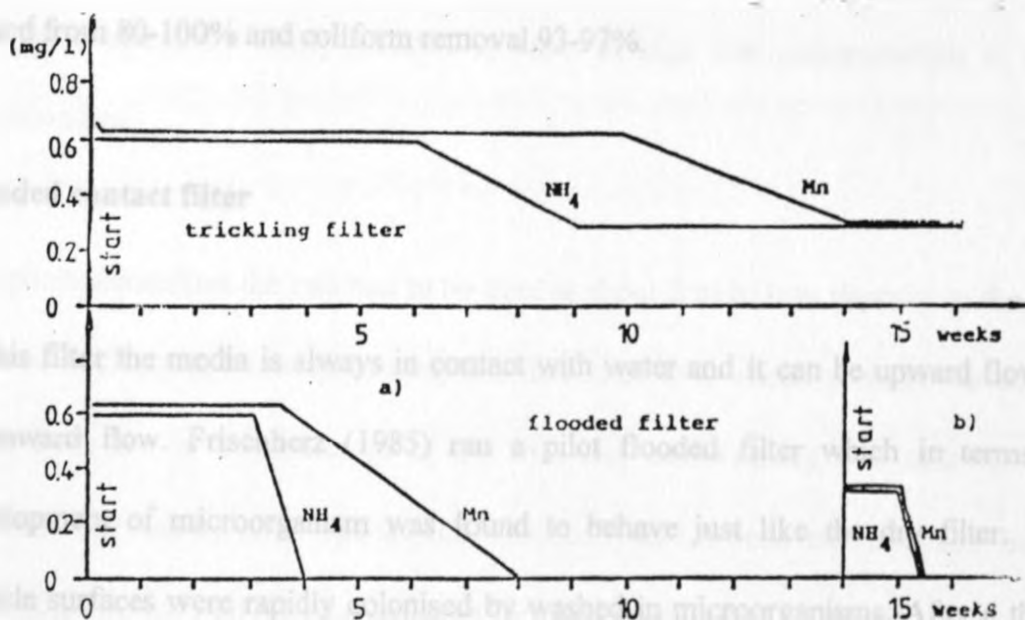


Fig. 2.2.2    Start-up behaviour of a trickling filter and a flooded filter (Frischherz et al., 1985)

Manganese oxidation began after ten weeks and continued steadily for four weeks after which the rate of oxidation of the filter remained unchanged.

Further investigations at different filtration rate showed that, the rate had no effect on the time pattern but the quality of the treated water as concerns iron, manganese and ammonium concentrations was greatly affected. Dry filter has been widely used in Finland where it is often combined with slow sand filter. Efficiencies of over 80% have been achieved (Ashenafi Kibret, 1986). A modified model of a dry filter (contact filter followed by a matrix filter) was studied on a laboratory scale by Joshi in 1989 and was found to have an iron removal efficiency of 85-90%. The manganese removal varied from 80-100% and coliform removal 93-97%.

**Flooded contact filter**

In this filter the media is always in contact with water and it can be upward flow or downward flow. Frischherz (1985) ran a pilot flooded filter which in terms of development of microorganism was found to behave just like the dry filter. The particle surfaces were rapidly colonised by washed in microorganisms. After a three hour filter run the bacteria count was $6-9 \times 10^3$ colonies per cubic centimetre of filter material. The bacteria colony count steadily rose to $2-3 \times 10^6$ colonies per cubic centimetre which was maintained for a major period. The quantitative change was also

accompanied by a qualitative change. The manganese oxidising bacteria count rose from 1-3% in the raw water to about 35% at the end of maturation phase.

Though a great number of different heterotrophic iron and manganese depositing bacteria were isolated from various different sites, their role in the environment has not been thoroughly explained and their metal depositing mechanisms are not well understood. It is assumed as a hypothesis that there is a close relationship between oxide deposition and extracelluar polymers. In this mechanism free $Mn^{2+}$ would bind to negatively charged polymer matrix. While the succession of development stages in the flooded filter was more or less the same as that of the dry filter, it took place at a faster rate than that of the dry filter. The performance of the flooded filter was however found to be highly affected in cases of high iron concentrations at high filtration rates.

At high concentration the rate had to be kept at about 2 m/h. Iron deposits in the top layer led to clogging hence shortening the filter runs. Even minor pressure variations in the filter led to breakthrough of the iron and backwashing was followed by relatively long start-up time. Upward flow flooded filter has been used in Orissa, India where efficiency of iron removal has been shown to range between 90 and 100 percent (Patnaik, 1991). It has also been tried successfully in levelled region of Northern Transvaal in South Africa. A six month observation indicated that efficiency in excess of 90% was achieved with respect to iron and turbidity removal (Cecil Chibi, 1991). A

form of downward flow flooded filter has been used in Kano, Nigeria with efficiency of 99.4 - 99.7% (Kwame Ofori-Tutu, 1989).

### 2.3.6.2 Biological oxidation reactions in iron removal by contact filter method

The method utilizes the presence of aerobic and anaerobic bacteria usually present in most aquifers. In reduced aquifers, nitrate, sulphate, manganese (IV) and iron (III) reducing bacteria are more abundant than bacteria with a potential to oxidize ammonia, sulphide, iron (II) and manganese (II). Both reducing and oxidizing bacteria can exist in a reduced aquifer (Gottfreund et al., 1985). The amount of aerobic or anaerobic iron bacteria does not depend on the aquifer depth (Rott, 1985). The development of these bacteria is supposed to be favoured whenever there is a change in redox potential in the aquifer (Gottfreund et al., 1985).

Development of different types of iron bacteria has been found to be dependent on the redox potential, pH and chemical characteristics of the aquifer. Due to their alkaline cell surface, iron bacteria are capable of oxidation of iron (II) to iron (III), an observation common in water works filters (Rott, 1985). Autotrophic bacteria oxidize Fe(II) to Fe (III) at pH 0.5 - 3.0 and gain energy for metabolism.

At pH above 4.0 and depending on the conditions, iron oxidation could be organically or chemically mediated. At higher pH values, iron oxidation is chemically mediated and aerobic bacteria gain energy from the reaction only if they anticipate chemical oxidation. Frischherz et al. (1985) revealed that Fe (II) can be biologically oxidized at pH 5 - 6 in presence of aerobic bacteria. Investigations by Richard (1978) in a biological pilot plant showed defferisation development at pH values of 6.0 - 6.3.

Pure culture observations showed gallionella ferrugiena development in the pH range 6.3 - 6.6 (Kucera and Wolfe, 1957). The identified aerobic iron oxidizing bacteria are gallionella, crenothrix, siderocapsa, leptothrix and sphaerofilus. Leptothrix and sphaerofilus are heterotrophic and require organic energy source. Crenothrix is facultative autotrophic. Gallionella is strictly autotrophic (Richard, 1978). The autotrophic bacteria derive their energy from the exothermic reaction shown in Equation 2.15 (Richard, 1978).

$$4Fe\,(HCO_3)_2 + O_2 + 2H_2O \; \text{----------} \; 4Fe(OH)_3 + 8CO_2 \; \text{.......(2.15)}$$

Lundgren and Dean (1979) developed a relationship showing the domains of some iron compounds and the main groups of iron bacteria involved in oxidation. According to their findings, iron carbonates and sulphates are substrates for leptothrix and gallionella organisms. Other conditions necessary for growth of these organisms are low oxygen partial pressure, low redox potential, neutral pH and continuous supply of

iron. Siderocapsa organisms function near Fe(II) - Fe (III) border line and mainly oxidizes organically bound iron which resist oxidation to ferric hydroxide. Siderocapsa liberates Fe (II) from the organic chelate and utilizes the organic part for nutrition. Oxidation of the liberated Fe(II) to form ferric hydroxide results in precipitates which accumulate on the cell surface (Lundgren and Dean, 1979).

Czekella et al. (1985) carried out a study on 21 groundwater treatment plants in West Germany which revealed that iron bacteria was responsible for the oxidation of iron Fe (II) to iron Fe(III). In the study, identification and photography of iron oxides in particular with biological structures was made by analyzing backwashing material and microbial settlement on the filter sand using scanning electron microscope in particular with the aid of in site time on growth experiments which show the formation of the oxides. The water in different plants varied in chemical quality with iron concentration ranging from 0.05 to 16.5 mg/l and pH values of 6.5 to 7.9

From the study the following bacteria were identified:-

(i)    Slime depositing rod shaped bacteria. The slime (extracelluar polymeric substances) termed as E.P.S. exhibited a high adsorption and oxidation of Fe(II). The slime contained equal proportions of Fe (II) and Fe (III) ions.

(ii)    Gallionella bacteria which was characterized by formation of fine ferric iron fibres. The fibres were formed by intracellular iron oxidation whereby iron produced by the cell was excreted in form of these fibres. The stock length as observed in 1 $cm^3$ of aqueous backwashing material was 46 km long which was found to be within the range of iron stalk production in pure culture (Czekella et al., 1985).

(iii)   Leptothrix ochracea bacteria which was characterized by thick mesh of ferric iron sheaths. This bacteria developed in low hardness water in comparison to gallionella. Gallionella required a higher calcium concentration (about 70 mg/l) than leptothrix ochracea (Czekella et al., 1985). The requirement of calcium by gallionella was confirmed by pure culture bacteria cultivation (Wolfe, 1958).

(iv)    Torothrix trichogenes bacteria was characterized by typical curved oxide structures which formed extremely fine, hair pin-like fibres (Czekella et al., 1985).

The principal regarding biological oxidation and precipitation has not been very definite. This is due to little experience in the field of biological water treatment.

### 2.3.6.3    Slow sand filtration and re-infiltration

Slow sand filtration offers a cost effective method for removal of dissolved iron and manganese from groundwater in comparison to conventional physical - chemical methods. The technique has been extensively applied in Finland with promising results. According to Hatva and Seppänen (1983), a slow sand filtration plant was successfully made by Placenta Limited whose results encouraged the Finnish National Fund for Research and Development to provide financial assistance for research in other several plants.

A slow sand filter for iron removal consists of a pretreatment unit and a filtration unit. The pretreatment unit is a contact filter which reduces iron content by oxidation and consequent sedimentation in a clarifier to avoid fast clogging of the treatment unit. In the filtration unit, the filtered water can either be taken to distribution or infiltrated into the aquifer.

Bacteriological analysis revealed the participation of micro-organisms in iron oxidation in the system (leptothrix and gallionella etc). According to a study by Hatva et al. (1985):-

(a)     Manganese remained in solution at $E_h$ of + 500 mV and pH 6.5 - 7.0

(b)     At $E_h$ of 600 mV and pH 6.5 - 7.0 manganese precipitated.

(c)     Oligotrophic conditions of raw water supported the growth of gallionella only.

(d)     Leptothrix, siderocapsa and ochrobium thrived in the infiltration basin.

Other studies have come up with the following observations:-

(i)     Iron is generally precipitated when the pH is high and $E_h$ is over + 230 mV (Hatva et al., 1971).

(ii)    Small amounts of oxygen (0.2mg/l) can rapidly change $E_h$ increasing it by more than 250 mV (Richard, 1979).

(iii)   Chemical oxidation of manganese could be achieved only by raising the pH to 9 or over (Hem, 1963; ).

(iv)    Both the $E_h$ and pH are important environmental factors for iron and manganese bacteria and each type has its own optimum $E_h$ and pH environment (Lundgren and Dean, 1979). Manganese bacteria require a higher level of $E_h$ than iron precipitating bacteria.

The biological processes prevailing in iron and manganese oxidation is not clearly understood. According to the classical theory, bacteria are able to exploit the energy derived from the oxidation of iron and manganese. The processes can be explained by Equations 2.16 and 2.17 (Beger, 1966).

$$2Feo + \tfrac{1}{2}O_2 + 3H_2O -> 2Fe(OH)_3 + 1058.6 \ KJ/mol \ .................. (2.16)$$

$$2Mno + O_2 + 2H_2O -> 2Mn(OH)_2 + 167.4 \ KJ/mol \ ................. (2.17)$$

43

The sheaths of capsules of iron and manganese bacteria are formed of polysaccharide molecules and their pH is high. It is on these sheaths where adsorption and autocatalytic oxidation occurs. Manganese oxidation reach a significant rate at ph = 8.5 (Hem, 1963). Studies have revealed that precipitation of iron and manganese is a result of the sum of different mechanisms, including the active bacterial oxidation and pure chemical oxidation of reduced iron and manganese. According to the study:-

(a)    Pretreatment reduces iron concentration of the raw water by 40 - 60%

(b)    Manganese reduction was 20%

(c)    Oxidation of ammonium compounds to nitrates and organic matter in general also seemed to affect the purification process. Iron and manganese oxidation was decreased in the presence of organic matter. Organic matter reduction was 82%.

## 3.0    OBJECTIVE OF THE STUDY

Development of iron removal plants in the Kenya - Finland Western Supply Programme area was meant to improve the quality of water in rural groundwater supplies where consumers complained of bad taste and colour. Consumers from areas with wells installed with iron removal plants have often complained of taste, colour and odour. This could have been caused by;

a.    Poor performance of the iron removal systems

b.    Lack of operation and maintenance technical skills required in the plants.

Several iron removal plants appear neglected and some have been abandoned. The overall objective is therefore to assess the success of iron removal plant development project in provision of improved quality water and their future sustainability. Thus the results will form the basis for future design development.

In achieving the overall objective the following will be determined.

(i)        The effectiveness   of the various models in water quality improvement in terms of iron concentration without affecting the other parameters.

Comparative cost of producing the desired standard of treated water in terms of capital investment and operation and maintenance.

(iii)     Assessment of the effect of technological sophistication in sustainability of iron removal plants. This includes availability of necessary technical skills.

(iv)     How far the locally available material can be used in development of desired iron removal systems without compromising the standard of the treated water.

# 4.0   METHODOLOGY

## 4.1   Introduction

Iron removal by contact filters has been in progress in the programme area since 1985. Thus some background information is available. Performance evaluation of iron removal installation meant for the rural area is mainly geared to evaluation of water quality improvement in those parameters that cause objection of the water by the consumers e.g colour, turbidity and taste. In addition to those parameters which are mainly associated with aesthetic qualities of the water improvement in other parameters that can cause health problems should also be monitored. This would ensure that there is no deterioration of the quality in other parameters. This is especially important where the water could leach out other chemical contaminations from the filter media. Monitoring of bacteriological quality variations was carried out to determine any improvement or deterioration. Though groundwater is expected to be free of bacteriological contamination shallow wells have occasionally shown some contamination. This was monitored by examination of coliform organisms. In the programme area, groundwater is free from contaminating minerals apart from excessive iron concentration in isolated cases.

## 4.2 Methods

The study started with a general survey of the existing iron removal plants. During the survey, operation and maintenance conditions were assessed. Raw and treated water samples from the plants were analyzed for chemical and physical qualities as is normally done during routine work. This provided preliminary data for site selection. The following parameters were analyzed.

- Colour
- Turbidity
- Conductivity

- Total Hardness
- Total Alkalinity
- Chloride

- Sulphate
- Nitrite
- Nitrate

- Ammonia
- Manganese

- Permanganate Value (PV) - Iron

Site selection was based on; (i) general water quality variation, (ii) variation in iron concentration and (iii) operation and maintenance conditions. Therefore the selected sites were to be preferably located in different water quality zones.

In rural community water supplies, water demand vary widely during the cause of the day. This meant that the study had to be designed to cover both peak and off peak hours. Thus the initial step was to identify the two periods. During the two periods the retention time of the plant varied which consequently affected the filter performance and hence the quality of the treated water. If peak hours seemed to fluctuate, the study

48

was spread over the day at appropriate intervals so that there was no risk of missing peak hours.

Initially each plant was cleaned by the consumers as they do during routine operations. The volume of water drawn from the plant at peak hours was determined using a calibrated pail. The flow rate was also determined from the average of the discharge rates when the water level in the filter was constant.

The following parameters were analyzed in raw and treated water.

- pH                                - Total Iron (Fe Total)
- Ferrous Iron (Fe$^{++}$)          - Dissolved oxygen    - Ammonia
- Nitrite                           - Nitrate
- Permanganate Value (PV)           - Total Coliform
- Manganese

Dissolved oxygen, redox potential and pH are important parameters affecting the occurrence of soluble manganese and iron in groundwater. Monitoring of variations in these parameters during iron removal process can yield information valuable for design improvement. Redox potential $E_h$ was not measured due to lack of appropriate equipment. More details on modification of methodology are found in Chapter 6.0. Bacterially medicated iron removal is also associated with ammonia removal through nitrification reactions. Nitrification processes tend to compete with iron removal

49

processes and occur in late stages of the filter cycle. Monitoring of relative reduction of ammonia in relation to iron removal is therefore important and can provide important information for future plant development.

Relative reduction in permanganate value in relation to iron can also yield information on the chemical relationship between iron and organic matter. That is whether the iron is present in form of organo metallic complex or not. Iron in this form is difficult to remove and calls for careful design consideration. Most of the parameters were analyzed in the field. Permanganate value and coliform determination were carried out at Kakamega Water quality laboratory. Iron and turbidity are the most important performance parameters. Due to their close association with iron and turbidity respectively, colour and manganese variations were closely monitored. The plants were left to run until the consumers themselves were not satisfied with the quality or the flow rate decreased due to clogging.

Previous studies in iron removal by contact filtration have confirmed involvement of various types of iron bacteria. Therefore the study was initially designed to include isolation and characterization of the various types of iron bacteria which could be involved. The following type of bacteria have been identified in various contact filter pilot plants.

(i) Gallionella

(ii) Torothrix

50

(iii)  E.P.S. producing bacteria  (Extra cellular polymer structures)

(iv) Crenothrix

(v)  Metallogenium

(vi) Leptothrix

The iron removal plants were also expected to reduce bacteriological contamination especially in shallow wells. Therefore iron removal plants were also monitored for effectiveness in coliform removal.

The effect of disinfection of the wells with iron removal installation is an important preliminary step in the confirmation of the bacterial involvement in iron removal. Disinfection with chlorine is known to produce chlorinous tastes especially in turbid water which could cause objection of a well. Also the resultant reduction in iron removal efficiency can cause abandonment of a well. Therefore this can be tried in a pilot plant but not a well in use.

### 4.2.1   Laboratory work

#### 4.2.1.1 Physico-chemical analysis

The following parameters were analyzed on site using HACH DR 2000 portable environmental laboratory and HACH digital titrator.

- Turbidity           - Colour           - Iron

- Manganese        - Ammonia       -Nitrite

- Nitrates           - Sulphate        - Total

-Total Hardness       - Chlorides

- Total Alkalinity

- Conductivity, measured with a portable conductivity meter

- Oxygen, measured with a dissolved oxygen meter

- pH, measured with a portable pH meter

- Total coliform, measured by membrane filter technique.

- Turbidity, measured with a portable turbiditimeter Hach model 16800.

The Hach methods are derived from "Standard Methods For Examination Of Water And Waste Water, " but modified to fit application in the field by packing various reagents into adequate quantities in form of powder pillows which are convenient for use in the field. In determination of Alkalinity, Chlorides and Hardness, the Hach methods are the same as standard methods for water and waste water analysis but

again modified to use a digital titrator where the titrating solution is packed in a cartridge which can be fitted into the titrator in the field. The solid reagents are in form of powder pillows.

**Oxygen**

**Method - Oxygen Electrode**

Dissolved oxygen concentration was measured using an oxygen electrode. The electrode comprises of platinum cathode and a silver anode forming a cell. The cell is normally covered with gas permeable membrane to shield it from contamination with liquids and solids.

**Principle**

When 0.5 - 0.8 volt is applied across the anode and cathode, any oxygen which passes through the membrane will be reduced at the cathode causing a current to flow. The magnitude of the current will depend on the oxygen concentration in the sample.

**Turbidity**

**Method - Nephelometer method**

**Principle**

The sample is illuminated from the light source through a slit to form a parallel beam. The scattered light is detected by a phototube placed at right angle to the light source. Therefore, nephelometer measures the amount of scattering unlike a turbidimeter which measures the transmitted light at 180° to the light source. Measurement of turbidity involves calibration using known standards within particular ranges of turbidity.

**Iron**

**Phenanthroline Method**

**Principle**

The method depends on the fact that 1, 10 - phenanthroline combines with $Fe^{++}$ to form a complex ion which orange in colour. The colour produced conforms to Beers Law and is readily measured by Photometric or Visual comparison. To measure the total iron i.e Ferric ($Fe^{+++}$) and Ferrous ($Fe^{++}$), Ferric Iron is first reduced to Ferrous state. Ferric iron precipitates are dissolved using hydrochloric acid and then reduced using hydroxylamine.

**Manganese**

**Method - Periodate Oxidation**

Oxidation of manganese from its lower valence state to the highly coloured permanganate ion makes it possible to determine manganese concentration using a spectrophotometer. The colour produced is directly proportional to the concentration of manganese present over a considerable range of concentration in accordance to Beer's Law.

**Ammonia**

**Method - Nesslerization**

**Principle**

Treatment of Ammonia nitrogen with Nessler reagent or Potassium Mercuric Iodide in alkaline solution forms a yellowish-brown colloidal dispersion whose intensity of colour is directly proportional to the amount of ammonia originally present. The colour intensity can be matched by visual comparison or by photometric methods.

**Sulphate**

**Method - Turbidimetric**

**Principle**

Barium Sulphate tends to precipitate in a colloidal form and this tendency is enhanced in the presence of a Sodium Chloride - hydrochloric acid solution containing glycerol and other organic compounds. The turbidity level depends on the concentration of sulphate ions and above 10 mg/l the sample can be analyzed by taking smaller samples and diluting them to the recommended 50 ml size. The level of turbidity is detected by photometric methods.

**Nitrate**

**Method - Phenoldisulphonic Acid**

**Principle**

Nitrates react with phenoldisulphonic acid to produce a nitro derivative that in Alkaline solution rearranges its structure to form a yellow coloured compound with characteristics that conform to Beer's Law. The colour produced can best be measured by photometric methods.

**Nitrite**

**Method - Modified Griess - Ilosvay diazotization**

**Principle**

Under acid conditions, nitrite ion as nitrous acid reacts with the amino group of sulphanilic acid to form a dazonium salt that combines with I-naphthylamine hydrochloride to form a bright coloured pinkish red azo dye. The colour produced is directly proportional to the amount of nitrite present in the sample and determination of the amount can be done either visually using standards or by photometric means.

**Colour**

**Method - Potassium Chloroplatinate colour standards**

**Principle**

Solutions of Potassium Chloroplatinate tinted with small amounts of cobalt chloride yield colours very close to natural colours. The colour produced by 1 mg/l of platinum (as $K_2PtCl_6$) is taken as the standard unit of colour. Colour matching can be done visually using Nessler tubes or by photometric methods.

**Titrations**

Total hardness, total alkalinity and chlorides are determined by volumetric methods.

**Hardness**

**Method - EDTA Titrimetric**

**Principle**

The hardness forming ions, Calcium and Magnesium, react with EDTA by chelation to form stable complexes. During titration, the excess EDTA react with the indicator Eriochrome T dye to produce a blue colour marking the end point. Therefore, the wine red colour due to reaction of Eriochrome T dye with the divalent ions, Calcium and Magnesium, at pH 10 slowly turns blue at the end of titration. The amount of hardness can be calculated from the volume and concentration of EDTA.

**Alkalinity**

**Method - Titration with N/50 Sulphuric Acid**

**Principle**

Dilute sulphuric acid reacts with the hydroxide, bicarbonate and carbonate alkalinities of the water neutralizing it and converting to carbon dioxide. In normal practice, total alkalinity is usually determined and represents all the acid consumed by all three types of alkalinity. Total alkalinity determination involves acid titration using methyl orange indicator which marks the end point by colour change at pH 4.5.

Caustic and carbonate alkalinity is be determined by using phenolphthalein indicator which marks the end point at pH 8.3 when the solution turns from pink to colourless. The amount of alkalinity can hence be calculated from the volume and concentration of the acid.

## Chlorides

### Method - Mercuric Nitrate

### Principle

At pH 2.5, mercuric ions combine with chloride ions to form poorly ionized mercuric chloride. As the mercuric nitrate is added the chloride concentration approaches zero, the mercuric ions concentration increases to a level where it becomes significant as the mercuric nitrate is added. The indicator used is diphenylcarbazone which combines with mercuric ions to form distinct purple colour. A pH indicator, xylene cynol FF, which is blue-green at pH 2.5 is also included to improve the end point. The concentration of chlorides can be calculated from the titration volume and the concentration of mercuric nitrate.

In Hach method of titration, no calculations are required. The concentration of the parameter in question is read directly on the digital titrator making it suitable for field work.

## Conductivity

### Method - Conductivity Meter

### Principle

An electrical current can flow through a solution of an electrolyte where the current is carried by ions which move towards the electrodes immersed in the solution.

Conductivity of a solution is a measure of its ability to carry an electrical current and varies both with the number and type of ions the solution contains. Conductivity can be measured in a conductivity cell (solution) by connecting it to a wheatstone bridge which allows the measurement of the electrical resistance provided by the solution. A conductivity meter is designed to interpret resistance in terms of reciprocal value of the conductance. Dissolved solids concentrations can be approximated by multiplying the value of conductivity by an empirical factor varying from 0.55 to 0.9.

**pH**

**Method - Glass Electrode**

**Principle**

A glass electrode is used in conjunction with a standard calomel reference electrode. The single electrode potential established on the glass electrode is determined by the concentration of hydrogen ions in the solution in relation to the concentration in the electrolyte within the electrode. The potential is determined by the relative concentrations of adsorbed hydrogen ions on the two sides of the glass membrane. Since the glass electrode is in essence a calomel electrode, its inherent electromotive force cancels that of a calomel reference electrode and the potential established on a glass electrode is equal to that generated by the difference in hydrogen ion activities on the two sides of the glass membrane.

The potential developed by a glass electrode is so small that measurements cannot be made by ordinary galvanometers. Hence a vacuum tube (pH meter) is commonly employed and calibrated to read pH directly.

### 4.2.2   Coliform Bacteria Culturing

**Method - Membrane Filtration**

**Procedure**

Using a sterile bottle a sample was taken during the afternoon high peak demand period and transported to Kakamega laboratory for incubation. The most distant study sites were Siginga and Khayinga and the trip took about two hours. In the laboratory, 100 ml of the sample was filtered using a vacuum pump through a nitrocellulose membrane of 0.45 mm pore size that allows water through while retaining the bacteria. The filter was then placed on a ready to use wet nutrient(mackonky broth) pad on a petri-dish. The petri-dish was then placed in an incubator regulated to maintain 35 - 37°C for 24 hours. After 24 hours the petri-dish was observed for bacteria colony development. The colonies were then counted and expressed as coliform per 100 ml. Bacterial enumeration in this technique assumes that each colony originated from a single bacterium.

## 4.3    Modification of methods

Due to unavoidable circumstances, the methodology was modified as follows:

1.    In the iron removal systems developed by Finnish expatriates in Kenya-Finland Western Water Supply Programme, iron bacteria and related organisms were thought to play a more important role in ferrous iron oxidation than physico-chemical mechanisms. It is for this reason that it was initially thought necessary to isolate and characterize the microorganisms. Bacteria growth is known to be influenced by environmental factors eg. availability of nutrients, pH, temperature etc. Investigations on the variation of the types of bacteria in different environments and their rates of activity would be a step forward in further development of the existing systems. This work was not done due to lack of funds for hiring the services of an experienced microbiologist.

2.    Redox potential, $E_h$ variation at various stages of filtration was not monitored due to lack of equipment. Redox potential measurement in the field required special equipment. The sponsor experienced an unexpected shortage of funds and was unable to purchase the equipment. Redox potential is an important parameter in the design of groundwater differisation plant.

On further consideration and discussion with the supervisors, it was agreed that the two parameters, redox potential and iron bacteria are mainly important in the

62

determination of mechanisms and processes but not primarily necessary for performance evaluation. Initially, study in variations of the following factors in various models was thought necessary in provision of additional information for further improvement of the iron removal plants.

(i)     - hydraulic loading

(ii)    - filter depth

(iii)   - water distribution over the surface

(iv)    - size of the media and

(vi)    - mode of filter ventilation.

Since there was no time the filters exceeded the hand pump discharge, it was found unnecessary to try performance under higher loads. Parameters (ii) to (vi) could not be studied for the following reasons:

a)      These parameters had very little variation if any in the adopted model (Siginga and Khayinga). Most of the existing plants of this model were situated in areas of differing water quality characteristics especially in terms of iron.

b)      The other two existing models (Shivanga and Lugusi) were completely different in design and only one unit of each model existed and were situated in different water quality zones in terms of iron concentration.

63

As mentioned earlier, most of water quality complaints in rural water supplies in western Kenya were mainly aesthetic in nature. These were mostly associated with physical qualities though in certain cases could also be due to chemical causes.

Taste, colour and turbidity problems were the most frequently reported cases. Later, these problems came to be associated with iron content of the groundwater. Due to its low concentration relative to iron, there were no cases where manganese caused a serious concern. Manganese is usually associated with iron and that is why its removal by these plants was also considered important. The presence of manganese and its removal efficiency yields important information in the improvement of design of the existing models. Emphasis was laid on the performance in iron and turbidity removal. The corresponding bacteriological improvement has also been shown.

## 5.0    FIELD INVESTIGATIONS

Field investigations started with survey on the existing iron removal plants. During the survey it was established that most of the plants had broken down and disconnected from the hand pumps. According to Operation and Maintenance Department this was caused by poor maintenance whereby the plants got clogged up with Iron precipitates (Ferric hydroxide, $Fe(OH)_3$) forcing the consumers to draw raw water by disconnecting the pumps. The Community and Training Department did not adequately  to train the consumers on participation in maintenance of their water supplies. Some iron removal plants were deliberately disconnected from the well when it was realised that change of types of pumps resulted in water quality improvement. Corrosion of galvanised iron rising pipes in shallow wells contributed to increased iron concentrations. Use of Nira AF 85 pumps in shallow wells solved the corrosion problem. Nira AF 85 has plastic rising pipes. Corrosion problem in boreholes was solved by use of Afridev pump (which has a plastic rising pipe) instead of India Mark II. Earlier corrosion problems in boreholes wells were due to use of black steel casings which were later changed to plastic.

In total twenty four iron removal plants were visited.  At the time of the study only five plants were in operation.  Three of these five plants were very poorly maintained and urgently needed rehabilitation.  In order to start the study the necessary rehabilitation was carried out in Lugusi and Shivanga.

### Summary of Field Survey

The total number of Iron removal plants = 24

### Survey results

| Encountered Cases | No. in Category | % | Comments |
| --- | --- | --- | --- |
| 1. Operating | 5 | 22.5 | Well maintained, good community participation and trained maintenance team |
| 2. Disconnected deliberately | 8 | 30 | Iron concentration decreased after changing pump and or well structures |
| 3. Clogged and abandoned | 6 | 25 | Poor maintenance due to lack of implementation-training co-ordination and closeness to alternative sources |
| 4. Clogged up but the well used through bypass | 5 | 22.5 | Poor maintenance due to lack of training-implementation co-ordination and community paticipation |

Khayinga and Siginga models Fig.5.1.3 dominated with a total number of twenty two plants while one of each models, Lugusi Fig.5.1.1 and Shivanga Fig.5.1.2 existed.

Lugusi model was the oldest in the area but had been dismantled in three sites due to some of the reasons given above.

The model shown in Figure 5.1.3 was the dominant and therefore found in most places. The reason given for adoption of this model was low capital investment coupled with simple technology.

## 5.1 Description of models and observations during the study

Designs of the existing models are shown in Figures 5.1.1 5.1.2, and 5.1.3.

### 5.1.1 Lugusi Iron removal plant

This plant is situated at Lugusi, East Isukha location in Kakamega district. This model was developed by Juhani Heinanen (1985) the then Project Chemist. As shown in Figure 5.1.1 and Plate 9, the plant consists of two concrete tanks interconnected by a pipe at the bottom. The first tank is for aeration followed by a filtration unit. The filter is provided with a backwash drain pipe at the bottom.

**Operation and Maintenance**

Water is pumped into the aeration tank where it is spray aerated from the top. From this tank it flows into the filtration unit through the interconnecting pipe at the base. Oxidation of iron starts at the aeration tank and continues into the filtration unit. The filtration is upward flow and the treated water is drawn from the top. After some period of operation the filter is expected to clog and must be backwashed.

**Fig. 5.1.1    Iron removal installation at Lugusi**

69

Backwashing is carried out by opening the drain valve at the bottom of the filter. Unless there are leaking valves, this is the only routine maintenance expected in this plant.

The plant was initially rehabilitated and backwashed on 11th July 1993. The plant was ran from 12th July to 29th October 1993. Two peak periods were identified i.e one in the morning and the other in the afternoon. The morning peak was not well defined and seemed to oscillate between 11.00 a.m and 2.00 p.m. The afternoon peak was well defined and occurred at 4.00 - 6.30 p.m. The consumers of this plant never seemed to be concerned with its maintenance. There is no well committee and nobody is in-charge of the operation and maintenance. Reasons for the mismanagement as given from the water programme were:-

(i)     The water quality was initially very poor and there was an alternative source quite close.

(ii)    The owner of the land where the well is situated was very uncooperative

The same reasons were given by the consumers but when the well was rehabilitated the number of consumers rose tremendously. The communities appreciated the improved quality of their water in terms of physical characteristics and it was felt that

they only require mobilisation to start a committee to maintain the well. Throughout the operation period the flow rate and quality of the treated water remained fairly constant. Therefore the filter was never backwashed.

### 5.1.2 Shivanga Iron removal plant

This plant is situated at Shivanga, Central Kabras location, Kakamega district. The model was developed from a prototype developed earlier by DANNIDA in India. In India it was shown to have an iron removal efficiency of 97-99.0% (S. Viegand, 1984). The plant is made up of an aeration unit resting on an upward flow filter (see Figure 5.1.2 and Plate 10). Both units are made of concrete. The aeration unit is connected to the filter through a PVC pipe. The filter is provided with a backwash drain valve at the base.

### Operation & Maintenance

Water is pumped and sprayed from the top into the aeration chamber. The water trickles over the gravel into the PVC pipe and finally into the filter through the sieve at the bottom. The filtered water is drawn from the top. The clogging of the filter is marked by overflow in the aeration chamber and is followed by backwashing. Backwashing is done by opening the backwash drain valve at the bottom. The plant was backwashed and operation started on 6th July 1993. It operated until 2nd

September when it was due for backwashing. During the operation period it was noticed that the high peak period fell between 4.00 - 5.30 p.m. There were two low peaks early in the morning, 6.00 - 8.00 a.m and 12.00 -2.00 p.m. The consumer communities were not keen to participate in maintenance and there was no existing well committee. Before the study began, the well had clogged up and the consumers had resulted in drawing water at the aeration spray. It was found that if the plant was left to clog completely, it become very difficult to backwash and required emptying the media to remove the slimy masses manually. Throughout the operation period the consumers appreciated water quality improvement but were not committed to its maintenance. Discussion with the consumers revealed that the main reason for not participating in maintenance of this plant was availability of alternative sources. There is a spring only 300 m away. During the study a teacher from a nearby primary school was trained in backwashing and it is hoped that he will be able to convince the community on the importance of availability of clean water before the well is abandoned.
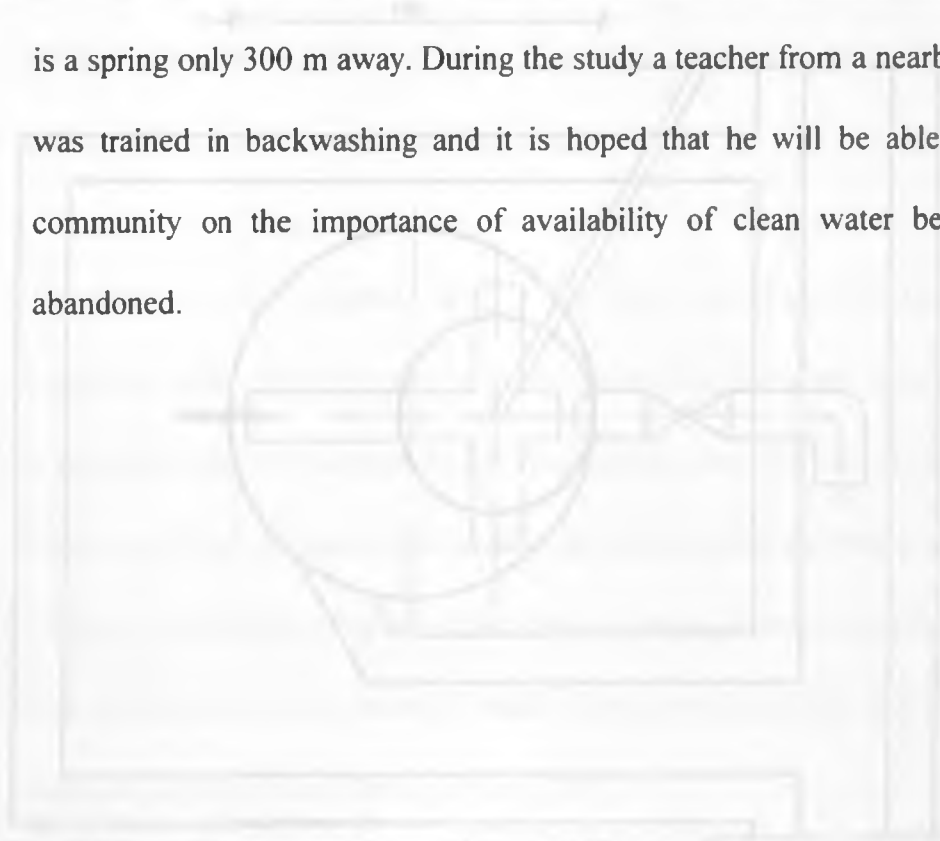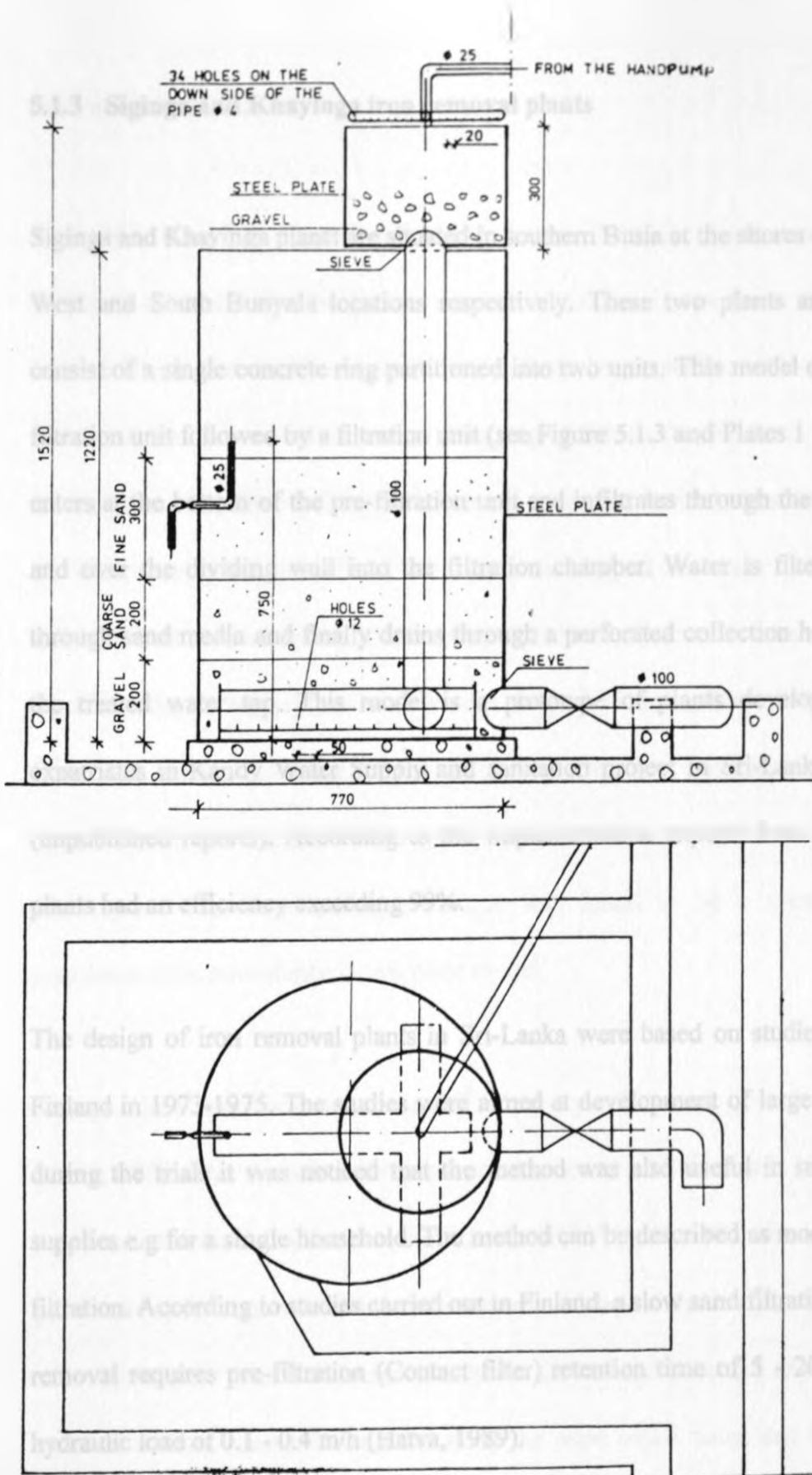
Fig. 5.1.2    Iron removal installation at Shivanga

### 5.1.3 Siginga and Khayinga iron removal plants

Siginga and Khayinga plants are situated in southern Busia at the shores of L. Victoria in West and South Bunyala locations respectively. These two plants are identical and consist of a single concrete ring partitioned into two units. This model comprises a pre-filtration unit followed by a filtration unit (see Figure 5.1.3 and Plates 1 to 8). The water enters at the bottom of the pre-filtration unit and infiltrates through the gravel upwards and over the dividing wall into the filtration chamber. Water is filtered downwards through sand media and finally drains through a perforated collection hose which feeds the treated water tap. This model is a prototype of plants developed by Finnish expatriates in Kandy Water Supply and sanitation project in Sri-Lanka in 1983-1984 (unpublished reports). According to the implementation experts from this project the plants had an efficiency exceeding 99%.

The design of iron removal plants in Sri-Lanka were based on studies carried out in Finland in 1973-1975. The studies were aimed at development of large scale plants but during the trials it was noticed that the method was also useful in small scale water supplies e.g for a single household. The method can be described as modified slow sand filtration. According to studies carried out in Finland, a slow sand filtration plant for iron removal requires pre-filtration (Contact filter) retention time of 5 - 20 minutes and a hydraulic load of 0.1 - 0.4 m/h (Hatva, 1989).

74

## Operation and Maintenance

The water from the hand pump enters the pre-filtration chamber at the base and infiltrates upwards over the gravel. From this chamber it overflows the dividing wall into the filtration unit. The filtered water collects into a perforated hose at the bottom and is fed into the treated water tap. Clogging of the filter is followed by reduced well discharge and the filter is filled with floating masses of ferric hydroxide (see Plates 1 to 8). Backwashing of this model involves removing all the sand media, cleaning it manually and then replacing it. The procedure normally used in washing a slow sand filter is raking the top layer to remove mud and precipitates without disturbing the whole filter. The manual cleaning of the filter sand was not only found to increase the contamination but also resulted in poor physio-chemical quality at the beginning of the filter cycle. This backwashing technique was found to be a great operation and maintenance inconvenience in this plant model.

Siginga plant was backwashed on 28th February, 1993 and operation started on 1st March, 1993. The operation continued uninterrupted until 6th April, 1993 when it was backwashed. Data collection then continued until 21st April, 1993. The consumers of this plant were quite committed to the maintenance of their water supply. There was a very active committee which collected money for the maintenance and any breakdown was rectified without delay. During the study the plant broke down and was repaired the following day. It was surprising that the well is quite close to alternative sources like

Nzoia river and irrigation canals, but the consumers are quite committed to the maintenance of this plant. It was understood that the initial mobilisation and training was done very well and also availability of funds from the flourishing fishing industry contributed to its success. The activities and the level of maintenance in both Siginga and Khayinga plants were quite similar. There was a well committee in charge of collection of well maintenance funds and repairs were carried out promptly. Siginga plant was backwashed in the morning of $2^{nd}$ June, 1993. Operation and data collection continued until $22^{nd}$ June, 1993 when it was backwashed and left to run until $29^{th}$ June, 1993 when the data collected was found adequate. In both wells there were two peak periods. The low peak was at 11.00 - 2.00 p.m while the high peak was at 3.00 - 6.00 p.m.

Fig. 5.1.3    Iron removal installation at Siginga and Khayinga

## 6.0    RESULTS AND DISCUSSIONS

The data was collected as outlined in the methodology and is discussed in this chapter.

Detailed results are shown in Appendices A1 to A4. Performance results are shown in

Tables 6.1 and 6.2.

Water quality summary for selected parameters is shown in Table 6.3.

**Table 6.1    Mean values at steady state conditions (peak period)**

| PLANT | REDUCTION /EFFICIENCY EVALUATION | IRON (mg/l) | MANGANESE (mg/l) | TURBIDITY (mg/l) |
|---|---|---|---|---|
| SIGINGA | R | 16.7 | 1.66 | 64.00 |
| | F | 0.7 | 1.31 | 2.72 |
| | % Remaining | 4.2 | 78.2 | 4.25 |
| | % Reduction | 95.8 | 21.08 | 95.75 |
| KHAYINGA | R | 14.08 | 1.48 | 165 |
| | F | 0.58 | 1.01 | 7.0 |
| | % Remaining | 3.9 | 68.24 | 4.24 |
| | % Reduction | 96.1 | 31.76 | 95.76 |
| SHIVANGA | R | 0.59 | 0.44 | 25 |
| | F | 0.19 | 0.14 | 1.27 |
| | % Remaining | 5.29 | 31.82 | 5.1 |
| | % Reduction | 94.71 | 68.18 | 94.9 |
| LUGUSI | R | 0.9 | 0.30 | 43.5 |
| | F | 0.13 | 0.13 | 2.22 |
| | % Remaining | 14.44 | 43.33 | 5.1 |
| | % Reduction | 85.56 | 56.67 | 94.9 |

# Table 6.2 Water quality results at some iron removal plants visited during field investigations

| POINT SOURCE | Colour mg Pt/l | Turbidity N.T.U | Perm. No. mg KmnO/l | Conduct. µS/cm | Total Iron mg Fe/l | Manganese mg Mn/l | pH Units | Total Hardness mg CaCo₃/l | Total Alkalinity mg CaCo₃/l | Chloride mg Cl/l | Fluoride mg F/l | Nitrite mg NO₂/l | Nitrate mg NO₃/l | Ammonia mg NH₃/l | Sulphate mg SO₄/l |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C-5150 R | 25 | 5 | - | 103 | 0.74 | 0.00 | 6.55 | 79 | 74 | 9 | 0.12 | 0.03 | 0.16 | 0.80 | 0.00 |
| C-6119 R | 6 | 2.0 | - | 114 | 0.02 | 0.00 | 6.35 | 67 | 80 | 4 | 0.19 | 0.003 | 0.25 | 0.00 | 0.00 |
| C-6188 R | 6 | 1.5 | 8.90 | 107 | 2.03 | 0.00 | 6.23 | 66 | 72 | 7 | 0.30 | 0.002 | 0.28 | 0.00 | 0.00 |
| C-6108 R | 19 | 3 | 4.7 | 138 | 0.09 | 0.00 | 7.67 | 106 | 60 | 10 | - | 0.002 | 0.06 | 0.11 | 0.00 |
| KA-331 R | 39 | 3 | 7.9 | 145 | 0.00 | 0.00 | 6.53 | 63 | 64 | 47 | - | 0.004 | 0.08 | 0.13 | 0.00 |
| C-5481 R | 6 | 0.8 | 3.16 | 56 | 0.09 | 0.00 | 6.20 | 26 | 29 | 1.0 | - | 0.003 | 0.220 | 0.21 | 0.30 |
| C-6177 R | 8 | 1.0 | | 160 | 0.04 | 0.00 | 6.21 | 75 | 79 | 4 | - | 0.01 | 1.06 | 0.12 | 0.00 |
| C-5462 R | 3 | 0.5 | 1.7 | 68 | 0.05 | 0.1 | 6.03 | 48 | 33 | 1 | - | 0.001 | 0.308 | 0.6 | 0.12 |
| KA-69 R | 120 | 6 | - | 136 | 1.33 | 0.31 | 6.38 | 70 | 82 | 8.0 | 0.19 | 0.36 | 2.2 | 2.16 | 0.00 |
| F | 58 | 15 | - | 137 | 0.37 | 0.28 | 6.9 | 76 | 92 | 8.0 | 0.2 | 1.2 | 3.4 | 1.10 | 0.00 |
| C-5157 R | 2 | 0.3 | | 110 | 0.14 | 0.2 | 6.10 | 51 | 56 | 4 | 0.20 | 0.05 | 1.1 | 0.01 | 1.3 |
| C-5634 R | 115 | 1 | 9.48 | 66 | 0.75 | 1.30 | 6.3 | 75 | 110 | 5 | 0.09 | 0.01 | 2.7 | 0.04 | 1 |
| F | 4 | 0.8 | 1.3 | 144 | 0.10 | 0.2 | 6.3 | 48 | 70 | 2 | 0.1 | 0.1 | 4 | 0.2 | 0 |
| C-5152 R | 48 | 7 | 3.16 | 124 | 1.04 | 0.1 | 6.18 | 65 | 70 | 13 | | 0.00 | 0.132 | 0.20 | 1.00 |
| KA-223 R | 29 | 4 | 0 | 106 | 2.28 | 0.01 | 6.4 | 52 | 126 | 5.0 | 0.0 | | 2.3 | 3.3 | 26 |
| F | 6 | 2 | - | 133 | 0.60 | 0.30 | 6.8 | 35 | 90 | 5.0 | 0.0 | 3.1 | 2.8 | 1.5 | 23 |
| BS-12 R | 125 | 77 | 8.8 | 1750 | 14.7 | 1.3 | 6.0 | 296 | 450 | 16 | 0.3 | 0.02 | 0.14 | 0.12 | 0.00 |
| F | 20 | 13 | - | 1725 | 4.3 | 1.0 | 5.92 | 290 | 406 | 16.3 | 0.3 | 0.6 | 0.2 | 0.04 | 0.00 |
| BS-9 R | 150 | 56 | 9.8 | 550 | 15.6 | 12.3 | 6.3 | 167 | 251 | 13 | 0 | 0 | 0 | 3.9 | 0.00 |
| F | 45 | 8 | - | 498 | 6.7 | 1.9 | 6.21 | 154 | 240 | 12.8 | 0 | 0.42 | 2.4 | 1.4 | 0.00 |
| C-5933 R | 20 | 12 | | 120 | 1.9 | 0.60 | 72 | 43 | 63 | 4 | 0.45 | 0.06 | 2.6 | 0.12 | 0.00 |
| BS-17 R | 200 | 130 | 11.7 | 840 | 17.6 | 2.4 | 6.5 | 136 | 97 | 31 | 0.5 | 0.27 | 5.1 | 3.6 | 120 |

**Table 6.2 (Cont.)   Water quality results at some iron removal plants visited during field investigations**

| POINT SOURCE | Colour mg Pt/l | Turbidity N.T.U | Perm. No mg Kmno₄/l | Conduct. μS/cm | Total Iron mg Fe/l | Manganese mg Mn/l | pH Units | Total Hardness mg CaCo₃/l | Total Alkalinity mg CaCo₃/l | Chloride mg Cl/l | Fluoride mg F/l | Nitrite mg NO₂/l | Nitrate mg NO₃/l | Ammonia mg NH₃/l | Sulphate mg SO₄/l |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BS-102 R | 100 | 8.5 | 11.06 | 182 | 1.6 | 0.00 | 6.6 | 62 | 88 | 6.5 | 0.2 | 0.09 | 7.48 | 0.87 | 24 |
| BS-103 R | 45 | 54 | 10.4 | 115 | 2.5 | 0.00 | 6.8 | 50 | 64 | 3.0 | 0.2 | 0.00 | 4.4 | 0.73 | 0.00 |
| C-6182 R | 15 | 8 | 2.8 | 114 | 1.4 | 0.4 | 6.1 | 28 | 50 | 1.0 | 0.2 | 0.01 | 4.4 | 0.06 | 0.00 |
| BS-517 R | 18 | 2 | 0.0 | 717 | 0.16 | 0.0 | 6.9 | 181 | – | 34 | – | – | 0.5 | 0.2 | 14.0 |
| BS-15 R | 100 | 38 | 2.53 | 122 | 0.64 | 0.0 | 6.2 | 36 | 50 | 1.0 | 0 | 0.03 | 0 | 0.0 | 5 |
| BS-14 R | 70 | 22 | 11.3 | 300 | 2.0 | 1.6 | 6.5 | 82 | 141 | 3.0 | 0.15 | 0 | 0 | 2.0 | 14 |
| BS-10 R | 150 | 98 | 16.43 | 950 | 6.1 | 1.9 | 6.9 | 214 | 307 | 93 | 0.41 | 0.63 | 0 | 0.83 | 30 |

KEY

R        Raw water

F        Filtered or treated water

80

**Table 6.3     Water quality summary for selected parameters**

| SOURCE | PARAMETER | MINIMUM | | MAXIMUM | | MEAN VALUE | |
|---|---|---|---|---|---|---|---|
| | | R | F | R | F | R | F |
| SHIVANGA | Manganese, mg/l | 0.00 | 0.00 | 2.1 | 0.61 | 0.4 | 0.2 |
| | Iron, mg/l | 1.5 | 0.00 | 8.4 | 0.18 | 3.6 | 0.1 |
| | Colour, mgPt/l | 1.7 | 0.00 | 239 | 61.0 | 64 | 1.9 |
| | Turbidity, NTU | 1.5 | 0.00 | 58 | 3.0 | 24 | 1.0 |
| | pH, units | 5.5 | 5.95 | 6.84 | 7.82 | 6.3 | 6.7 |
| KHAYINGA | Manganese, mg/l | 1.1 | 0.07 | 1.95 | 1.84 | 1.5 | 1.0 |
| | Iron, mg/l | 11.5 | 0.00 | 17.2 | 1.65 | 15.4 | 0.46 |
| | Colour, mgPt/l | 110 | 2.0 | 290 | 75 | 160 | 8.9 |
| | Turbidity, NTU | 51 | 0.5 | 190 | 15 | 163 | 5.0 |
| | pH, units | 6.1 | 5.73 | 6.63 | 6.85 | 6.4 | 6.3 |
| SIGINGA | Manganese, mg/l | 0.5 | 0.3 | 3.0 | 2.0 | 1.5 | 1.1 |
| | Iron, mg/l | 18 | 0.05 | 14.3 | 10 | 17 | 1.0 |
| | Colour, mgPt/l | 90 | 9 | 250 | 60 | 162 | 3.7 |
| | Turbidity, NTU | 43 | 1.0 | 75 | 11.5 | 56 | 2.5 |
| | pH, units | 5.5 | 5.2 | 6.9 | 6.65 | 6.0 | 6.3 |
| LUGUSI | Manganese, mg/l | 0.00 | 0.00 | 0.42 | 0.2 | 0.2 | 0.1 |
| | Iron, mg/l | 1.0 | 0.00 | 2.2 | 1.1 | 1.6 | 0.1 |
| | Colour, mgPt/l | 40 | 1.0 | 190 | 20 | 79 | 4.1 |
| | Turbidity, NTU | 8 | 0.5 | 62 | 3.2 | 33 | 1.4 |
| | pH, units | 5.35 | 6.17 | 6.4 | 7.2 | 5.3 | 6.7 |

## 6.1 Water quality trend in general

As shown in Table 6.3 above, Appendices A1 and A2, it is clear that in all iron removal plants, filtration resulted in water quality improvement in terms of iron, manganese, turbidity and colour. The variation of these parameters through the filter cycle is shown in Table 6.4.

**Table 6.4    Daily mean values at Khayinga plant**

| DATE | Fe TOT mg/l | COL. mgPt/l | TURB. NTU | COND. ms cm⁻¹ | T/ALK mgCaCO₃/l | T/HARD. mgCaCO₃/l | pH units | MANG. mg/l |
|------|-------------|-------------|-----------|---------------|------------------|---------------------|----------|------------|
| 1.3.93 | R 15.7 F 0.56 | 6.3 | 2.8 | 1643 | 450 | 345 | 6.4 | 1.4 |
| 3.3.93 | R 16.6 F 0.47 | 4.6 | 4.3 | 1497 | - | - | 6.0 | 1.4 |
| 5.3.93 | R 157 F 0.47 | 6.7 | 4.1 | - | - | - | 6.0 | 1.4 |
| 8.3.93 | R 13.2 F 0.19 | 6.5 | 3.0 | 1655 | 440 | 401 | 6.2 | 1.2 |
| 10.3.93 | R 15 F 0.34 | 6.3 | 4.6 | - | 447 | 384 | 6.3 | 0.9 |
| 12.3.93 | R 14.7 F 0.45 | 7.0 | 4.2 | 1667 | 421 | - | 6.3 | 0.6 |
| 15.3.93 | R 15.5 F 0.56 | 9.6 | 5.4 | 1715 | 405 | 395 | 6.2 | 0.6 |
| 17.3.93 | R 14.7 F 0.6 | 10 | 4.6 | 1597 | 390 | 376 | 6.3 | 0.5 |
| 19.3.93 | R 14.7 F 0.6 | 10.1 | 5.2 | 1674 | 359 | 376 | 6.3 | |
| 22.3.93 | R 15.4 F 0.53 | 24.8 | 6.4 | 1637 | 467 | 418 | 6.3 | 0.8 |
| 24.3.93 | R 14.6 F 1.0 | 12.8 | 4.6 | 1677 | 397 | 383 | 6.3 | 0.7 |
| 26.3.93 | R 15.4 F 1.2 | 169 15.8 | 122 9.2 | 1651 1640 | 424 408 | 409 368 | 6.3 6.2 | 1.4 0.72 |
| 27.3.93 | R 16 F 0.41 | 117.4 14,2 | 102 5.1 | 1637 1592 | 475 439 | 415 393 | 6.3 6.1 | 1.7 1.4 |

**Table 6.4 (Cont.)    Daily mean values at Khayinga plant**

| DATE | Fe TOT mg/l | COL. mgPt/l | TURB. NTU | COND. ms cm$^{-1}$ | T/ALK mgCaCO$_3$/l | T/HARD. mgCaCO$_3$/l | pH units | MANG. mg/l |
|---|---|---|---|---|---|---|---|---|
| 30.3.93 | R 16<br>F 0.41 | 117.8<br>14 | 96<br>5.6 | 1665<br>1637 | 469<br>440 | 422<br>392 | 6.3<br>6.1 | 1.8<br>1.7 |
| 3.4.93 | R 16.2<br>F 0.43 | 121<br>12.2 | 85<br>5.4 | 1619<br>1579 | 470<br>436 | 427<br>394 | 6.4<br>6.3 | 1.7<br>1.5 |
| 6.4.93 | R 13.7<br>F 0.4 | 115.8<br>9 | 77<br>3.6 | 1681<br>1593 | 460<br>454 | 406<br>331 | 6.4<br>6.4 | 1.7<br>1.6 |
| 8.4.93 | R 14.4<br>F 0.3 | 212<br>5 | 87<br>6.9 | 1548<br>1534 | 458<br>452 | 343<br>316 | 6.3<br>6.3 | 1.5<br>1.4 |
| 13.4.93 | R 15<br>F 0.2 | 156<br>3.8 | 76<br>2 | 1633<br>1597 | 448<br>405 | 392<br>367 | 6.4<br>6.3 | 1.5<br>1.2 |
| 14.4.93 | R 15<br>F 0.34 | 170<br>5 | 109<br>4.2 | 1612<br>1583 | 432<br>437 | 389<br>300 | 6.4<br>6.3 | 1.3<br>0.8 |
| 15.4.93 | R 15.6<br>F 0.33 | 148<br>4.4 | 25<br>5.4 | 1609<br>1580 | 488<br>438 | 385<br>352 | 6.3<br>6.2 | 1.6<br>0.8 |
| 16.4.93 | R 15<br>0.32 | 163<br>6.4 | 88<br>5.3 | 1688<br>1636 | 453<br>382 | 409<br>410 | 6.4<br>6.3 | 1.5<br>0.8 |
| 19.4.93 | R 15.5<br>0.32 | 133<br>7.1 | 123<br>5.4 | 1599<br>1574 | 485<br>434 | 406<br>396 | 6.4<br>6.3 | 1.4<br>0.7 |
| 21.4.93 | R 14.4<br>F 0.28 | 162<br>7.7 | 114<br>5.2 | 1606<br>1565 | 460<br>384 | 439<br>404 | 6.4<br>6.3 | 1.6<br>0.6 |

**Table 6.5    Daily mean values at Siginga plant**

| DATE | Fe TOT mg/l | COL. mgPt/l | TURB. NTU | COND. ms cm⁻¹ | T/ALK mgCaCO₃/l | T/HARD. mgCaCO₃/l | pH units | MANG mg/l |
|------|-------------|-------------|-----------|---------------|------------------|-------------------|----------|-----------|
| 2.6.93 | R 17.2<br>F 6.5 | 210<br>3.5 | 55<br>10.75 | 563<br>478 | 231<br>248 | 200<br>208 | 6.4<br>6.5 | 2.5<br>1.0 |
| 3.6.93 | R 17.1<br>F 0.79 | 125<br>3.8 | 54<br>1.54 | 466<br>383 | 262<br>262 | 204<br>200 | 6.66.5 | 1.4<br>1.4 |
| 4.6.93 | R 16.4<br>F 0.4 | 118<br>4 | 40<br>1.1 | 477<br>393 | 262<br>262 | 195<br>191 | 6.5<br>6.4 | 1.4<br>1.4 |
| 7.6.93 | R 16.7<br>F 0.14 | 105<br>4 | 53<br>1.8 | 467<br>458 | 257<br>253 | 200<br>193 | 6.5<br>6.4 | 1.2<br>1.3 |
| 9.6.93 | R 17<br>F 0.2 | 129<br>1.7 | 60<br>1.8 | 469<br>468 | 260<br>256 | 198<br>192 | 6.5<br>6.4 | 1.5<br>1.1 |
| 10.6.93/ | R 17.2<br>F 0.27 | 125<br>1.15 | 57.3<br>1.4 | 459<br>378 | 266<br>211 | 202<br>198 | 6.0<br>6.3 | 1.5<br>1.3 |
| 11.6.93 | R 17<br>F 0.3 | 160<br>4 | 55<br>1.5 | 469<br>462 | 264<br>259 | 202<br>197 | 6.4<br>6.2 | 1.4<br>1.3 |
| 14.6.93 | R 17.1<br>F 0.14 | 184<br>2.5 | 58<br>1.4 | 476<br>472 | 265<br>260 | 208<br>198 | 6.5<br>6.4 | 1.3<br>0.86 |
| 17.6.93 | R 17<br>F 0.12 | 181<br>2 | 57<br>1.7 | 490<br>473 | 290<br>267 | 208<br>194 | 6.5<br>6.4 | 1.4<br>0.9 |
| 18.6.93 | R 16.7<br>F 0.15 | 244<br>1.8 | 49<br>1.1 | 459<br>465 | 281<br>263 | 195<br>175 | 6.5<br>6.4 | 1.7<br>1.1 |
| 21.6.93 | R 15.8<br>F 0.13 | 161<br>5 | 56<br>2.0 | 447<br>440 | 290<br>265 | 219<br>207 | 6.5<br>6.4 | 1.5<br>0.92 |
| 22.6.93 | R 16.1<br>F 0.4 | 162<br>4.4 | 61<br>1.3 | 462<br>429 | 296<br>273 | 212<br>190 | 6.4<br>6.3 | 1.7<br>0.8 |
| 23.6.93 | R 15.4<br>F 1.15 | 219<br>1.8 | 61<br>4.8 | 451<br>437 | 293<br>268 | 224<br>212 | 6.6<br>6.4 | 1.4<br>1.4 |
| 25.6.93 | R 16.1<br>F 0.55 | 131<br>3.1 | 63<br>2.1 | 463<br>449 | 260<br>249 | 199<br>188 | 6.5<br>6.2 | 1<br>0.93 |
| 29.6.93 | R 16<br>F 0.4 | 176<br>3.3 | 62<br>2.7 | 473<br>451 | 276<br>264 | -<br>264 | 6.5<br>6.3 | 1.1<br>0.8 |

**Table 6.6    Daily mean values at Shivanga plant**

| DATE | Fe TOT. mg/l | COL. mgPt/l | TURB. NTU | COND. ms cm⁻¹ | T/ALK mgCaCO₃/l | T/HARD. mgCaCO₃/l | pH units | MANC mg/l |
|---|---|---|---|---|---|---|---|---|
| 28.6.93 | R 3.2 F 0.12 | 57 2 | 17 1.03 | 203 217.5 | 128 144 | 121 119.5 | 6.1 6.8 | 0.22 0.18 |
| 6.7.93 | R 3.3 F 0.14 | 71 1.84 | 30 1.1 | 174 213 | 118 140 | 125 151 | 6.3 6.7 | 0.69 0.35 |
| 7.7.93 | R 3.3 F 0.09 | 43 3.2 | 29 1.2 | 214 242 | 155 159 | 125 143.5 | 6.3 6.6 | 0.16 0.3 |
| 8.7.93 | R 3.3 F 0.1 | 65 2.6 | 27 1.7 | 84 109.7 | 129 134.7 | 101 132 | 6.5 6.8 | 0.71 0.7 |
| 14.7.93 | R 3.9 F 0.1 | 81 2.8 | 41 1.2 | 148 173 | 135 152.6 | 111 118 | 6.6 7.2 | 0.15 0.1 |
| 19.7.93 | R 2.1 F 0.09 | 99 3.3 | 19 1.0 | 169 201.7 | 118 144 | 102 107 | 6.4 6.9 | 1.2 0.03 |
| 22.7.93 | R 4.0 F 0.08 | 65 2.3 | 17 1.3 | 131 164 | 123 143 | 167 126 | 6.5 5.9 | 0.16 0.01 |
| 23.7.93 | R 3.2 F 0.1 | 58 1.3 | 17 0.6 | 116 127 | 130 144 | 113 130 | 6.4 6.9 | 0.6 0.12 |
| 24.7.93 | R 4.0 F 0.1 | 53 1.0 | 26 0.8 | 101 111 | 109 148 | 111 130 | 6.2 7.0 | 0.71 0.59 |
| 25.7.93 | R 3.6 F 0.07 | 50 0.9 | 30 0.9 | 66 75 | 75 97 | 89 91 | 6.3 6.7 | 0.53 0.36 |
| 27.7.93 | R 4.8 F 0.12 | 77 1.6 | 24 0.7 | 184 200 | 106 140 | | 6.3 | |
| 28.7.93 | R 3.1 F 0.1 | 64 1.8 | 23 0.8 | - - | 111 152 | 97 99 | 6.4 6.5 | 0.31 0.165 |
| 29.7.93 | R 4.5 F 0.08 | 53 1.3 | 30 0.8 | 212 230 | - - | - - | 6.3 6.9 | 0.1 0.02 |

86

Table 6.6 (Cont.)     Daily mean values at Shivanga plant

| DATE | Fe TOT. mg/l | COL. mgPt/l | TURB. NTU | COND. ms cm⁻¹ | T/ALK mgCaCO₃/l | T/HARD. mgCaCO₃/l | pH units | MANG mg/l |
|---|---|---|---|---|---|---|---|---|
| 30.7.93 | R 4.1<br>F 0.01 | 102<br>2.1 | 29<br>0.5 | 251<br>229 | 204<br>138 | 69<br>99 | 5.9<br>6.4 | 0.2<br>0.05 |
| 31.7.93 | R 3.2<br>F 0.09 | 56<br>2.7 | 23<br>0.8 | 219<br>212 | 155<br>159 | 155<br>118 | 6.0<br>6.6 | 0.4<br>0.20 |
| 1.8.93 | R 4.7<br>F 0.13 | 123<br>3.4 | 28<br>1.1 | 219<br>199 | 123<br>123 | -<br>82 | 6.0<br>6.9 | 0.3<br>0.23 |
| 2.8.93 | R 4.8<br>F 0.1 | 103<br>1.8 | 25<br>1.1 | 223<br>214 | 168<br>138 | 124<br>96 | 6.6<br>6.9 | 0.4<br>0.05 |
| 3.8.93 | R 3.0<br>F 0.07 | 54<br>1.4 | 16<br>1.4 | 210<br>222 | 111<br>150 | 168<br>100 | 6.4<br>6.7 | 0.5<br>0.35 |
| 5.8.93 | R 4<br>F 0.09 | 57<br>1.3 | 20<br>0.7 | 204<br>223 | -<br>- | 81<br>- | 6.1<br>6.6 | 0.54<br>0.03 |
| 10.8.93 | R 4.2<br>F 0.16 | 42<br>1.4 | 19<br>0.7 | 210<br>219 | 127<br>145 | | | |
| 11.8.93 | R 3.2<br>F 0.13 | 40<br>1.6 | 20<br>0.9 | 194<br>211 | 134<br>140 | | | |
| 12.8.93 | R 3.9<br>F 0.15 | 65<br>1.2 | 16<br>0.7 | 200<br>221 | 144<br>154 | 88<br>123 | 6.4<br>6.8 | 0.58<br>0.2 |
| 16.8.93 | R 2.6<br>F 0.17 | 54<br>1.7 | 50<br>5.0 | 201<br>223 | 128<br>154 | 117<br>155 | 6.3<br>6.9 | 0.32<br>0.17 |
| 17.8.93 | R 2.2<br>F 2.24 | 34<br>2.7 | 13<br>1.2 | 197<br>223 | 180<br>205 | 138<br>- | 5.9<br>6.5 | 0.27<br>0.16 |
| 20.8.93 | R 3.6<br>F 0.19 | 42<br>1.1 | 25<br>0.6 | 208<br>216 | 133<br>153 | -<br>192 | 5.9<br>6.6 | 0.35<br>0.14 |
| 2.9.93 | R 3.4<br>F 0.13 | 55<br>1.2 | 20<br>0.7 | 215<br>224 | 138<br>129 | 136<br>131 | 6.4<br>6.5 | R 0.5<br>0.3 |

**Table 6.7    Daily mean values at Lugusi plant**

| DATE | Fe TOT mg/l | COL. mgPt/l | TURB. NTU | COND. ms cm⁻¹ | T/ALK mgCaCO₃/l | T/HARD. mgCaCO₃/l | pH units | MANG. mg/l |
|------|-------------|-------------|-----------|----------------|------------------|--------------------|----------|------------|
| 12.7.93 | R 123<br>F 0.128 | 126<br>13.2 | 41<br>1.32 | 109<br>152 | 74<br>102 | 54<br>82 | 6<br>6.6 | 0.3<br>0.18 |
| 15.7.93 | R 1.5<br>F 0.075 | 75<br>6.25 | 22<br>1.5 | 111<br>165 | 70<br>69 | 52<br>73 | 6<br>6.35 | 0.3<br>0.23 |
| 21.7.93 | R 1.1<br>F 0.12 | 88<br>6.2 | 23<br>1.46 | 100<br>135 | 64<br>98 | 62<br>90 | 6.3<br>6.9 | 0.3<br>0.18 |
| 28.7.93 | R 2.1<br>F 0.112 | 86<br>4.1 | 33<br>1.16 | 121<br>162.7 | 66<br>88.7 | 53<br>75.3 | 6.3<br>6.8 | 0.2<br>0.11 |
| 2.8.93 | R 1.5<br>F 0.09 | 82<br>2.2 | 35<br>0.98 | 125<br>140.7 | 82<br>105.8 | 58<br>80.8 | 6<br>6.7 | 0.2<br>0.09 |
| 10.8.93 | R 1.7<br>F 0.13 | 96<br>2.95 | 38<br>1.43 | 115<br>149.5 | 78<br>123.3 | 56<br>87.3 | 6<br>6.7 | 0.3<br>0.28 |
| 16.8.93 | R 1.6<br>F 0.1 | 76<br>1.9 | 43<br>1.2 | 137<br>170 | 69<br>82 | 56<br>74 | 6<br>6.9 | 0.2<br>0.08 |
| 24.8.93 | R 1.6<br>F 0.1 | 76<br>2.6 | 44<br>1.5 | 94<br>122 | 81<br>102 | 63<br>91 | 6<br>6.8 | 0.3<br>0.1 |
| 30.8.93 | R 2<br>F 0.1 | 88<br>2.7 | 43<br>1.2 | 118<br>142 | 72<br>108 | 53<br>88 | 6<br>6.5 | 0.3<br>0.5 |
| 6.9.93 | R 1.5<br>F 0.09 | 62<br>2.7 | 18<br>1.42 | 79<br>139 | 77<br>111.5 | 61<br>84 | 6<br>6.6 | 0.3<br>0.08 |
| 14.9.93 | R 1.8<br>F 0.09 | 67<br>3.8 | 26<br>2.15 | 86<br>129 | 63<br>86.7 | 70<br>99.5 | 6<br>6.6 | 0.3<br>0.04 |
| 21.9.93 | R 1.3<br>F 0.09 | 67<br>2.2 | 30<br>1.45 | 90<br>145 | 74<br>104.9 | 59<br>93.8 | 6<br>6.5 | 0.3<br>0.00 |
| 29.9.93 | R 1.5<br>F 0.11 | 63<br>1.9 | 22<br>1.47 | 79<br>130 | 54<br>79 | 81<br>128 | 6<br>6.6 | 0.2<br>0.04 |
| 4.10.93 | R 1.8<br>F 0.09 | 58<br>2.6 | 26<br>1.4 | 76<br>128 | 73<br>94 | 65<br>87 | 6<br>6.7 | 0.2<br>0.05 |
| 13.10.93 | R 1.5<br>F 0.05 | 73<br>4.25 | 36<br>1.5 | -<br>120.5 | -<br>87.5 | -<br>76.5 | 6<br>6.8 | -<br>0.075 |
| 19.10.93 | R 1.5<br>F 0.11 | 77<br>4.9 | 40<br>1.1 | -<br>114 | -<br>133 | -<br>85 | 6<br>6.6 | -<br>0.055 |
| 29.10.93 | R 1.3<br>F 0.13 | 78<br>4.6 | 37<br>1.5 | -<br>126 | -<br>110 | -<br>103.5 | 6<br>6.8 | -<br>0.10 |

In Siginga and Khayinga plants, pH decreased after filtration but was still within a tolerable range for drinking water standards. The pH decrease could be attributed to the following reactions:

$$4\ Fe(HCO_3)_2 + O_2 + H_2O \rightleftharpoons 4\ Fe(OH)_3 + 8CO_2 \quad \text{.................... (6.1)}$$

The resultant release of Carbon Dioxide raises the pH of the water especially if the water is well aerated. Nitrafication reaction depresses the pH by production of Carbonic Acid (as shown below) and therefore if both reactions (6.1) and (6.2) are occuring in the same water, then the pH of the treated water could be slightly lower than expected. This explains the importance of good ventillation in biological iron removal systems for waters of high organic matter.

$$55NH_4^+ + 76O_2 + 109HCO_3. \xrightarrow{\text{Bacteria}} \text{More bacteria} + 54NO_2 + 57H_2O + 104H_2CO_3 \ \text{.... (6.2)}$$
$$(C_5\ H_7\ NO_2)$$
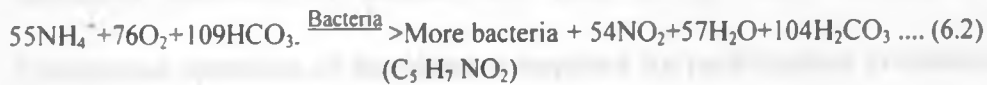
$C_5\ H_7\ NO_2$ represent bacteria cells. The production of carbonic acid results in pH depression. This reaction results from autotrophic metabolism by Iron bacteria. In these two plants there was also a marked decrease in conductivity after filtration. This is expected due to removal of ferrous ions.

In Lugusi and Shivanga plants, pH and conductivity levels increased after filtration but fell within the acceptable standards. The release of carbon dioxide from deep waters results in pH elevation. Increase of conductivity in Shivanga and Lugusi plants could be explained as due to possible ion exchange as the water passes over the media surface. In Siginga and Khayinga plants, filtered water quality varies all over the day. The variation has been shown to follow the demand pattern.

The best quality water is drawn very early in the morning. The reason is that this water has stayed in the plant overnight and whatever the reactions involved in iron removal tend to be favoured by retention time. Decrease in water quality is noted as more and more water is drawn in the course of the day. The maximum amount of water in each day is drawn in the late afternoon followed by another low peak in the late morning hours. Continuous operation of the plants is required for performance evaluation. It was observed that a steady state condition was established only in the afternoon peak. The peak in different wells oscillated between 3.00 and 6.30 pm. Therefore, only the afternoon peak was used in the performance evaluation. Performance evaluation for the four iron removal plants concentrated mainly on iron and turbidity. Emphasis has been on efficiency rather than processes and mechanisms.

## 6.2    Siginga Plant

**Table 6.8    Average parameter removal efficiency at Siginga Plant**

| 1. | Iron | 95.80% |
|----|------|--------|
| 2. | Turbidity | 95.75% |
| 3. | Manganese | 21.10% |

From Figure 6.2.1, the following is evident:

i.    Immediately after backwashing the well both the iron content of filtered water and the average flow increased sharply.

ii.    The iron content of the filtered water decreased after approximately 2 days and stabilised at a low level for the following 14 days.

iii.    The filter cycle is 20 days. The method of backwashing as mentioned earlier destabilizes the clogged filter and therefore takes two days to stabilise.

iv.    As indicated by the flow rate and filtered water iron levels, backwashing is necessitated by clogging rather than deterioration of filtered water quality.

Figures 6.2.2 and 6.2.3 show that iron removal efficiency does not vary with discharge and that both raw and filtered water turbidities vary with the rate of discharge. Immediately before the end of the filter cycle, turbidity of the filtered water becomes independent of the discharge. Figure 6.2.4 shows that the efficiency of turbidity removal increases with the age of the filter. It also shows that at the initial stages, the turbidity of the filtered water is dependent on the raw water turbidity.
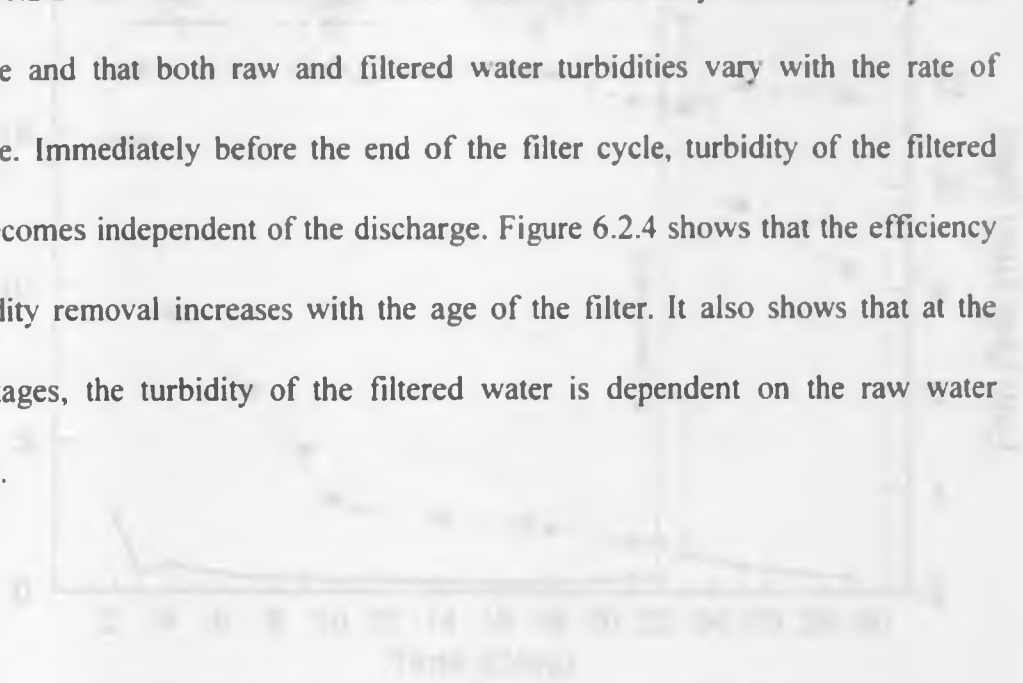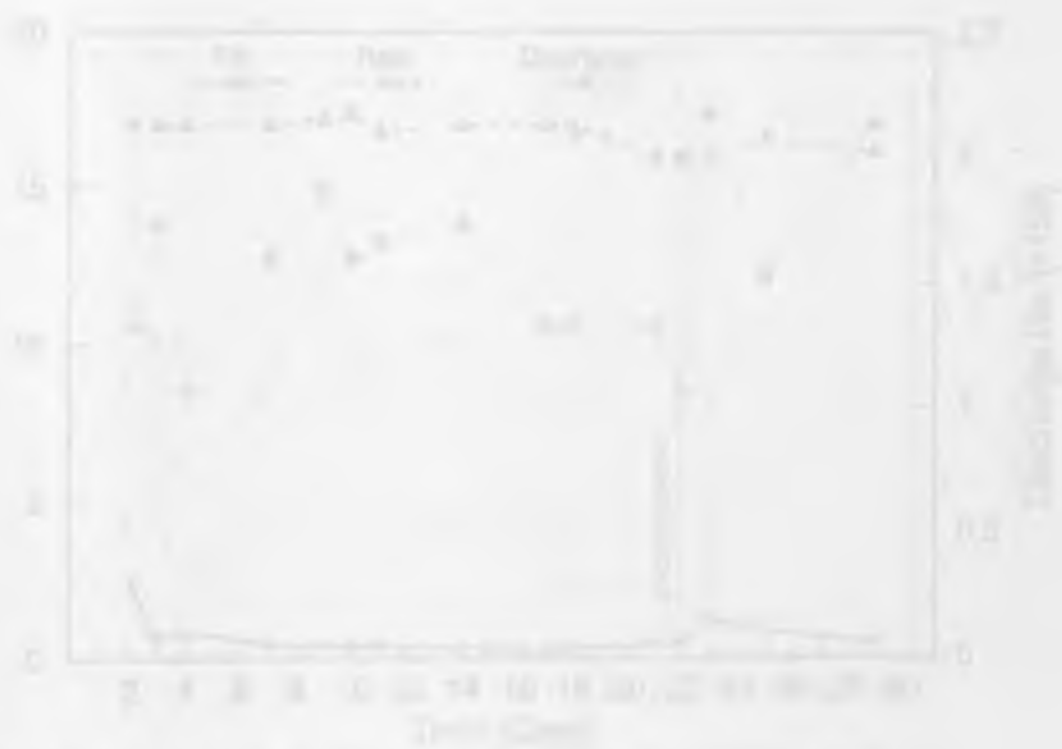
Fig 6.2.1  Iron and Flow rate versus Time at Siginga Plant



Fig 6.2.2  Iron and Discharge versus Time at Siginga Plant

Fig 6.2.3   Turbidity and Flow rate versus Time at Siginga Plant
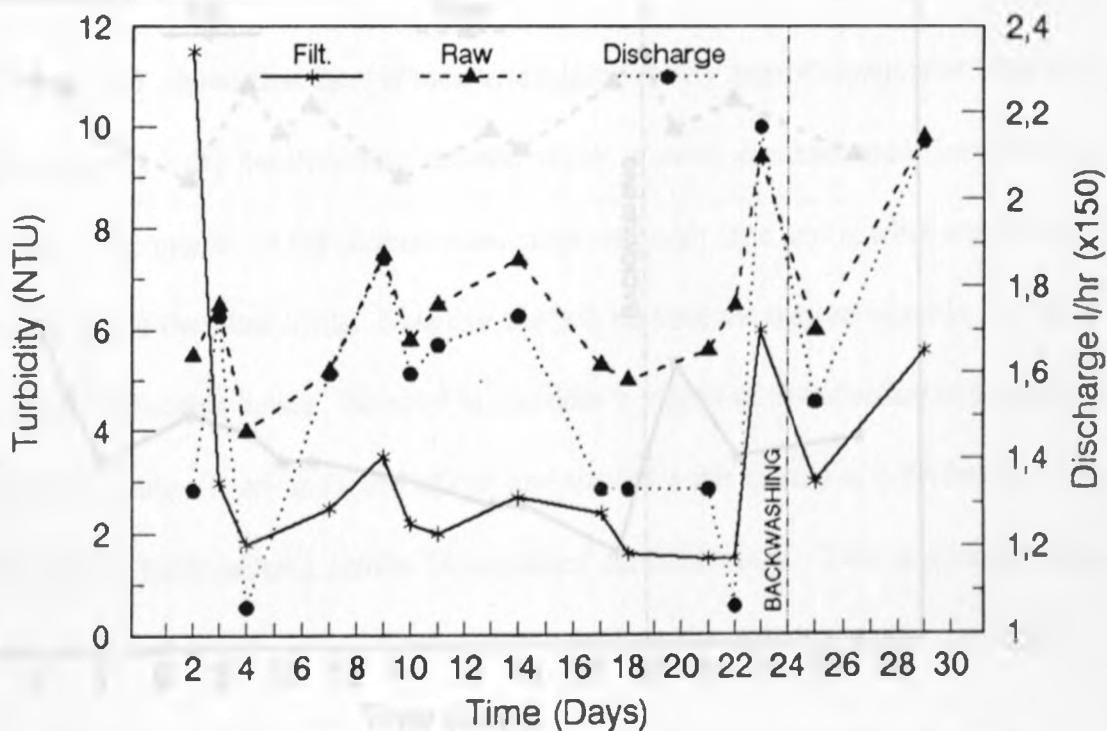


Fig 6.2.4   Turbidity and Discharge versus Time at Siginga Plant
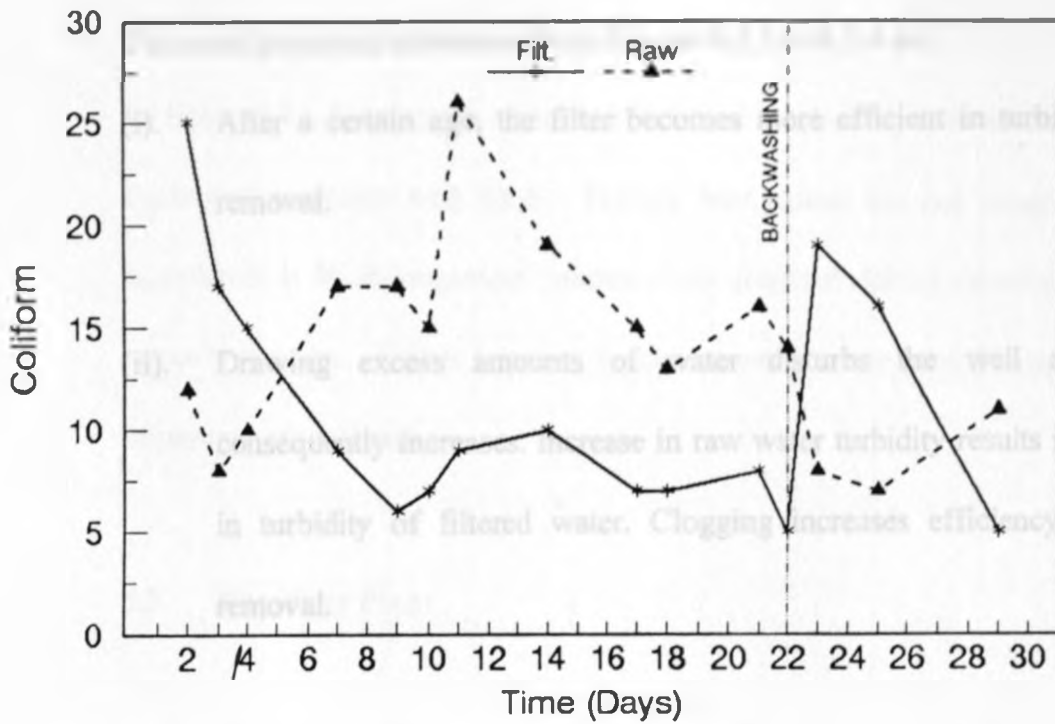
Fig 6.2.5   Coliform  versus Time at Siginga Plant
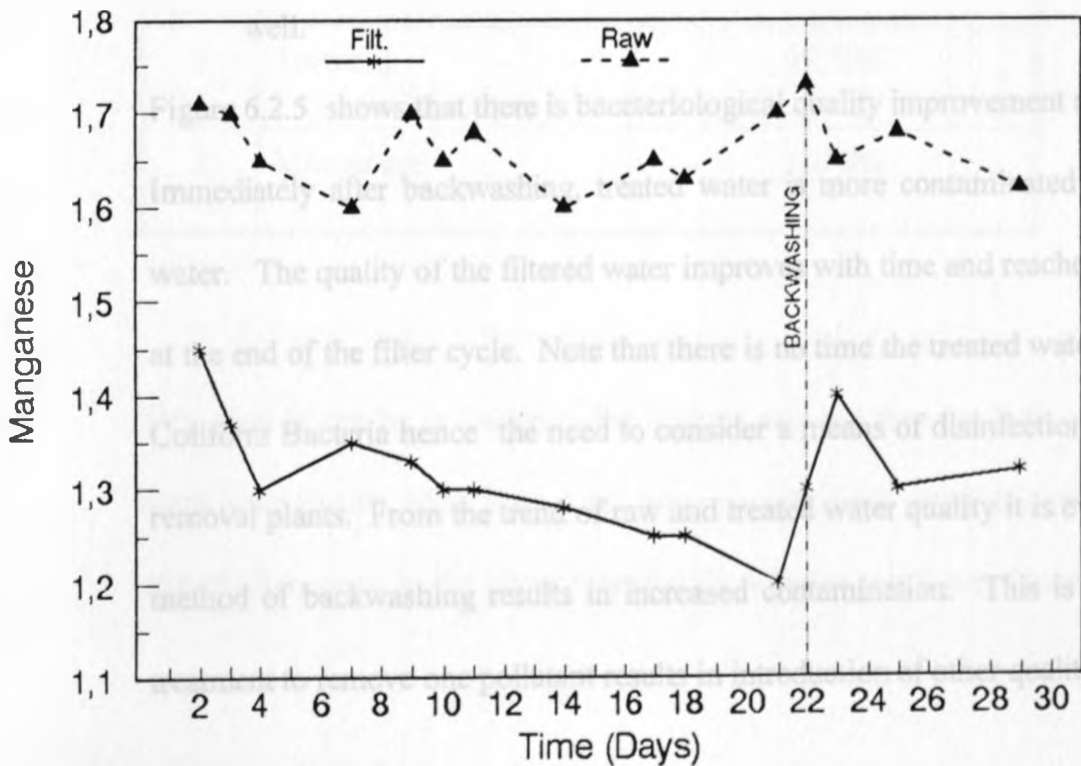


Fig 6.2.6   Manganese Versus Time at Siginga Plant

95

The most important inferences from Figures 6.2.1 to 6.2.4 are;

(i).    After a certain age, the filter becomes more efficient in turbidity and iron

        removal.

(ii).   Drawing excess amounts of water disturbs the well and turbidity

        consequently increases. Increase in raw water turbidity results in an increase

        in turbidity of filtered water. Clogging increases efficiency of turbidity

        removal.

(iii).  Though iron and turbidity removal capacity increases with age, clogging

        reduces the flow such that consumers end up wasting most of the day at the

        well.

Figure 6.2.5 shows that there is baceteriological quality improvement after filtration.

Immediately after backwashing, treated water is more contaminated than the raw

water.  The quality of the filtered water improves with time and reaches a maximum

at the end of the filter cycle.  Note that there is no time the treated water is free from

Coliform Bacteria hence  the need to consider a means of disinfection in these Iron

removal plants.  From the trend of raw and treated water quality it is evident that the

method of backwashing results in increased contamination.  This is a case where

treatment to remove one pollutant results in introduction of other quality problems.

In figure 6.2.6 Manganese removal efficiency is relatively low at the start of filter cycle and increases with time. Though Manganese has not caused any quality complaints it is an important parameter to consider during development of Iron removal systems. This is because the consumers become sensitive to a wide range of parameters with time.

### 6.3    Khayinga Plant

**Table 6.9    Average parameter removal efficiency at Khayinga Plant**

| 1. | Iron | 96.10% |
|----|------|--------|
| 2. | Turbidity | 95.76% |
| 3. | Manganese | 31.76% |

This plant is similar in design to the Siginga one and they are both situated in the same water quality zone. Raw water iron concentrations were also quite close. The size of filter media in the plants was slightly different and it was found necessary to

determine the effect of the media size on efficiency and the length of the cycles. The results of comparison of efficiency and cycle length are as shown in Table 6.10.

**Table 6.10    Efficiency and cycle length at Siginga and Khayinga plants**

| Parameters | SIGINGA | KHAYINGA |
|---|---|---|
| Iron | 95.8 | 96.1 |
| Turbidity | 95.75 | 95.76 |
| Length of the cycle (days) | 20 | 26 |
| Media size (mm) | 0.60 - 3.55 | 0.85 - 3.55 |

Iron removal efficiency in both plants is almost the same (Table 6.10). This is in agreement with the findings by Hatva (1989). In his work with slow sand filters, he found that the media grain size does not affect removal efficiency. The slight decrease in grain size only affected the flow which resulted in longer queues during peak periods. Fig. 6.3.1 and 6.3.2 indicate that;

i.      Initially after backwashing, flow rate increases rapidly and decreases with time.

98
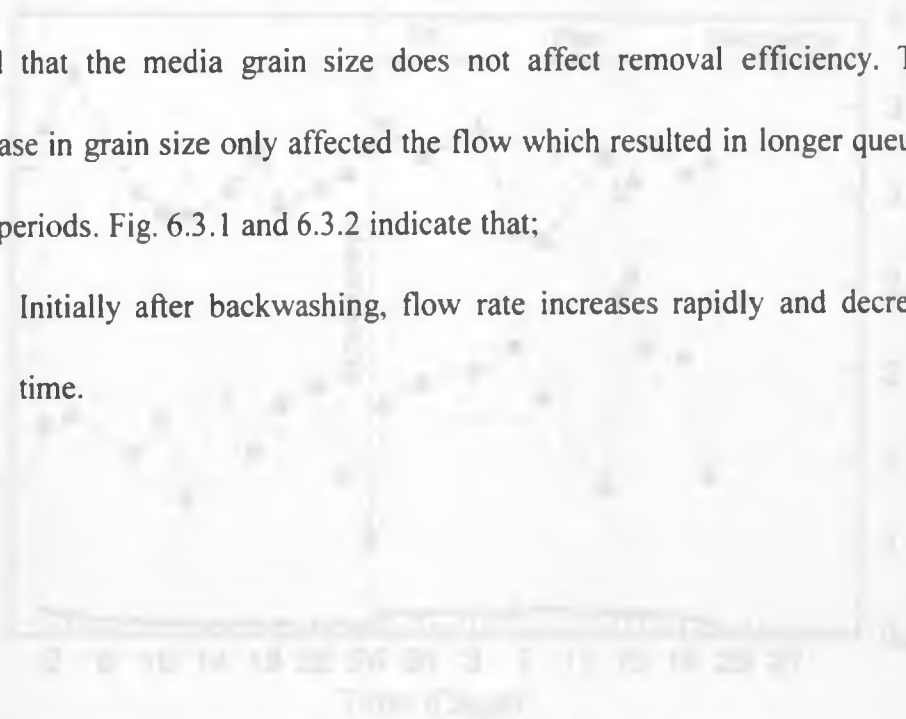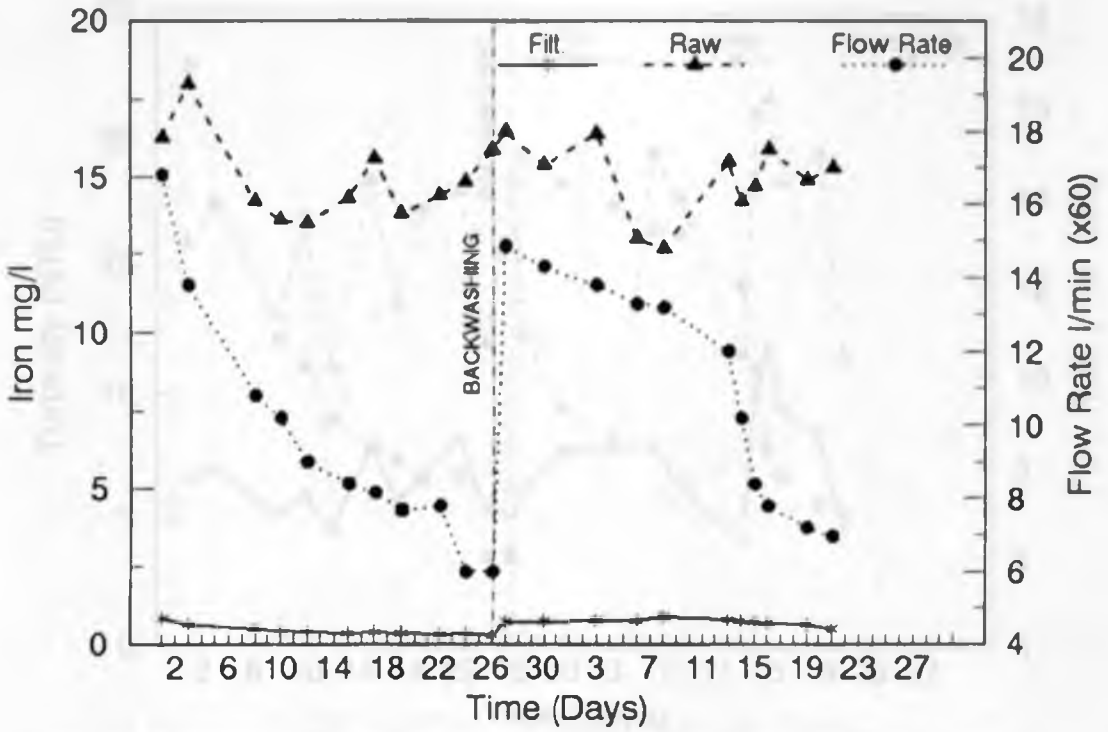
Fig 6.3.1   Iron and Flow Rate versus Time at Khayinga Plant
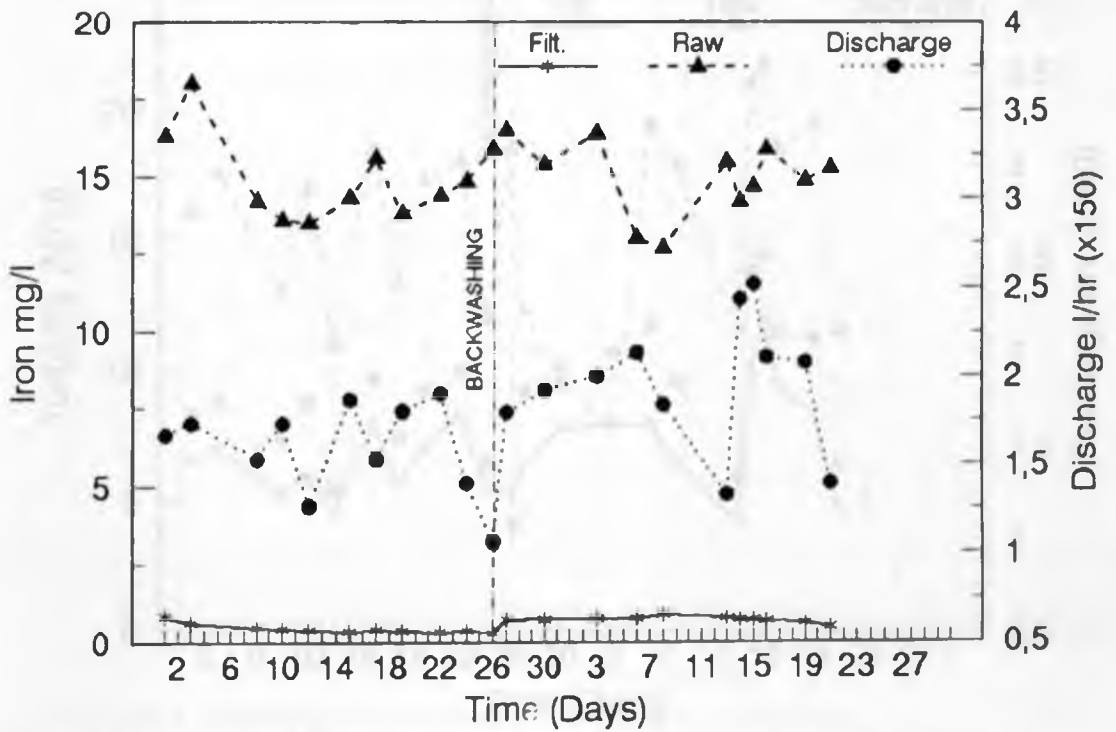


Fig 6.3.2   Iron and Discharge versus Time at Khayinga Plant

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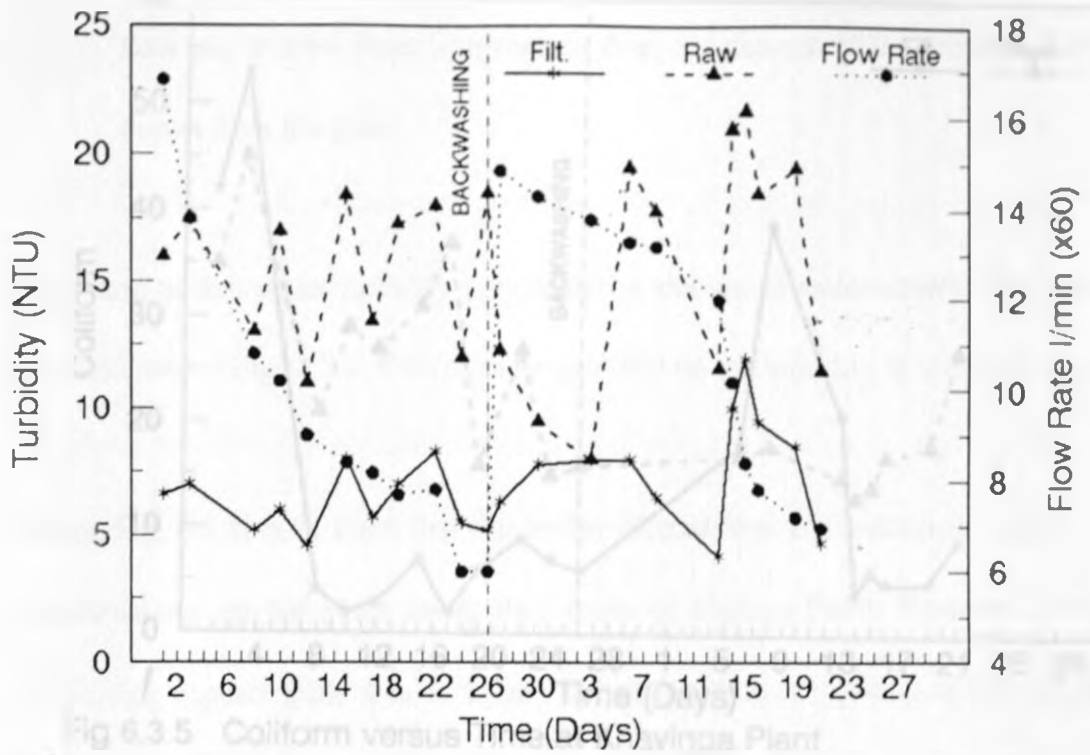
Fig 6.3.3   Turbidity and Flow Rate versus Time at Khayinga Plant
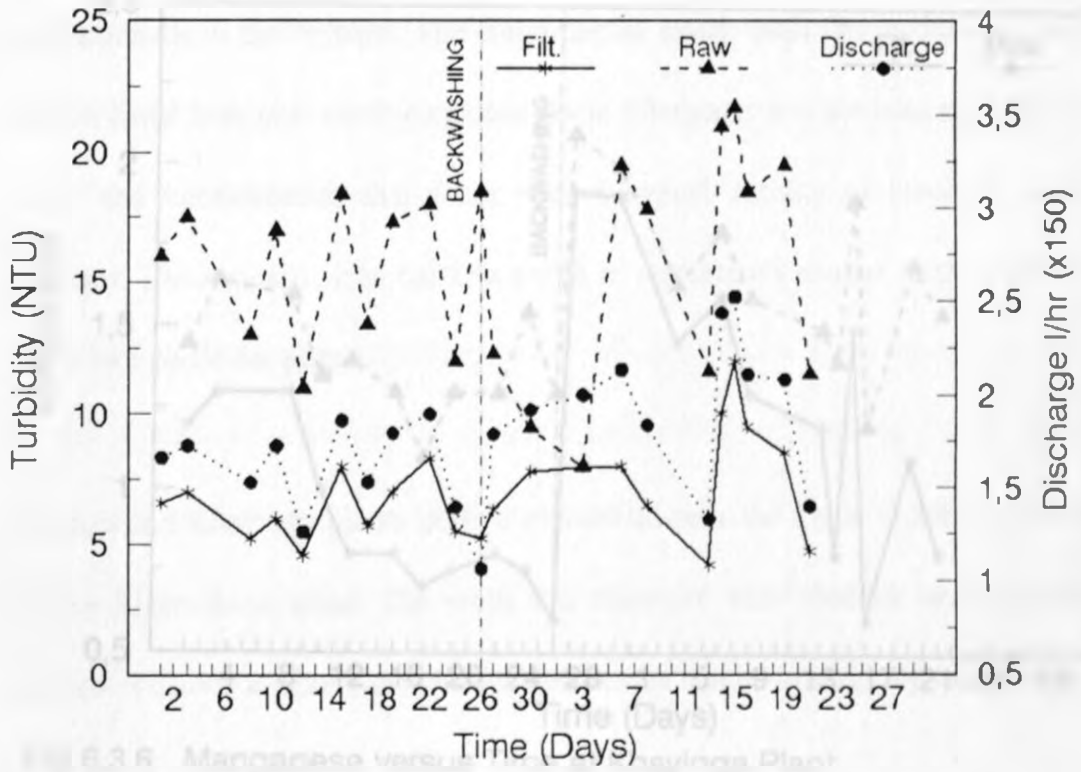


Fig 6.3.4   Turbidity and Discharge versus Time at Khayinga Plant
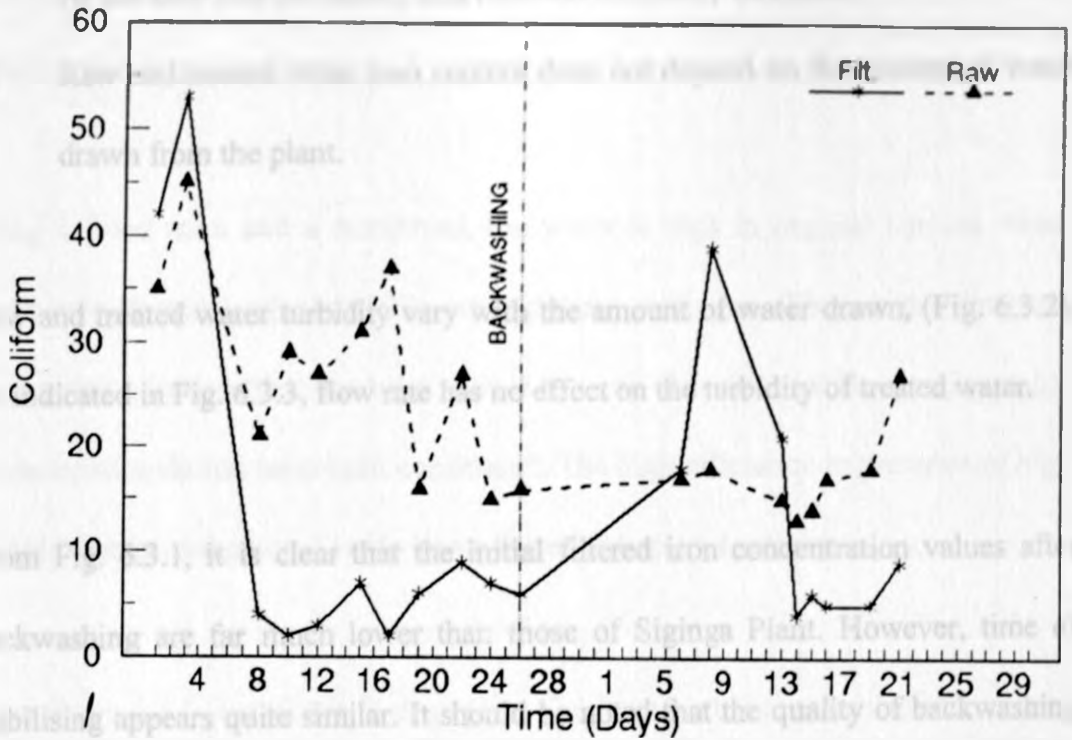
Fig 6.3.5    Coliform versus Time at Khayinga Plant
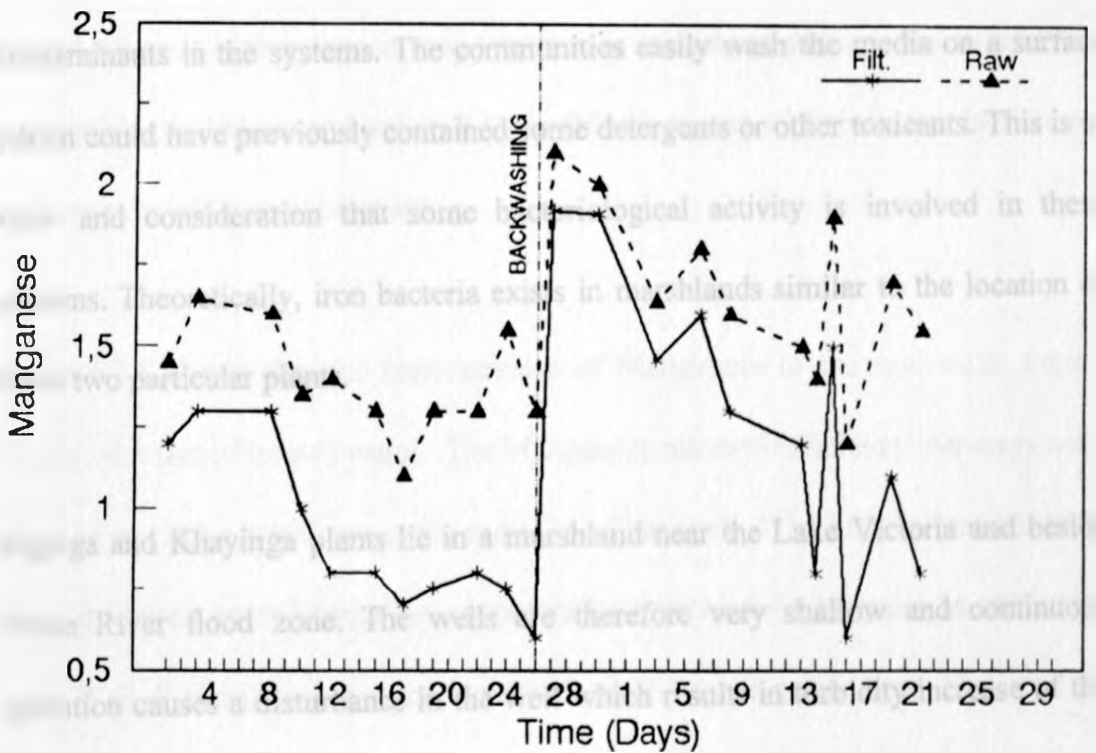


Fig 6.3.6    Manganese versus Time at Khayinga Plant

ii.     As the flow rate decreases, iron removal efficiency increases.

iii.    Raw and treated water iron content does not depend on the amount of water

        drawn from the plant.

Raw and treated water turbidity vary with the amount of water drawn, (Fig. 6.3.2).

As indicated in Fig. 6.3.3, flow rate has no effect on the turbidity of treated water.

From Fig. 6.3.1, it is clear that the initial filtered iron concentration values after

backwashing are far much lower than those of Siginga Plant. However, time of

stabilising appears quite similar. It should be noted that the quality of backwashing

in these plants can affect initial filtered water iron concentration values. The rate of

recovery to the optimum efficiency can be affected by haphazard introduction of

contaminants in the systems. The communities easily wash the media on a surface

which could have previously contained some detergents or other toxicants. This is in

view and consideration that some bacteriological activity is involved in these

systems. Theoretically, iron bacteria exists in marshlands similar to the location of

these two particular plants.

Siginga and Khayinga plants lie in a marshland near the Lake Victoria and beside

Nzoia River flood zone. The wells are therefore very shallow and continuous

operation causes a disturbance in the well which results in turbidity increase of the

raw water (Fig.6.3.4, 46th - 48th day). The designs of the plants should have taken turbidity into consideration.

Being a flood zone and a marshland, the water is high in organic content which could have formed organometallic combinations with iron. Though the designers were trying a system that has been shown to work elsewhere, difference in quality characteristics should have been considered. The high efficiency in presence of high organic matter content could only be attributed to bacterial activity.

From figure 6.3.5 just like in Siginga plant Coliform bacteria contamination occured in both raw and treated water. Backwashing of the well increased contamination of the filtered water and as shown at the start of the filter cycle the bacteria count in the filtered water is higher than in raw water. As mentioned earlier, this arises from backwashing technique and unless it is modified a means of disinfection in shallow well water points should be sought.

Figrue 6.3.6 shows that the concentration of Manganese in the raw water varies closely with that of treated water. The Manganese removal efficiency increases with time and reaches a maximum at the end of the filter cycle. The high increase in both raw and filtered water Manganese concentration after backwashing can be attributed to the Well disturbance due to the increased water demand at this time. The trend of

103

Manganese removal is similar to that of Iron but the efficiency differs due to high pH and redox potential requirement.

Figures 6.2.5 and 6.3.3 show the trend of Coliform organisms in raw and filtered water in Siginga and Khayinga plants. The reduction of Coliform bacteria in the filtered water is an important factor in water quality in the shallow wells. The efficiency of the plant in bacteria removal increases with time and reaches a maximum at the end of the filter cycle when the filtration efficiency is also at maximum.

Immediately after backwashing, the filtered water becomes more contaminated than the raw water. As mentioned earlier this is due to poor backwashing methods involving complete removal of filtration media and cleaning manually. This is one area where improvement is required in this Iron removal plant model.

## 6.4    Shivanga Plant

Among the four plants, only this plant has a borehole source. The water is therefore better in physico-chemical and bacteriological quality. The only problem has been taste and coloration on storage due to elevated iron concentrations. The removal efficiencies for the three parameters are as shown in Table 6.11.

**Table 6.11    Parameter removal efficiencies at Shivanga Plant**

| PARAMETER | PERCENTAGE |
|-----------|------------|
| IRON | 94.71 |
| MANGANESE | 68.2 |
| TURBIDITY | 94.9 |

Manganese and turbidity of the raw water was relatively low and had not caused any complaints. Their concentrations were close to World Health Organization guideline values for drinking water. The quality of treated water from this plant met the WHO standards.

Raw and treated water was free of bacteriological contamination. Operation procedures in this plant do not allow for contamination at all. In Fig. 6.4.1, it is shown that filtered water iron concentration increases as the flow rate decreases.

105

Concentration of iron in the raw water has no effect on the filtered water iron concentration. This is an indication that the plant is not overloaded at the prevailing raw water iron concentrations.

The amount of water drawn (discharge) does not appear to have a significant effect on the filtered water iron concentrations (Fig. 6.4.2). The middle region of Figure 6.4.2, where the demand fluctuation is high, shows a dependence of filtered water iron concentration on discharge. This results from system disturbance. Variation of turbidity with discharge and the flow rate are shown on Figures 6.4.3 and 6.4.5. To a good extent, filtered water turbidity is dependent on the amount of water drawn (Fig. 6.4.3) due to continuous disturbance of the well.

Removal of iron involves oxidation of ferrous iron to ferric hydroxide which is trapped in the media and thereby removed from upward moving water (Equation 2). As the discharge increases, the increased pumping produces turbulence in the system disturbing the settling floc particles which result in increased turbidity in the filtered water. The increase in turbidity of the filtered water with time can also be explained as follows: There are several forces involved in floc formation which are chemical in nature. Saturation of these forces produces repulsion among various particles which are finally dislodged by upward moving water to constitute turbidity. Figure 6.4.1 shows how clogging affects the flow rate.
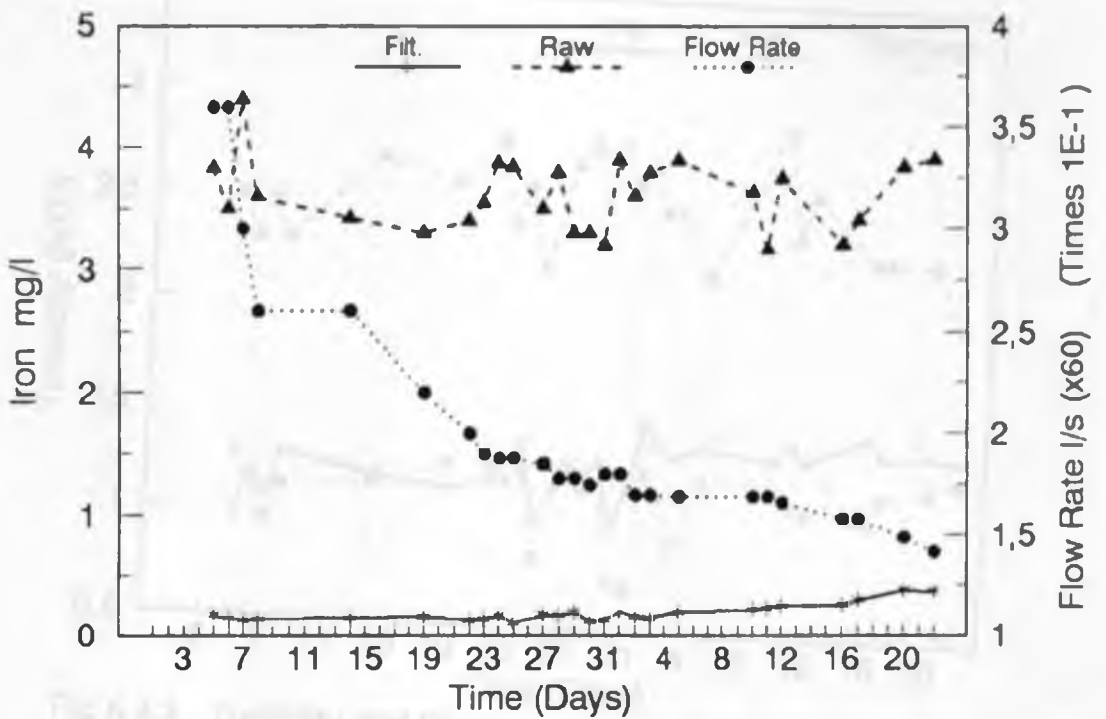
Fig 6.4.1   Iron and Flow Rate versus Time at Shivanga Plant
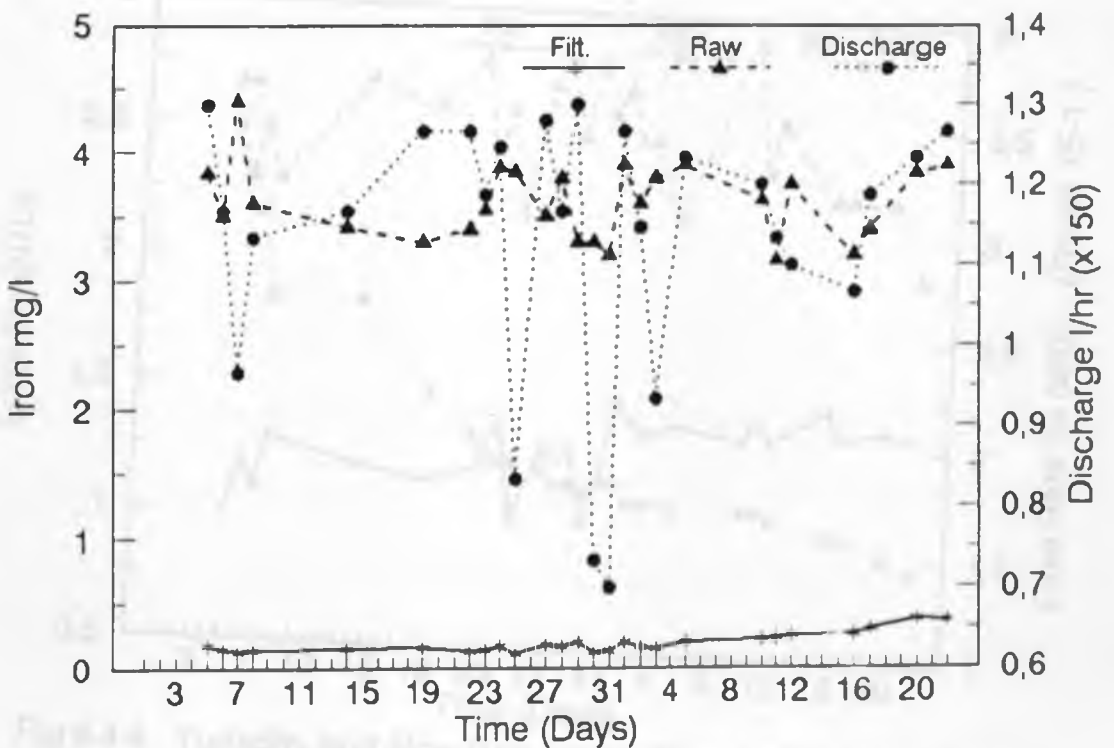


Fig 6.4.2   Iron and Discharge versus Time at Shivanga Plant
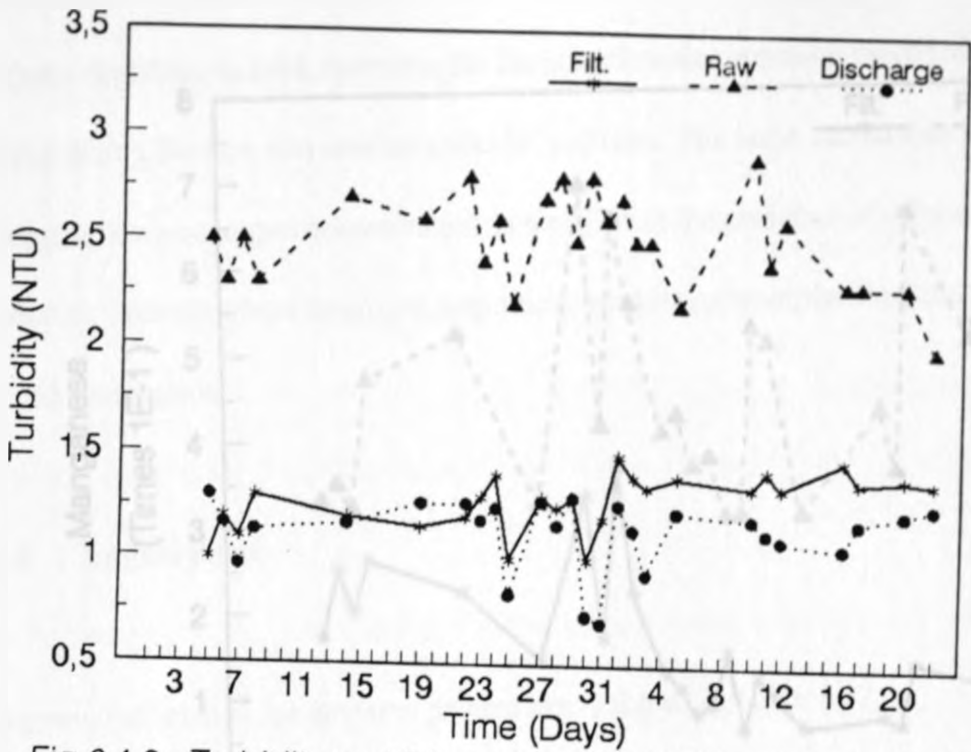
Fig 6.4.3   Turbidity and Discharge versus Time at Shivanga Plant
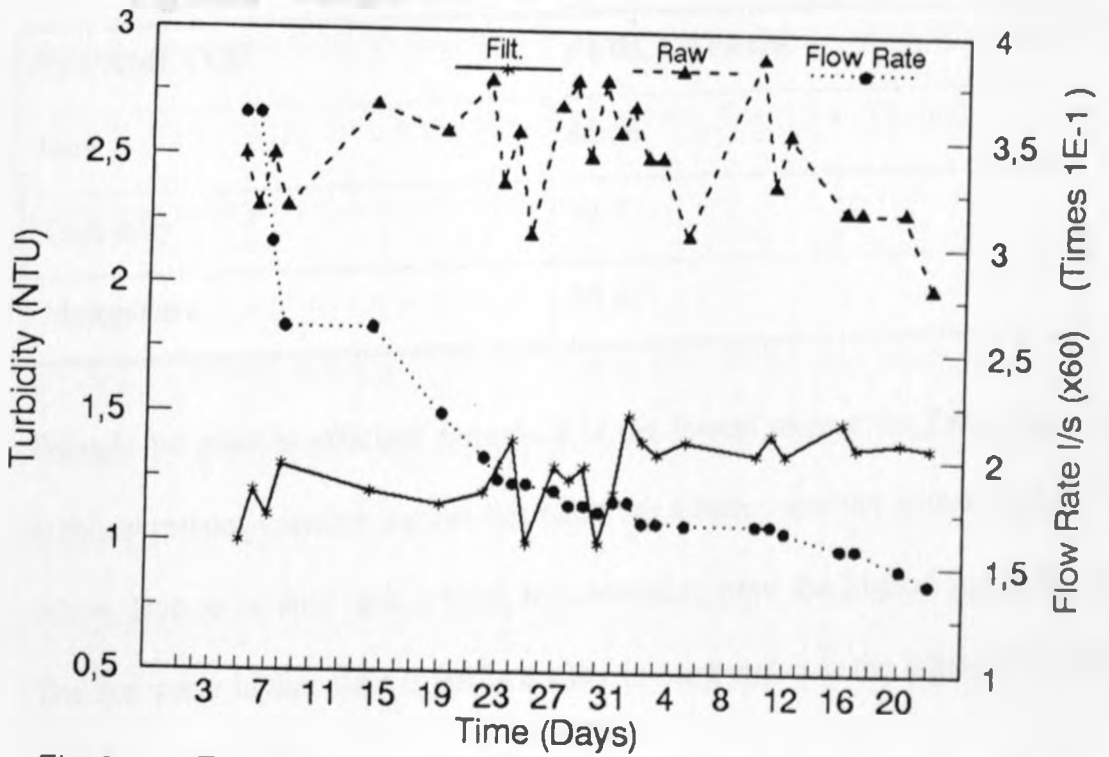


Fig 6.4.4   Turbidity and Flow Rate versus Time at Shivanga Plant

108
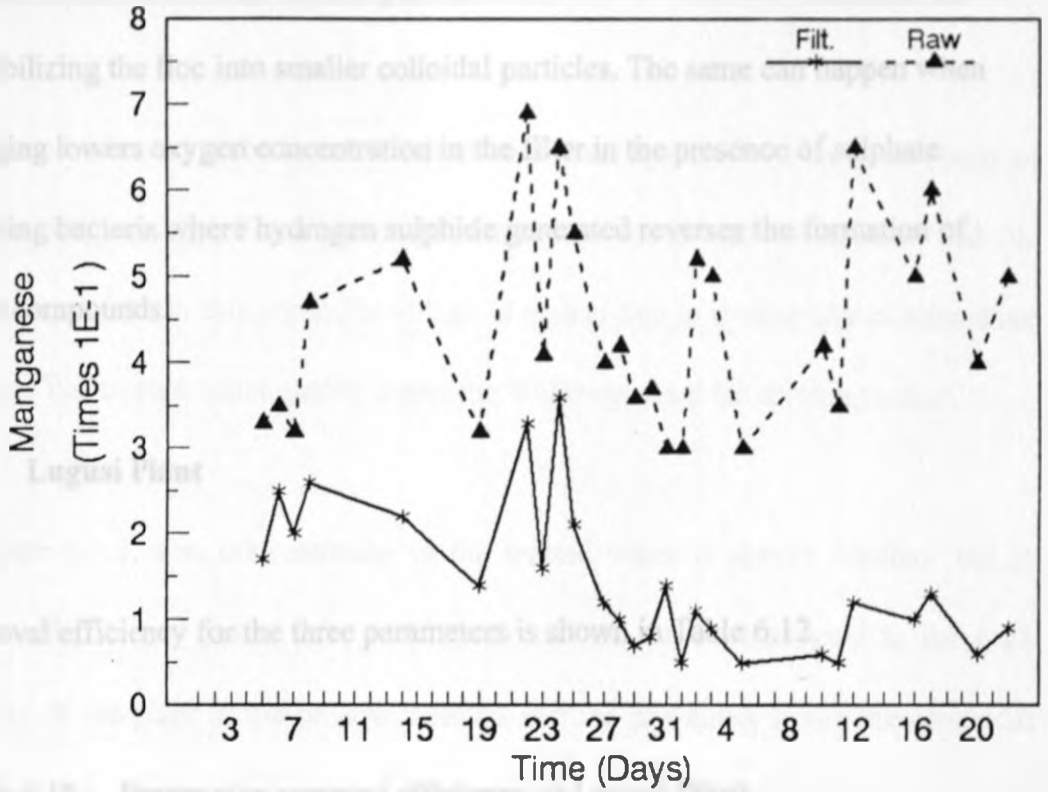
Fig 6.4.5   Manganese versus Time at Shivanga Plant

| PARAMETER | PERCENTAGE |
|---|---|
| Iron | |
| Turbidity | |
| Manganese | |

Action of nitrifying bacteria which occurs at late stages of filter cycle can result in oxygen depletion thereby reversing the ferric hydroxide formation reactions hence destabilizing the floc into smaller colloidal particles. The same can happen when clogging lowers oxygen concentration in the filter in the presence of sulphate reducing bacteria where hydrogen sulphide generated reverses the formation of ferric compounds.

## 6.5    Lugusi Plant

Removal efficiency for the three parameters is shown in Table 6.12.

**Table 6.12    Parameter removal efficiency at Lugusi Plant**

| PARAMETER | PERCENTAGE |
|-----------|------------|
| Iron | 85.56 |
| Turbidity | 48.97 |
| Manganese | 56.67 |

Though the plant is efficient enough, it is the lowest among the four. This was highly surprising considering that this plant has a better aeration system than all the others. Due to its dual tank system, it is bound to have the highest retention time. The raw water in this plant is fair in quality in comparison to the other shallow well

110

plants. The well has been at a possible spring outcrop and therefore the physico-chemical qualities are similar to borehole well.

The plant is situated at the bottom of the Nandi Escarpment where there are plenty of good quality springs. From comparison with the other wells it appears that the quality complaint in this particular village is mainly due to availability of alternative sources. The treated water quality meets the WHO standard for drinking water.

In Figure 6.5.1, iron concentration in the treated water is almost constant and is independent of raw water iron concentration. This can be attributed to the high capacity of the plant at the present demand and the prevailing iron concentrations. The two tank system also ensures minimum turbulence in the filtration unit. The flow rate was almost constant during the 3½ month operation. Due to this uniformity in treated water quality and flow rate, it was not found necessary to sample at a high frequency, samples were taken once a week.

For the 3½ month operation, the plant had not shown any signs of clogging (Fig.6.5.1) and therefore was never backwashed. The amount of water drawn from this plant at the high peak period is far much lower than its capacity. This is shown in Figure 6.5.2 where filtered water iron concentration does not vary with the amount of water drawn. Flow rate is a measure of the rate of clogging. This plant did

not clog throughout the study period and therefore the flow rate was almost constant. Continuous operation of shallow wells results in a disturbance of water underground which increases turbidity. The increased turbidity is reflected in the treated water. In Fig. 6.5.3, it is shown that the raw water turbidity varies with that of treated water. Increase in the amount of water drawn during the peak hours affects the treated water turbidity. This is evident in Fig. 6.5.4 where discharge, raw and treated water turbidity vary uniformly. As mentioned above, turbidity increase in the well is a local effect created by turbulence as water is sucked during pumping.
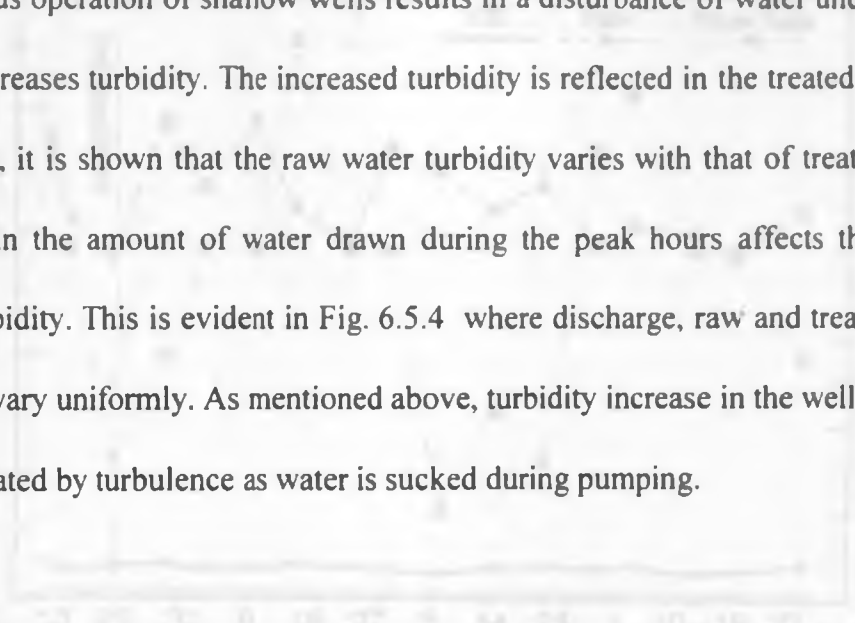
In both Shivanga and Lugusi plants, manganese removal efficiency is far much higher than at the other two plants i.e 68 and 57% respectively. Manganese removal efficiency in these plants is low immediately after backwashing but increases with time (Fig. 6.5.3 and 6.5.6).

Coliform removal in Lugusi plant is evident (Fig. 6.5.5) and appears to follow a pattern. The filtered total coliform number varies with that of the raw water. Owing to rapid multiplication of bacteria, this plant cannot be considered very effective. A few bacteria colonies can multiply into vast colonies in a very short time and therefore a secondary means of disinfection should be considered for production of improved quality bacteria free water.
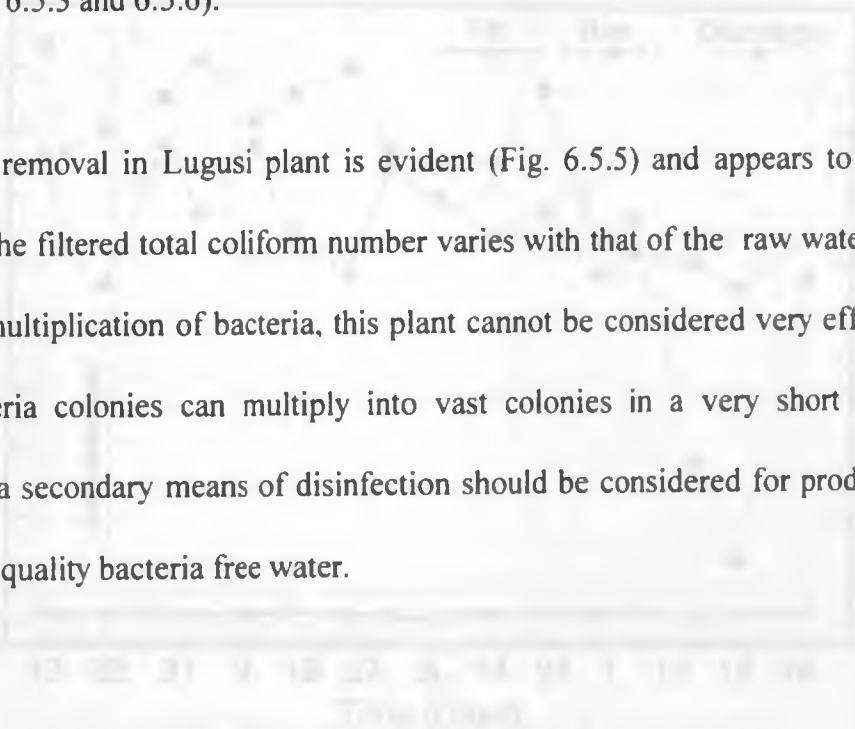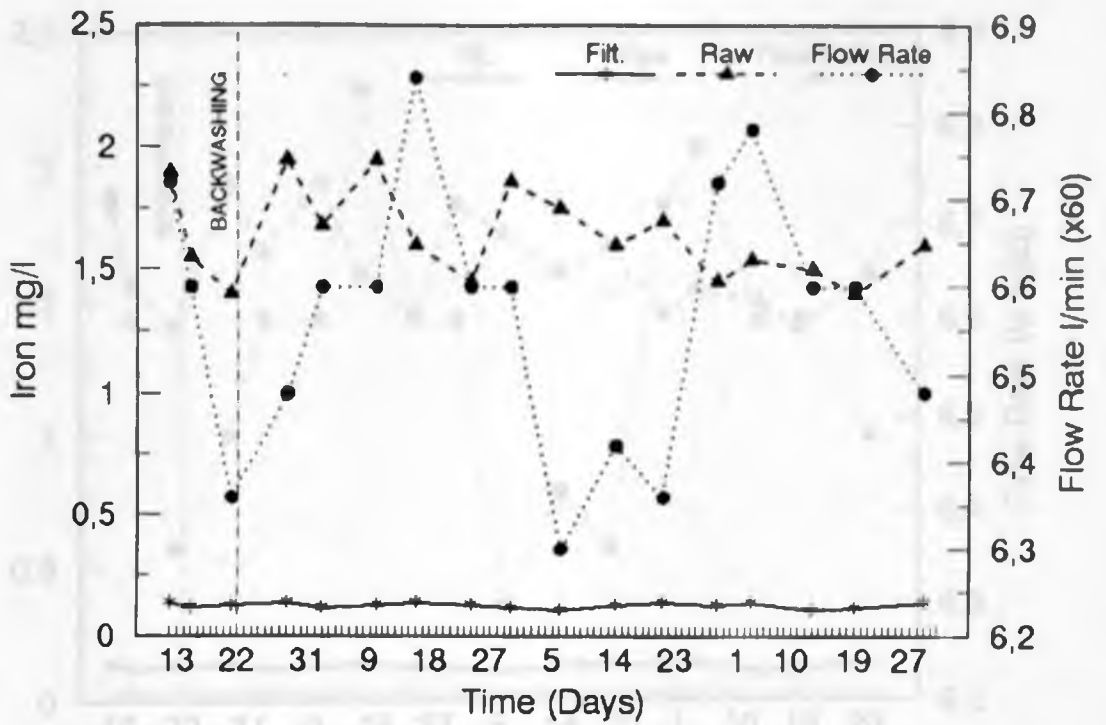
Fig 6.5.1   Iron and Flow Rate versus Time at Lugusi Plant
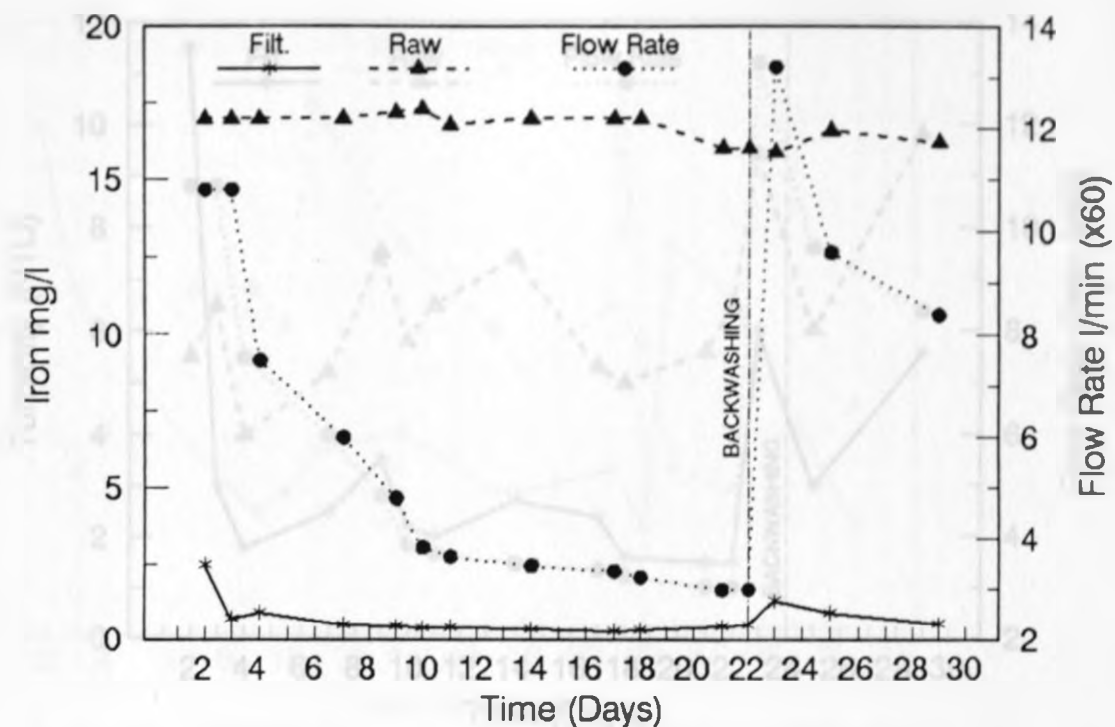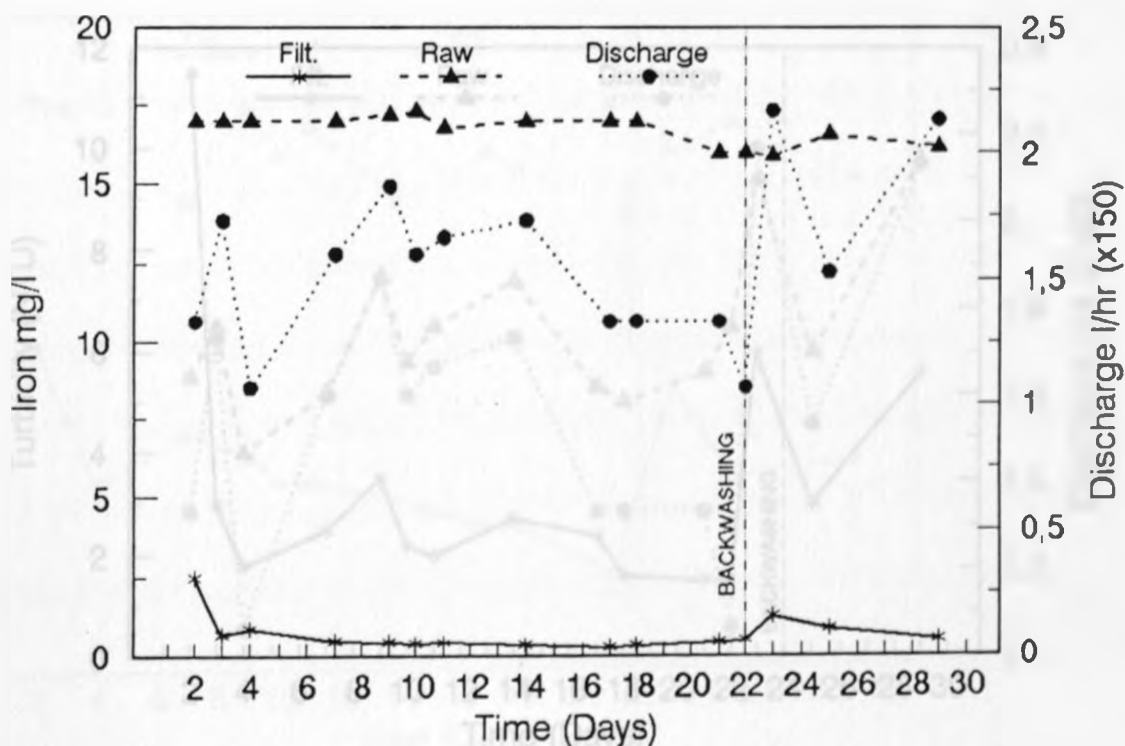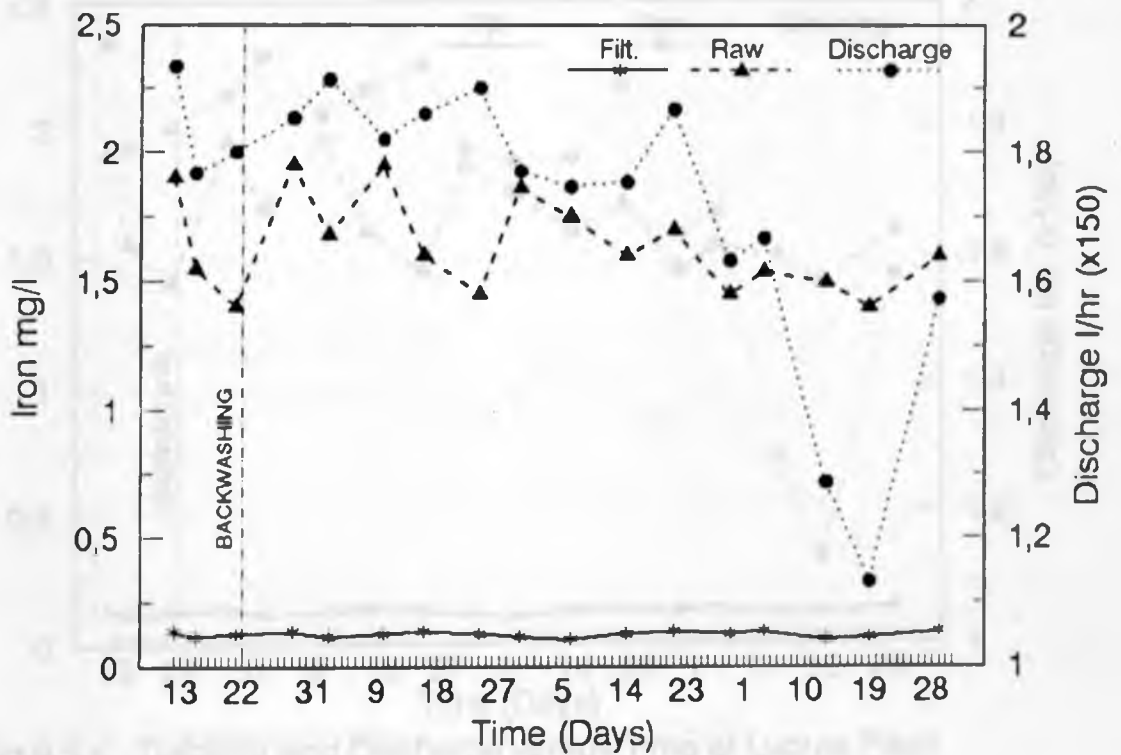


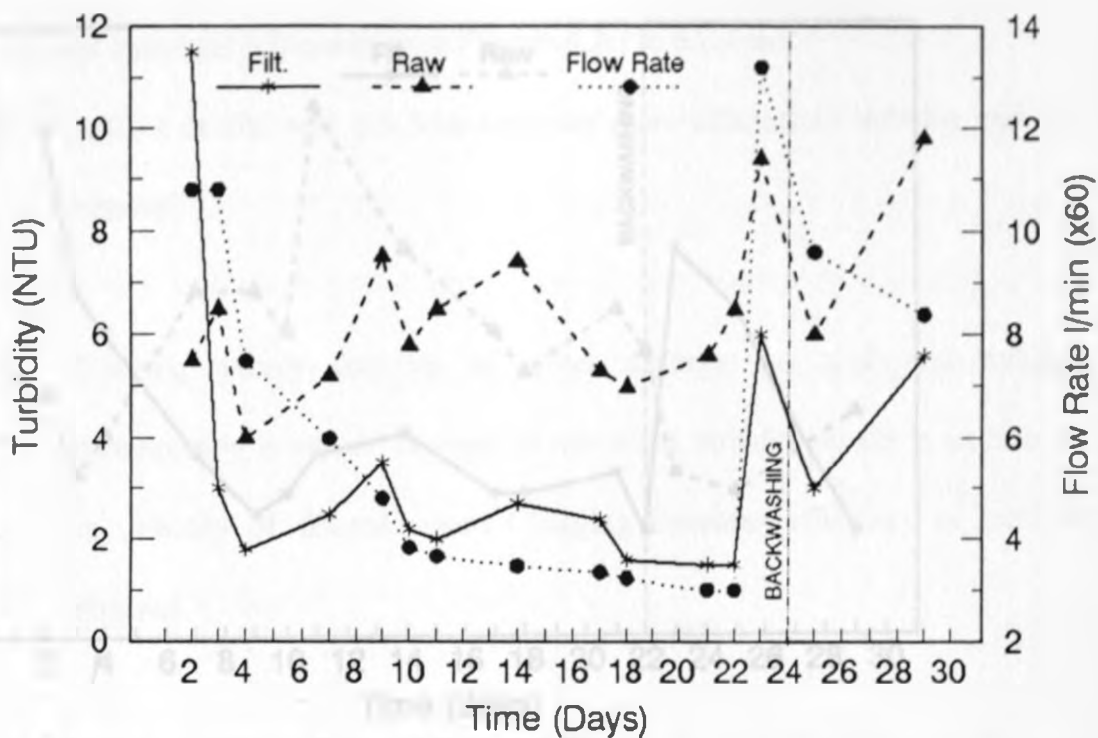Fig 6.5.2   Iron and Discharge versus Time ay Lugusi Plant
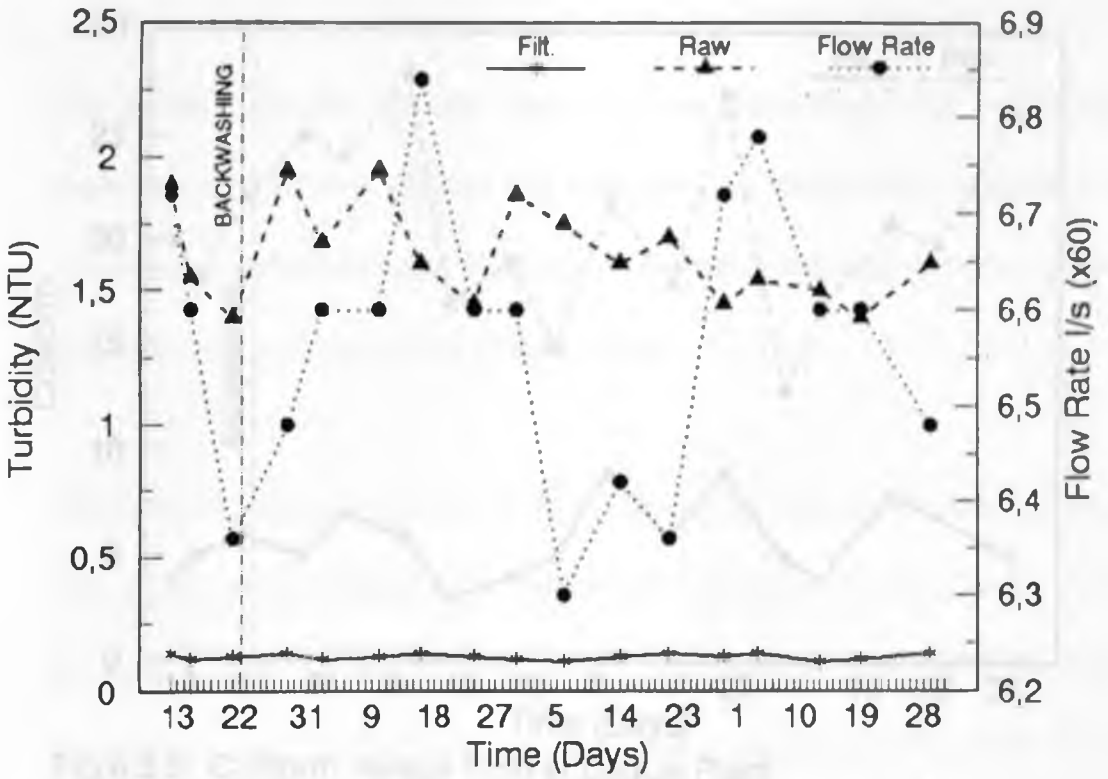
Fig 6.5.3   Turbidity and Flow Rate versus Time at Lugusi Plant
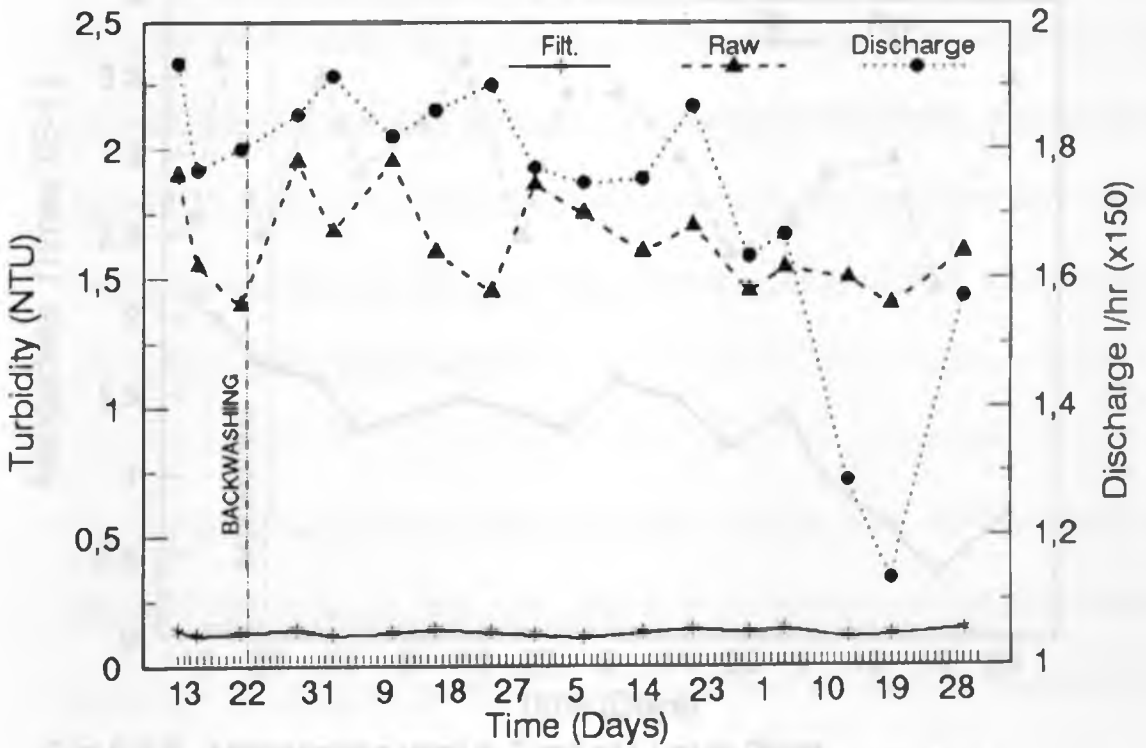


Fig 6.5.4   Turbidity and Discharge versus Time at Lugusi Plant
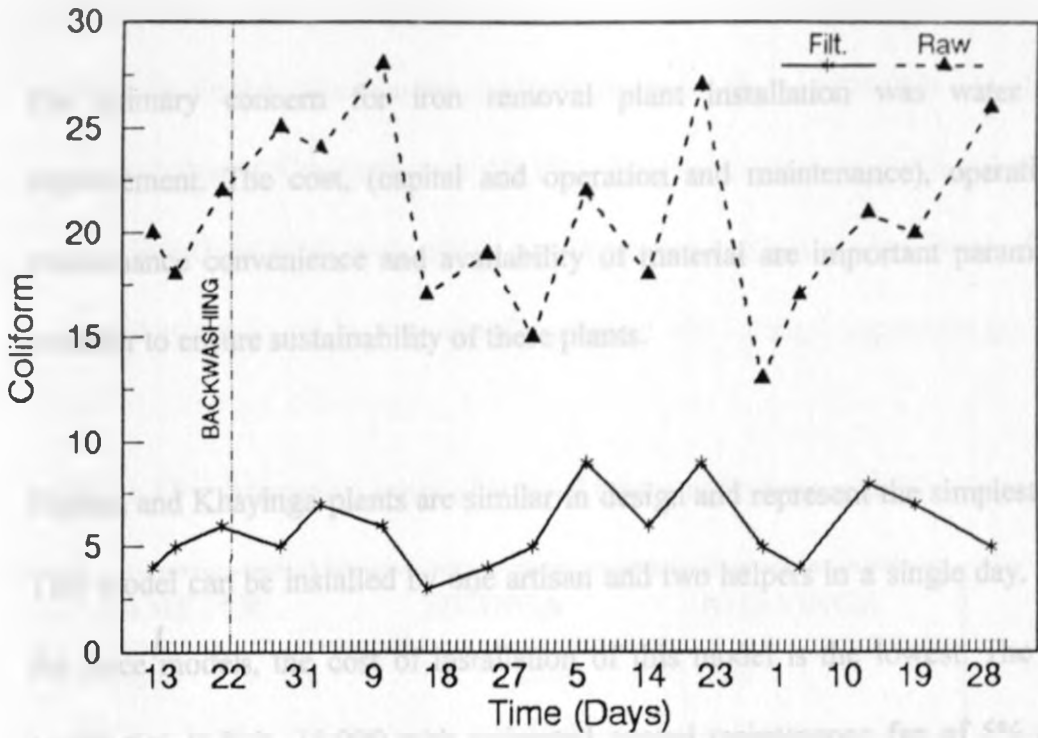
Fig 6.5.5   Coliform versus Time at Lugusi Plant
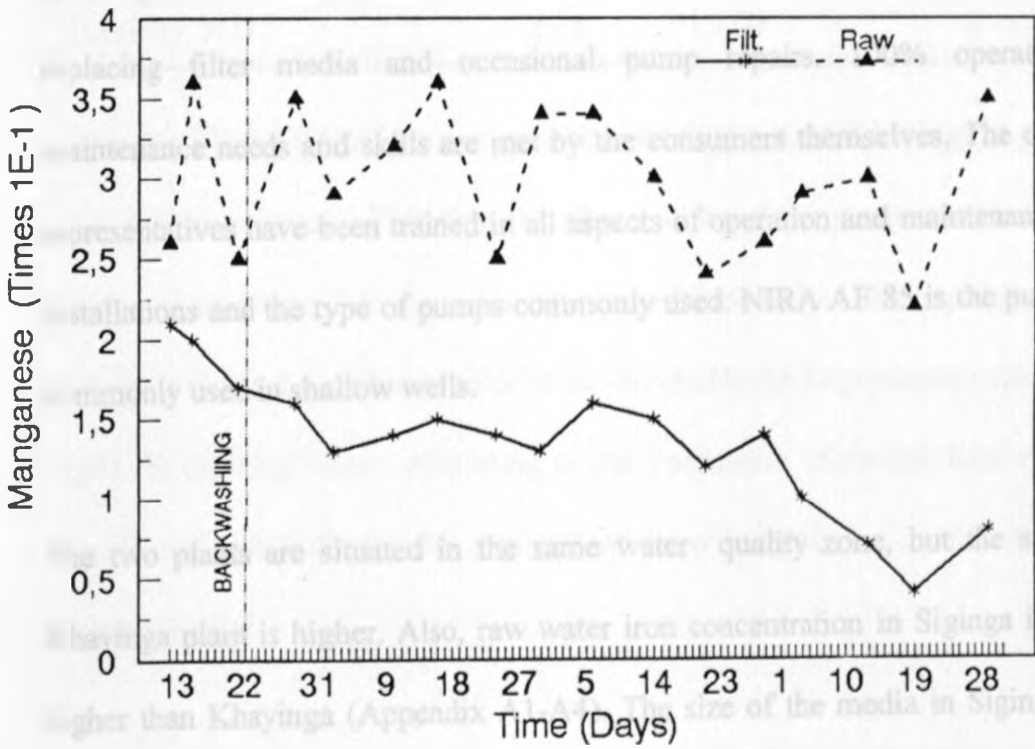


Fig 6.5.6   Manganese versus Time at Lugusi Plant

## 6.6    Discussions

The primary concern for iron removal plant installation was water quality improvement. The cost, (capital and operation and maintenance), operation and maintenance convenience and availability of material are important parameters to consider to ensure sustainability of these plants.

Siginga and Khayinga plants are similar in design and represent the simplest model. This model can be installed by one artisan and two helpers in a single day. Among the three models, the cost of installation of this model is the lowest. The cost of installation is Ksh. 11,000 with estimated annual maintenance fee of 5% or Ksh. 550. Operation and maintenance activities include cleaning the filter media, replacing filter media and occasional pump repairs. 100% operation and maintenance needs and skills are met by the consumers themselves. The consumer representatives have been trained in all aspects of operation and maintenance of the installations and the type of pumps commonly used. NIRA AF 85 is the pump most commonly used in shallow wells.

The two plants are situated in the same water quality zone, but the salinity in Khayinga plant is higher. Also, raw water iron concentration in Siginga is slightly higher than Khayinga (Appendix A1-A4). The size of the media in Siginga (0.60-

3.55) is slightly lower than in Khayinga (0.85-3.55). Due to the similarity of design and raw water quality the iron removal mechanisms in these two plants are expected to be quite similar. The iron removal efficiency for Siginga (95.8%) was almost the same with that of Khayinga plant (96.1%). The slight effective media size difference only affected the filter cycle which was shortened in Siginga plant by six days. The standard originally set by the water Programme was 1.0 mg/l (Appendix B).

Table 6.13    Average quality of treated water at Siginga and Khayinga plants

| PARAMETER | SIGINGA | KHAYINGA |
|---|---|---|
| Iron, mg/l | 0.70 | 0.58 |
| Manganese, mg/l | 1.31 | 1.01 |
| Turbidity, NTU | 2.72 | 7.00 |

The mean filtered water iron concentration for Siginga and Khayinga were 0.7 and 0.58 mg/l respectively. Therefore the plants achieved the programme's anticipated quality of less than 1.0 mg/l. Though the efficiencies of these plants were the highest, it was not possible to achieve the World Health Organization standard (0.3 mg/l) for drinking water. According to the consumers, there has been occasional complaints. This indicates the requirement for redesigning or modification of the existing works.

There is no variation of filtered iron concentration with discharge (Fig.6.2.2 and 6.3.2). The general water quality trend in appendix A1-A4 shows that water quality improved when the time interval between successive consumers was increased (indicated by low discharge). This is an indication that iron removal efficiency is a function of retention time.

Turbidity removal efficiency in both plants is quite high (96%) with residual levels of 2.72 and 7.0 NTU for Siginga and Khayinga respectively. Filtered water turbidity is a function of discharge (Fig.6.2.3 and 6.3.3). Lowering discharge resulted in increased clarity (low turbidity) in the filtered water. Thus increase of dimensions of the plant, and/or modification to increase the retention time, will be necessary. This is in agreement with results of pilot studies by Frischherz et al., 1985.

Manganese removal efficiency in this plant model was lower than Lugusi and Shivanga with Khayinga plant (31.76%) being higher than Siginga (21.08%). Physico-chemical removal of manganese by aeration and settling is minimal at pH values lower than 9.5. Bacterially mediated removal of manganese has been shown to compete with nitrification (organic oxidation processes) and occur at late stages of the filter cycle.(Appendix A1-A4). Reduction of ammonia through filtration is evidence of nitrification processes.

In both Khayinga and Siginga plants, manganese removal has been shown to begin at a low efficiency and increasing towards the end of the cycle. This finding, together with the low pH values prevailing in the removal systems, shows that microbiological or other processes other than physico-chemical might be involved in the removal processes. The effect of manganese on water quality has been masked by excessive iron concentrations and therefore, there has been no direct manganese related quality complaints.

As mentioned above, this plant model is easy to install and maintain, and the cost is affordable by the rural communities. The study site's good maintenance conditions were manifestations of sustainability of the systems. During the study, the hand pump broke down but was repaired overnight. The trained pump attendants for this particular model (Nira AF 85) are easy to reach at village level. Throughout the study period, backwashing of the plants was carried out by the consumers themselves. The greatest disadvantage in operation and maintenance of this plant model was the fact that backwashing had to be done by removing the media completely, washing on the slab, and then replacing it. This is a very inconvenient backwashing method. After a few filter cycles, there is substantial loss of media which must be made up. This does not only result in increased bacteriological contamination but also maintenance cost due to sand loss. To avoid contamination

and filter media loss, either the method of backwashing is changed or a different design should be developed.

The method of backwashing has also been associated with the system disturbances and water quality deterioration. Raking or scrapping the top media as done in slow sand filtration is a better alternative. Raking can also introduce some contamination in these water supplies but is a good temporary measure pending design improvement. These measures would make the operation very convenient for the consumers.

Shivanga Plant has iron and turbidity removal efficiencies of 94.7% and 94.9% respectively and therefore close to that of Khayinga and Siginga plants. Among the four plants, Shivanga showed the highest manganese removal efficiency (68.2%). The average concentration values for the three performance parameters in the filtered water are as shown in Table 6.14.

**Table 6.14    Average quality of treated water at Shivanga Plant**

| PARAMETER | CONCENTRATION (mg/l) |
|-----------|----------------------|
| Iron | 0.19 |
| Manganese | 0.14 |
| Turbidity | 1.27 |

Therefore, this plant met the WHO standards for drinking water. At an average raw water iron concentration of 3.59 mg/l, the plant had a filter cycle of seven weeks. This model is moderately sophisticated for the rural communities and therefore its installation requires experienced plumbers and masons. It also requires limited modification to an already installed hand pump but involves extensive pipe work.

Experienced artisans who were laid off by the Programme in the process of staff reduction usually became contractors within the communities and this has gone a long way in solving the technical skills requirement for installation of water treatment facilities. Information from the Programme's training section rates the consumer operation and maintenance participation at 75%. The basic construction materials, e.g., sand, gravel, piping and fittings are readily available in the

programme area. The total cost of installing this model is Ksh. 16,000 with an annual maintenance fee of Ksh. 1,000.

As mentioned earlier, the main routine maintenance work is backwashing. Backwashing in this plant is carried out by opening the drain valve at the bottom. During the study, it was found that failure to backwash at the right time (after 7-8 weeks) can make the operation very inconvenient. The system clogs up to the extent that opening of the drain valve does not dislodge the precipitates. This results in the complicated work of removing the media and washing it manually. Therefore, though very convenient to operate and maintain, negligence can lead to complicated and time consuming procedures.

As mentioned in Section 6.4, the plant's capacity in terms of iron concentration and discharge is not yet exhausted, there is no need for any other design changes at present apart from mobilization of communities to participate in operation and maintenance.

Though Lugusi Plant has the lowest iron removal efficiency, the filtered water meets the WHO standards for drinking water. This is due to the low raw water iron concentration involved. The quality of the treated water is shown in Table 6.15.

**Table 6.15    Treated water quality at Lugusi Plant**

| PARAMETER | CONCENTRATION |
|-----------|---------------|
| Iron | 0.13 mg/l |
| Manganese | 0.13 mg/l |
| Turbidity | 2.2 NTU |

In comparison with the other plants having shallow well sources (Siginga and Khayinga) the raw water at this plant is far much better and the water demand at present allows reduction of iron concentration to acceptable level. The fact that raw water iron concentration does not affect the removal efficiency of iron is an indication that this plant can also cope with higher hydraulic load than the hand pump discharge. The variation in discharge does not affect the filtered water iron concentration. The plant operated for 3½ months without clogging and this shows that its capacity to remove iron is too high for the current population. Since the plants are designed to serve 200 to 300 consumers, this plant's high capacity ensures good quality water and extended filter cycles even at maximum consumer population. The plant has a high manganese removal efficiency (56.67%) which has been explained as due to a good aeration system and the resultant high pH. This finding can be useful where the groundwater contains excessive manganese.

Alkalization and modification to increase aeration efficiency has lead to improvement in manganese removal in Finland (Hatva, 1989). The plant was also meant to remove bacteriological contamination. The results indicate inadequacy and other techniques have to be used if the water is to be free of bacteria. Since installation of this plant, maintenance has been carried out by the Programme. Initially, there was a dispute over the well ownership and this prevented participation by consumers and training of attendants.

The plant is the most sophisticated of the three models and takes seven to ten days to install. The total cost of installation has been given as Ksh.27,000. Installation involves a lot of pipe work which requires elaborate maintenance procedures. This system involves pumping of water over a delivery head into the aeration tank. An ordinary India Mark II pump has to be modified and this leads to technological sophistication. Leaks through valves and the hose pipe have frequently caused shutdown over long periods. Backwashing of the plant is quite convenient and is the main routine maintenance. This is made even better by the long filter cycles (3½ months).

# 7.0 CONCLUSIONS AND RECOMMENDATIONS

Observations from the survey casts a dull image of operation and maintenance conditions of the existing plants (Table 6.2 and Plates 11 and 12).

Information from the field survey indicates that most of the existing plants are Siginga and Khayinga models. Most of the plants were found to have been either abandoned or poorly maintained. Examples are shown in Plates 11 and 12. The main reason for poor maintenance of most of them can be given as poor community participation in operation and maintenance. Backwashing technique has also resulted in bacteriological quality deterioration. The solution to the problem would be to change to the raking method to remove the top mud and iron hydroxide precipitates or to redesign the plant into an upward flow filter in the final stage. By doing this, backwashing would only involve opening a drain valve. To achieve treated water iron concentration of 0.3 mg/l would require design modifications. Increasing the detention time by extending the plant to include a pretreatment unit would increase the efficiency to achieve iron concentration levels below 0.3 mg/l. Concentration of iron at which different communities respond to iron and hence raise objections vary depending on the past water quality problems and experiences. Therefore the fact that there is high iron concentration in a certain area will not

automatically desire removal systems. Iron removal considerations should be guided by complaints which have to be confirmed by laboratory before any action is taken. For the consumers to appreciate and hence become committed to maintenance, the iron removal plant installation should follow a demand driven approach. The consumers should also be thoroughly trained on all aspects of operation and maintenance. Poor community participation was caused by poor mobilisation and training coupled with availability of alternative sources and tedious backwashing techniques.

Various categories of artisans e.g. plumbers, masons etc., who can be utilized for installation, have been trained and are easily available all over the programme area. This, coupled with the fact that all the raw material required can be found within the programme area, will make future developments quite sustainable. From the results and discussions, it can be concluded that in all the plant models, treatment resulted in water quality improvement. Efficiencies of iron and turbidity removal was highest in Khayinga and Siginga plants, followed by Shivanga plant.

Khayinga and Siginga plants are efficient enough to remove Iron to levels below 1.0 mg/l which is the programme guideline concentration but could not achieve WHO standard of 0.3 mg/l.

The present reduction from 14 mg/l to 0.50 mg/l and from 17 mg/l to 0.7 mg/l in Khayinga and Siginga respectively is a drastic improvement which was highly appreciated by the consumers. Colour and turbidity are very important quality parameters to rural communities. The plants have been quite efficient in turbidity removal and hence, the resultant reduction in staining of fabrics and discoloration of tea. Coliform removal in these plants is not very effective and thus, appropriate disinfection technique should be formulated.

Khayinga and Siginga plants are good examples of successful technical implementation and sustainability. The quality of water produced is highly improved and acceptable. The communities are adequately maintaining the plants and the technology level is to the tune of rural communities. In most cases where this model has failed, it can be blamed mainly on community mobilization and operation and maintenance training. Shivanga and Lugusi plants produce water of high quality which always met WHO standards. The consumers of these plants are not organized to manage them. As mentioned before in discussions, due to:

(i) lack of mobilization,

(ii) availability of alternative sources and

127

(iii) well and land ownership disputes,

these plants will not be sustainable. As per technical implementation, the plants were quite successful and represent models convenient to operate and maintain.

The primary concern of initiating the Iron removal project was to develop a technologically simple and affordable system for Iron removal using the locally available material. As highlighted in earlier chapter the Iron removal plants were designed to suit the available rural technology. The details of routine maintenance as described in cahpter 5 are simple and have been practised by the consumers successfully since 1985. Now that the programme's final implementation phase is almost complete the beneficiaries will be required to meet the cost of maintenance of their water supplies and where possible initiate development of new ones. The local office of the Ministry of Land Reclamation, Regional and Water Development will provide the necessary technical assistance required by the communities. The reduction of implementation activities by the water programme has left a lot of trained artisans available for maintenance assignment in various water points within the communities. The availability of maintenance funds is ensured by water committees who are directly in charge of the running of the water points.

Experience from Siginga and Khayinga water points where active water committee exist show that the communities are capable of funding operation and maintenance of Iron removal plants comfortably.

The water committees have opened accounts in the local banks and financial institutions where the money collected from the consumers is deposited and withdrawn when need arises. Simple routine maintainance of the water points is usually carried out by a few members of the consumers who have been trained through the programme's community training and development department. Iron removal construction materials (sand, cement and gravel) and hand pumps are readily available in the programme area at affordable cost.

Handpumps and their spares are available at the programme's offices at Kakamega. All the pump models are also available from the dealers in Nairobi. Plans are underway to have the pump spares stocked at selected handware shops in the divisional centres. Details on the installation cost are shown Appendix C as follows:-

> Khayinga and Siginga    -    KShs. 11,000.00
>
> Shivanga          -    KShs. 16,000.00

Lugusi                         -        KShs. 27,000.00

Basing the choice on cost, Khayinga and Siginga models would be the most

acceptable. The main draw back on this model has been inconvenient operation and

maintenance procedures which as described earlier can be modified at no extra cost.

The second choice is Shivanga model and the most expensive is Lugusi. Lugusi

model was also found to be least efficient of the three models and would be least

favoured.

Combining all the factors, e.g., treatment efficiency, technological level, operation

and maintenance convenience and acceptability, Khayinga and Siginga models

would be the choice. Though most of the plants have been neglected, the Programme

has spent most of the time training the communities on this model. Success of any

rural project depends on technical implementation and acceptability and hence,

participation by the beneficiaries. The Iron removal project was a technical success.

The technology used in these plants is within the level of the rural communities and

the materials used are available locally and within the project area.  Despite the

technical success the Iron removal project did not  proceed as intended due to

problems related to  community participation as follows:

(a).    The plants were not acceptable in most communities. The plants were installed without the knowledge of the consumers who were not aware of the problem the Programme was trying to solve.

(b).    Where implementation was prompted by water quality complaints, installation was not done concurrently with operation and maintenance training. Implementation was done by contractors whose main interest was to finish the work and get paid.

(c).    To some extent, the adopted model (Khayinga and Siginga) was inconvenient to backwash and clogging was often followed by abandonment.

## 7.1    Summary of Recommendations

1.    Design modification in high iron and turbidity waters (e.g. Siginga and Khayinga) should include pre-treatment and/or pre-settling units. Taking all factors to be constant, the cut-off raw water iron concentration requirement in order to achieve 0.3 mg/l in filtered water at a removal efficiency of 96% would be about 8 mg/l. Raw water iron concentration beyond this value would require increase in efficiency.

As mentioned in Chapter 5, Siginga and Khayinga models are modified slow sand filtration. Experience gained in Finland led to the following design guidelines:

    a.    Pre-filtration contact time of 30 minutes

    b.    Hydraulic load 0.1 - 0.4 $mh^{-1}$

These guidelines have not been closely followed and the current contact time and hydraulic load are completely out of this range e.g

    Pre-filtration contact time    - 1 Min

    System retention time    - 5 Min

    Hydraulic load    - 7.5 m/h

This is for a filter surface area of 0.4 $m^2$ and an average flow of 50 l/min

2.    Shivanga and Lugusi models should be tried in high iron concentration waters in different quality zones.

3. Rehabilitation of the existing plants should be done concurrently with 'on the job' training for consumers. A follow up programme should be formulated and its frequency to be determined by the consumers response and hence the effectiveness of the training.

4. Where the communities response is poor and the plants' maintenance conditions continue to deteriorate, the only solution would be to dismantle the installations. This will save the communities from drinking heavily contaminated water.

5. Installation of new plants should follow a demand driven approach. The communities should present their water quality problems first and formulation of solutions should involve them. Training should start before the iron removal plant installation and continue during the construction until completion. Operation and maintenance training and follow-up should be carried out until the community is fully conversant.

# 8.0    SUGGESTIONS FOR FURTHER RESEARCH

Design and development of any water treatment plant requires that thorough investigations on the actual mechanisms involved are carried out in the laboratory and pilot plants. Physico-chemical and microbiological processes are involved in iron removal by contact filtration and their relative contributions varies from place to place. Knowledge of relative contributions in different water quality regions would yield invaluable information for design development and modifications.

In biological systems, favourable conditions must be created to enhance bacterial growth. In physico-chemical iron removal systems, optimization of chemical dosages, contact time, air supply etc, must be considered for efficient removal. Preliminary information on the bacteriological contribution in the iron removal systems can be obtained by observing the effect of disinfection on the removal efficiencies in a pilot plants.  If disinfection is shown to affect the removal efficiency, it will be a confirmation of bacteria participation and hence characterization of various types of bacteria should follow. The efficiency of iron removal in biological systems depend on growth rate of micro-organisms which has been found to be influenced by environmental factors eg. salinity, pH, oxygen content, organic matter and nutrients. The optimal Carbon: Nitrogen: Phosphorous

ratio has been found to be 125: 11: 1 (Hatva et al., 1985). In Finland it has been shown that clogging of filters varied with the kind of bacteria present. Introduction of gallionella and leptothrix extended the filter cycle to one year as opposed to a few weeks when chrobium and metallegenum were utilized (Mellyvirta, personal communications, 1987).

Generally, bacterially mediated iron removal has not been thoroughly studied in Kenya. Knowledge of various types of bacteria involved in iron removal and their rates of growth in various environments should be extensively studied. The effect of variation in redox conditions, oxygen concentration and pH, nutrient level, ammonia etc on the removal efficiency will yield important information to supplement the existing literature which has mainly been obtained in the temperate lands. The studies can be carried out in and outside Western Province.

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# APPENDICES

**APPENDIX A**

# APPENDIX A1     SIGINGA PLANT (BS-9)

| Date | Time | Sample | Ferrous Iron mg Fe²⁺/l | Total Iron mg Fe/l | Perm No mg KmnO₄/l | Nitrate mg NO₃/l | Nitrite mg NO₂/l | Ammonia mg NH₄/l | Dissolved Oxygen mg O/l | Colour mg Pt/l | Turbidity N.T.U | Carbon Dioxide mg CO₂/l | Total Alkalinity mg CaCO₃/l | Total Hardness mg CaCO₃/l | Prod in hr | pH Units | Conduct. μm/cm | Manganese mg Mn/l | Flow Rate l/s | Total Coliform per 100 ml |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 02-06-93 | 8.00-2.00pm | B | A | C | K | | W | A | S | H | I | N | G | | | | | | |
| | 2.00-3.00pm | RAW FILT. | 5.1 2.31 | 17.4 10.5 | | | | | 3.8 1.5 | 240 60 | 55 10 | 170 85 | 261 250 | 200 215 | 80 | 6.4 6.65 | 515 480 | 3.0 1.0 | | |
| | 3.00-6.00pm | RAW FILT. | 5.15 2.25 | 17.0 2.5 | 19.5 9.6 | 0.09 0.12 | 0.33 0.32 | 2.85 2.66 | 3.8 2.5 | 180 10 | 55 11.5 | 85 170 | 200 245 | 200 200 | 200 | 6.4 6.5 | 490 476 | 2.0 1.0 | 0.18 | 12 25 |
| 03-06-93 | 7.05-8.00am | RAW FILT. | 5.5 0.0 | 18.0 0.1 | | | | | 2.5 5.0 | 120 3.0 | 50 1.0 | 152 140 | 258 260 | 200 200 | 40 | 6.62 6.55 | 467 467 | 1.0 1.3 | | |
| | 8.00-11.00am | RAW FILT. | 5.0 0.02 | 16.5 0.22 | | | | | 2.2 4.3 | 120 5.0 | 52 1.2 | | 258 255 | 220 200 | 60 | | 460 457 | 1.8 1.6 | | |
| | 11.00-2.00pm | RAW FILT. | 5.1 0.04 | 17.0 0.35 | | | | | 1.84 0.9 | 150 4.0 | 55 1.5 | 175 177 | 275 270 | 201 198 | 120 | | 469 458 | 1.3 1.3 | | |
| | 2.00-3.00pm | RAW FILT. | 5.4 0.02 | 17.0 0.2 | | | | | 2.7 2.0 | 110 3.0 | 50 1.0 | | 261 250 | 198 200 | 50 | 6.55 6.5 | 476 460 | | | |
| | 3.00-6.00pm | RAW FILT. | 5.0 0.04 | 17.0 0.7 | 18.50 8.9 | 0.19 0.20 | 0.26 0.24 | 3.10 3.08 | 3.5 1.9 | | 65 3 | 195 185 | 260 275 | 200 200 | 260 | | 460 458 | | 0.18 | 8 17 |
| 04-06-93 | 7.00-8.00am | RAW FILT. | 5.0 0.00 | 17.0 0.13 | | | | | 1.95 5.30 | 100 3.0 | 53 1.5 | 170 135 | 275 263 | 198 189 | 30 | | 489 480 | | | |
| | 8.00-11.00am | RAW FILT. | 5.0 0.02 | 16.3 0.26 | | | | | 3.30 5.8 | 100 4.0 | 50 1.4 | | 250 265 | 198 198 | 70 | 6.45 6.4 | 470 460 | 1.4 1.5 | | |
| | 11.00-2.00pm | RAW FILT. | 4.50 0.04 | 14.5 0.10 | | | | | 2.2 0.85 | 155 5.0 | 55 1.6 | 182 176 | 260 247 | 198 197 | 100 | 6.5 6.50 | 482 476 | 1.3 1.3 | | |
| | 2.00-3.00pm | RAW FILT. | 5.0 0.03 | 17.0 0.34 | | | | | 3.6 2.0 | | | | 275 277 | 200 195 | 140 | 6.4 6.3 | 485 482 | 1.3 1.3 | | |
| | 3.00-6.00pm | RAW FILT. | 5.7 0.04 | 17.0 0.9 | 19.2 6.2 | 0.18 0.185 | 0.52 0.48 | 3.8 3.65 | 2.9 2.0 | | 40 1.8 | 165 164 | 250 257 | 180 178 | 160 | 6.5 6.4 | 460 457 | 1.4 1.3 | 0.13 | 10 15 |
| 07-06-93 | 8.00-11.00am | RAW FILT. | 5.0 0.03 | 17.0 0.07 | | | | | 1.70 5.0 | 120 2.0 | 58 1.0 | 120 70 | 248 250 | 189 183 | 50 | 6.38 6.5 | 460 470 | 1.2 1.3 | | |
| | 11.00-1.00pm | RAW FILT. | 5.0 0.07 | 17.0 0.15 | | | | | 2.8 4.9 | | | 174 123 | 260 248 | 200 200 | 120 | 6.44 6.40 | 453 450 | | | |
| | 1.00-2.00pm | RAW FILT. | 5.2 0.05 | 17.2 0.1 | | | | | 2.3 0.75 | | | | 248 248 | 204 187 | 30 | 6.5 6.4 | 448 448 | | | |
| | 2.00-3.00pm | RAW FILT. | 5.8 0.05 | 15.2 0.10 | | | | | 3.50 2.20 | 90 5 | 50 2 | | 250 248 | 205 199 | 60 | 6.47 6.46 | 497 462 | | | |
| | 3.00-6.00pm | RAW FILT. | 5.0 0.1 | 17.0 0.3 | 18.80 8.5 | 0.15 0.155 | 0.00 0.09 | 0.33 0.20 | 2.7 2.10 | 105 5 | 52 2.5 | 154 175 | 277 270 | 204 195 | 240 | 6.6 6.4 | 478 459 | | 0.10 | 17 9 |

# APPENDIX A1 (Cont.)  SIGINGA PLANT (BS-9)

| Date | Time | Sample | Ferrous Iron mg Fe²⁺/l | Total Iron mg Fe/l | Perm No. mg KMnO₄/l | Nitrate mg NO₃/l | Nitrite mg NO₂/l | Ammonia mg NH₄/l | Dissolved Oxygen mg O/l | Colour mg Pt/l | Turbidity N.T.U | Carbon Dioxide mg CO₂/l | Total Alkalinity mg CaCO₃/l | Total Hardness mg CaCO₃/l | Prod in hr | pH Units | Conduct µs/cm | Manganese mg Mn/l | Flow Rate l/s | Total Coliform Per 100 ml |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 09-06-93 | 7.00-8.00pm | RAW | 5.4 | 17.2 | | 0.320 | 0.43 | 2.43 | 1.5 | 130 | 50 | 210 | 262 | 200 | 10 | | 470 | 1.3 | | |
| | | FILT | 0.05 | 0.1 | | 0.8 | 0.40 | 2.4 | 5.8 | 2 | 1.0 | 158 | 250 | 164 | | | 473 | 1.4 | | |
| | 8.00-11.00pm | RAW | 5.0 | 17.0 | | | | | 2.1 | | 50 | | 260 | 178 | 60 | 6.5 | 473 | 1.3 | | |
| | | FILT | 0.08 | 0.18 | | | | | 4.1 | | 1.3 | | 255 | 200 | | 6.38 | 473 | 1.2 | | |
| | 11.00-1.00pm | RAW | 5.0 | 15.0 | | | | | 2.5 | | 70 | | 277 | 200 | 120 | 6.5 | 470 | 1.3 | | |
| | | FILT | 0.5 | 0.25 | | | | | 1.13 | | 1.7 | | 258 | 200 | | 6.4 | 462 | 1.3 | | |
| | 1.00-2.00pm | RAW | 5.0 | 17.0 | | | | | 3.3 | 130 | 60 | | 253 | 200 | 50 | 6.55 | 448 | | | |
| | | FILT | 0.03 | 0.15 | | | | | 2.6 | 1.0 | 1.2 | | 264 | 200 | | 6.4 | 467 | | | |
| | 2.00-3.00pm | RAW | 5.3 | 16.7 | | | | | 2.30 | 128 | 53 | 175 | 258 | 198 | 100 | 6.4 | 467 | | | |
| | | FILT | 0.1 | 0.24 | | | | | 1.73 | 2 | 1.8 | 194 | 255 | 188 | | 6.4 | 467 | | | |
| | 3.00-6.00 | RAW | 5.0 | 17.2 | 13.6 | 0.72 | 0.66 | 5.60 | 3.1 | | 75 | 185 | 250 | 210 | 280 | 6.3 | 467 | 2.0 | 0.06 | 7 |
| | | FILT | 0.08 | 0.35 | 6.4 | 0.90 | 0.90 | 5.10 | 2.70 | | 5.5 | 167 | 252 | 198 | | 6.5 | 468 | 1.4 | | 3 |
| 10-06-93 | 7.10-8.10am | RAW | 5.0 | 17.0 | | | | | 2.60 | 130 | 50 | 190 | 270 | 200 | 20 | 6.5 | 453 | | | |
| | | FILT | 0.02 | 0.15 | | | | | 6.4 | 0.8 | 0.5 | 150 | 248 | 200 | | 5 | 450 | | | |
| | 8.10-11.10am | RAW | 5.0 | 17.3 | | | | | 3.8 | 120 | 52 | | 270 | 189 | 60 | 5.5 | 454 | | | |
| | | FILT | 0.09 | 0.25 | | | | | 1.9 | 15 | 1.4 | | 250 | 193 | | 6.2 | 454 | | | |
| | 11.30-2.00pm | RAW | 5.7 | 17.3 | | | | | 3.70 | | | 164 | 260 | 200 | 180 | 6.3 | 450 | | | |
| | | FILT | 0.15 | 0.3 | | | | | 2.40 | | | 156 | 248 | 193 | | 6.3 | 450 | | | |
| | 2.00-3.00pm | RAW | 5.5 | 17.0 | | | | | 2.80 | | 69 | | 257 | 200 | 100 | 5.8 | 467 | | | |
| | | FILT | 1.0 | 0.25 | | | | | 1.30 | | 1.6 | | 250 | 187 | | 6.2 | 458 | | | |
| | 3.00-4.00pm | RAW | 5.2 | 17.3 | 15.5 | 0.17 | 0.18 | 4.77 | 2.90 | | 54 | 200 | 273 | 220 | 240 | | 470 | 1.5 | | 15 |
| | | FILT | 0.2 | 0.4 | 8.7 | 0.22 | 0.21 | 4.72 | 1.93 | | 2.2 | 165 | 270 | 200 | | | 458 | 1.3 | 0.06 | 7 |
| 11-06-93 | 7.00-8.00pm | RAW | 5.0 | 17.0 | | 0.08 | 0.34 | 3.45 | 1.6 | 110 | 54 | 157 | 270 | 200 | 50 | 6.5 | 468 | | | |
| | | FILT | 0.05 | 0.1 | | 0.53 | 0.12 | 3.20 | 5.3 | 3 | 1.0 | 148 | 266 | 200 | | 6.4 | 465 | | | |
| | 8.00-11.00am | RAW | 5.3 | 17.5 | | | | | 2.1 | 120 | 52 | | 248 | 205 | 75 | 6.6 | 478 | | | |
| | | FILT | 0.07 | 0.2 | | | | | 3.2 | 3 | 1.2 | | 250 | 199 | | 6.4 | 470 | | | |
| | 11.00-1.00pm | RAW | 5.2 | 17.0 | | | | | 2.70 | 201 | 52 | 183 | 260 | 204 | 200 | 6.0 | 450 | | | |
| | | FILT | 0.25 | 0.4 | | | | | 1.25 | 5 | 1.5 | 187 | 250 | 200 | | 5.2 | 450 | | | |
| | 1.00-2.00pm | RAW | 5.2 | 17.8 | | | | | 3.0 | 200 | 50 | | 272 | 200 | 50 | 6.4 | 468 | | | |
| | | FILT | 0.2 | 0.35 | | | | | 1.6 | 4 | 1.3 | | 258 | 200 | | 6.5 | 455 | | | |
| | 2.00-3.00pm | RAW | 5.0 | 17.0 | | | | | 3.15 | 200 | 57 | | 270 | 200 | 150 | 6.55 | 478 | | | |
| | | FILT | 0.2 | 0.3 | | | | | 2.0 | 5 | 2.0 | | 270 | 191 | | 6.4 | 462 | | | |
| | 3.00-6.00pm | RAW | 5.7 | 15.2 | 19.5 | 0.15 | 1.13 | 5.2 | 2.65 | 130 | 65 | 194 | 262 | 200 | 250 | 6.6 | 470 | 1.4 | | 6 |
| | | FILT | 0.25 | 0.43 | 8.9 | 0.38 | 1.40 | 4.8 | 1.95 | 4 | 2 | 198 | 258 | 196 | | 6.3 | 470 | 1.3 | 0.06 | 3 |

# APPENDIX A1 (Cont.)  SIGINGA PLANT (BS-9)

| Date | Time | Sample | Ferrous Iron mg Fe/l | Total Iron mg Fe/l | Perm. No. mg KmnO₄/l | Nitrate mg NO₃/l | Nitrite mg NO₂/l | Ammonia mg NH₃/l | Dissolved Oxygen mg O₂/l | Colour mg Pt/l | Turbidity N.T.U | Carbon Dioxide mg CO₂/l | Total Alkalinity mg CaCO₃/l | Total Hardness mg CaCO₃/l | Prod. in ltr | pH Units | Conduct. µs/cm | Manganese mg Mn/l | Flow Rate l/s | Total Coliform Per 100 ml |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 14/06/93 | 7.00-8.00pm | RAW | 5.4 | 17.5 | | 0.24 | 1.56 | 0.04 | 1.6 | 220 | 50 | 153 | 250 | | 60 | 6.55 | 472 | 1.4 | | |
| | | FILT. | 0.04 | 0.098 | | 0.26 | 1.57 | 3.00 | 4.6 | 3 | 0.7 | 76 | 247 | | | 6.5 | 470 | 1.3 | | |
| | 8.00-11.00pm | RAW | 5.4 | 1.7 | | | | | 1.3 | 200 | 55 | | 273 | | 80 | 6.4 | 470 | 1.3 | | |
| | | FILT. | 0.05 | 0.12 | | | | | 3.8 | 2 | 1.0 | | 270 | | | 6.35 | 470 | 1.3 | | |
| | 11.00-1.00pm | RAW | 5.2 | 17.0 | | | | | 2.1 | 178 | 64 | 145 | 270 | 215 | 150 | 6.5 | 474 | 1.4 | | |
| | | FILT. | 0.055 | 0.11 | | | | | 1.1 | 2.2 | 1.3 | 188 | 263 | 192 | | 6.3 | 468 | 0.9 | | |
| | 1.00-2.00pm | RAW | 5.3 | 17.0 | | | | | 1.13 | 134 | 47 | | 270 | 212 | 40 | 6.5 | 477 | | | |
| | | FILT. | 0.05 | 0.09 | | | | | 6.53 | 2.0 | 1.4 | | 263 | 208 | | 6.4 | 474 | | | |
| | 2.00-3.00pm | RAW | | | | | | | | | | | | | | | | | | |
| | | FILT. | | | | | | | | | | | | | | | | | | |
| | 3.00-6.00 | RAW | 5.0 | 17.0 | 15.8 | 0.12 | 0.88 | 2.20 | 2.80 | 186 | 74 | 173 | 260 | 198 | 260 | 6.55 | 488 | 1.13 | | 19 |
| | | FILT. | 0.056 | 0.36 | 9.0 | 0.16 | 0.83 | 1.93 | 1.7 | 3.3 | 2.7 | 197 | 258 | 195 | | 6.35 | 476 | 0.8 | 0.06 | 10 |
| 17/06/93 | 7.00-8.00am | RAW | 5.6 | 16.0 | | | | | 2.30 | | | 192 | 295 | 250 | 40 | 6.6 | 453 | 1.4 | | |
| | | FILT. | 0.026 | 0.08 | | | | | 5.6 | | | 74 | 253 | 201 | | 6.5 | 443 | 0.8 | | |
| | 8.00-11.00am | RAW | 5.6 | 16.8 | | | | | 1.2 | 200 | 60 | | 290 | | 90 | 6.43 | 540 | 1.4 | | |
| | | FILT. | 0.03 | 0.06 | | | | | 6.75 | 3 | 2 | | 282 | | | 6.4 | 501 | 0.8 | | |
| | 11.00-1.00pm | RAW | 5.0 | 17.8 | | | | | 3.40 | | | 153 | 279 | 200 | 120 | 6.5 | 486 | 1.3 | | |
| | | FILT. | 0.04 | 0.089 | | | | | 2.70 | | | 125 | 281 | 190 | | 6.3 | 471 | 1.0 | | |
| | 1.00-2.00pm | RAW | 5.0 | 16.8 | | | | | 1.70 | | | | 288 | 195 | 20 | 6.4 | 489 | 1.3 | | |
| | | FILT. | 0.05 | 0.10 | | | | | 0.60 | | | | 253 | 200 | | 6.4 | 480 | 0.9 | | |
| | 2.00-3.00pm | RAW | 5.0 | 17.4 | | | | | 2.70 | 162 | 48 | | 290 | 195 | 80 | 6.5 | 508 | 1.3 | | |
| | | FILT. | 0.06 | 0.115 | | | | | 1.58 | 1 | 0.8 | | 278 | 190 | | 6.45 | 480 | 1.2 | | |
| | 3.00-6.00pm | RAW | 5.0 | 17.0 | 16.40 | 0.07 | 0.65 | 1.30 | 2.9 | | 53 | 169 | 295 | 201 | 200 | 6.5 | 463 | 1.4 | | 15 |
| | | FILT. | 0.062 | 0.30 | 11.1 | 0.17 | 0.64 | 1.12 | 2.0 | | 2.4 | 173 | 254 | 140 | | 6.3 | 465 | 0.6 | 0.06 | 7 |
| 18/06/93 | 8.00-11.00am | RAW | 5.60 | 16.5 | | | | | 1.55 | 180 | 48 | 187 | 270 | 200 | 200 | 6.6 | 470 | | | |
| | | FILT. | 0.022 | 0.078 | | | | | 2.80 | 1.5 | 0.6 | 125 | 268 | 204 | | 6.6 | 470 | | | |
| | 11.00-1.00pm | RAW | 4.3 | 16.3 | | | | | 2.20 | | | 168 | 290 | 182 | 180 | 6.5 | 420 | 2.0 | | |
| | | FILT. | 0.03 | 0.08 | | | | | 1.30 | | | 132 | 268 | 190 | | 6.4 | 463 | 1.5 | | |
| | 2.00-3.00pm | RAW | 4.5 | 16.9 | | | | | 5.2 | | | | 268 | 195 | 60 | 6.5 | 482 | | | |
| | | FILT. | 0.036 | 0.11 | | | | | 2.3 | | | | 260 | 167 | | 6.3 | 463 | | | |
| | 3.00-6.00pm | RAW | 5.0 | 17.0 | 17.1 | 0.056 | 0.63 | 3.35 | 2.6 | 128 | 50 | 194 | 295 | 201 | 200 | 6.5 | 463 | 1.4 | | 13 |
| | | FILT. | 0.063 | 0.35 | 12.7 | 0.160 | 1.30 | 2.95 | 2.10 | 2.0 | 1.6 | 170 | 254 | 140 | | 6.3 | 465 | 0.6 | 0.05 | 7 |

# APPENDIX A1 (Cont.)   SIGINGA PLANT (BS-9)

| Date | Time | Sample | Ferrous Iron mg Fe²/l | Total Iron mg Fe/l | Perm. No. mg KmnO₄/l | Nitrate mg NO₃/l | Nitrite mg NO₂/l | Ammonia mg NH₃/l | Dissolved Oxygen mg O₂/l | Colour mg Pt/l | Turbidity N.T.U | Carbon Dioxide mg CO₂/l | Total Alkalinity mg CaCO₃/l | Total Hardness mg CaCO₃/l | Prod. in ltr | pH Units | Conduct. µs/cm | Manganese mg Mn/l | Flow Rate l/Sec | Total Coliform Per 100 ml |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21/06/93 | 7.00-8.00pm | RAW | 4.58 | 15.7 | | 0.13 | 0.2 | 4.34 | 1.6 | 153 | 56 | 235 | 299 | 232 | 20 | 6.5 | 366 | 1.3 | | |
| | | FILT. | 0.06 | 0.08 | | 0.54 | 0.3 | 3.8 | 4.5 | 2 | 1.0 | 72 | 269 | 223 | | 6.44 | 368 | 0.8 | | |
| | 8.00-11.00pm | RAW | 5.0 | 16.5 | | | | | 1.9 | 162 | 48 | | 300 | 205 | 60 | 6.6 | 443 | 1.3 | | |
| | | FILT. | 0.06 | 0.059 | | | | | 1.1 | 3 | 2.5 | | 254 | 191 | | 6.4 | 437 | 1.0 | | |
| | 11.00-1.00pm | RAW | 4.8 | 14.5 | | | | | 2.2 | 188 | 67 | 198 | 280 | 224 | 130 | 6.6 | 501 | 1.9 | | |
| | | FILT. | 0.03 | 0.07 | | | | | 1.7 | 4 | 3 | 176 | 266 | 210 | | 6.45 | 478 | 1.3 | | |
| | 1.00-2.00pm | RAW | 4.8 | 15.5 | | | | | 1.9 | 4 | 3 | | 300 | 219 | 60 | 6.3 | 468 | | | |
| | | FILT. | 0.05 | 0.09 | | | | | 0.9 | | | | 266 | 211 | | 6.2 | 470 | | | |
| | 2.00-3.00pm | RAW | 5.6 | 17.0 | | | | | 3.10 | 124 | 53 | | 268 | 240 | 80 | 6.3 | 482 | 1.4 | | |
| | | FILT. | 0.05 | 0.08 | | | | | 2.5 | 2.8 | 2.0 | | 255 | 228 | | 6.1 | 468 | 0.6 | | |
| | 3.00-6.00 | RAW | 5.0 | 16.0 | 22.2 | 0.71 | 0.14 | 1.06 | 2.9 | 178 | 56 | 184 | 290 | 193 | 200 | 6.56 | 422 | 1.6 | | 6 |
| | | FILT. | 0.05 | 0.45 | 12.9 | 0.85 | 0.06 | 0.96 | 2.0 | 13 | 1.5 | 195 | 281 | 179 | | 6.57 | 423 | 0.9 | 0.05 | 2 |
| 22/06/93 | 7.00-8.00am | RAW | 4.8 | 16.5 | | | | | 1.50 | 180 | 52 | 212 | 290 | 238 | 50 | 5.8 | 463 | | | |
| | | FILT. | 0.0 | 0.2 | | | | | 5.7 | 4 | 1.0 | 165 | 279 | 209 | | 6.0 | 421 | | | |
| | 8.00-11.00am | RAW | 5.2 | 16.0 | 17.5 | 0.13 | 0.35 | 3.35 | 1.9 | 150 | 65 | | 302 | 190 | 100 | 6.88 | 486 | 1.2 | | |
| | | FILT. | 0.07 | 0.51 | 8.7 | 0.54 | 0.00 | 2.42 | 2.20 | 5.4 | 1.5 | | 284 | 175 | | 6.39 | 494 | 0.4 | | |
| | 11.00-1.00pm | RAW | 4.76 | 16.0 | | | | | 2.70 | 157 | 65 | 168 | 295 | 208 | 160 | 6.58 | 436 | 2.1 | | 4 |
| | | FILT. | 0.08 | 0.51 | | | | | 1.75 | 3.8 | 1.5 | 174 | 255 | 187 | | 6.5 | 371 | 1.1 | 0.05 | 1 |
| | 2.00pm | B | A | C | K | | W | A | S | H | I | N | G | | | | | | | |
| 23/07/93 | 9.00-11.00am | RAW | 5.6 | 14.85 | | 0.0 | 0 | 3 | 0.5 | 244 | 46 | 152 | | | 54 | 6.62 | 434 | 1.6 | | |
| | | FILT. | 0.7 | 1.06 | | 0.013 | 0.516 | 2.33 | 0.8 | 20 | 4 | 39 | | | | 6.51 | 403 | 2.0 | | |
| | 11.00-1.00pm | RAW | 5.4 | 15.0 | | 0.0 | 0.06 | 3.0 | 1.3 | 220 | 50 | 189 | | | 220 | 6.65 | 455 | 0.6 | | |
| | | FILT. | 0.75 | 1.16 | | 0.044 | 0.71 | 2.1 | 0.7 | 18 | 5 | 73 | | | | 6.46 | 450 | 0.8 | | |
| | 1.00-3.00pm | RAW | 5.4 | 16.0 | | 0.22 | 0.003 | 3.50 | 2.5 | 230 | 55 | | | | 67 | | | 1.3 | | |
| | | FILT. | 0.73 | 1.08 | | 0.88 | 0.08 | 2.14 | 0.8 | 20 | 4 | | | | | | | 1.1 | | |
| | 3.00-6.00pm | RAW | 4.4 | 15.9 | 23.40 | 0.80 | 0.92 | 4.2 | 3.0 | 180 | 94 | 179 | 293 | 224 | 325 | 6.4 | 465 | 2.0 | 0.22 | 8 |
| | | FILT. | 0.9 | 1.3 | 8.96 | 0.4 | 1.2 | 3.3 | 1.45 | 15 | 6 | 195 | 268 | 212 | | 6.15 | 458 | 1.8 | | 19 |
| 25/07/93 | 7.00-8.00am | RAW | 4.0 | 17.4 | | 0.53 | 0.00 | 2.83 | 2.5 | 138 | 60 | 193 | 256 | 195 | 25 | 6.2 | | 1.55 | | |
| | | FILT. | 0.1 | 0.3 | | 0.39 | 0.12 | 2.72 | 6.5 | 2.0 | 1 | 62 | 247 | 187 | | 6.0 | | 1.32 | | |
| | 8.00-11.00am | RAW | 3.75 | 14.6 | | 0 | 0.014 | 3.65 | 3.30 | 130 | 65 | | 264 | 203 | 60 | 6.9 | 472 | 0.5 | | |
| | | FILT. | 0.3 | 0.35 | | 0.044 | 0.029 | 2.49 | 0.60 | 3.5 | 2 | | 250 | 189 | | 6.4 | 460 | 0.3 | | |
| | 11.00-1.00pm | RAW | 4.5 | 15.3 | | 0.26 | 0.015 | 4.5 | 3.30 | 140 | 75 | 167 | | | 150 | 6.7 | | 1.3 | | |
| | | FILT. | 0.4 | 0.80 | | 0.44 | 0.033 | 2.6 | 1.20 | 3.0 | 2.5 | 89 | | | | 6.3 | | 1.5 | | |
| | 1.00-3.00pm | RAW | 6.95 | 16.8 | | 0.26 | 0.017 | 2.35 | 1.90 | 110 | 55 | | | | 70 | 6.00 | | 1.3 | | |
| | | FILT. | 0.25 | 0.40 | | 0.26 | 0.033 | 1.80 | 0.4 | 3.0 | 2.0 | | | | | 5.85 | | 1.5 | | |
| | 3.00-6.00pm | RAW | 5.5 | 16.6 | 17.4 | 0.15 | 0.08 | 3.65 | 2.64 | 135 | 60 | 200 | | | 230 | 6.5 | 453 | 0.8 | 0.16 | 7 |
| | | FILT. | 0.5 | 0.9 | 9.2 | 0.20 | 0.12 | 3.53 | 1.0 | 4 | 3.0 | 186 | | | | 6.30 | 438 | | | |

# APPENDIX A-1   SIGINGA PLANT (BS-9)

| Date | Time | Sample | Ferrous Iron mg Fe²⁺/l | Total Iron mg Fe/l | Perm. No. mg KmnO₄/l | Nitrate mg NO₃/l | Nitrite mg NO₂/l | Ammonia mg NH₃/l | Dissolved Oxygen mg O₂/l | Colour mg Pt/l | Turbidity N.T.U | Carbon Dioxide mg CO₂/l | Total Alkalinity mg CaCO₃/l | Total Hardness mg CaCO₃/l | Prod. in hr | pH Units | Conduct. µs/cm | Manganese mg Mn/l | Flow Rate l/Sec | Total Coliform Per 100 ml |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 29/07/95 | 7.00–8.45am | RAW | 4.8 | 15.0 | | 0.0 | 0.0 | 3.7 | 1.8 | 250 | 60 | 188 | 292 | | 40 | 6.5 | | 1.3 | | |
| | | FILT | 0.10 | 0.2 | | 0.13 | 0.14 | 2.43 | 5.8 | 250 | 1 | 45 | 282 | | | 6.2 | | 0.8 | | |
| | 8.45–11.00am | RAW | 4.5 | 15.2 | | 0.0 | 0.003 | 5.1 | 0.8 | 120 | 43 | 175 | 274 | | 200 | 6.6 | 470 | | | |
| | | FILT | 0.15 | 0.56 | | 0.176 | 0.01 | 4.6 | 0.5 | 3.0 | 2.0 | 72 | 257 | | | 6.3 | 410 | | | |
| | 11.00–1.00pm | RAW | 4.2 | 16.3 | | 0.170 | 0.0 | 3.5 | 2.0 | 175 | 53 | | 263 | | 120 | 6.5 | | 0.8 | | |
| | | FILT | 0.11 | 0.50 | | 0.194 | 0.75 | 2.79 | 1.5 | 4 | 3 | | 252 | | | 6.5 | | 0.6 | | |
| | 1.00–3.00pm | RAW | 4.0 | 17.3 | | 0.088 | 0.003 | | 2.3 | 160 | 55 | | | | 80 | 6.25 | 473 | | | |
| | | FILT | 0.10 | 0.43 | | 0.176 | 0.003 | | 0.5 | 3 | 2 | | | | | 6.18 | 458 | | | |
| | 3.00–6.00pm | RAW | 4.3 | 16.2 | 19.7 | 0.132 | 0.002 | 3.71 | 2.0 | 175 | 98 | 229 | | | 320 | 6.6 | 475 | 1.3 | | 11 |
| | | FILT | 0.2 | 0.53 | 9.6 | 0.132 | 0.53 | 2.85 | 2.4 | 4 | 5.6 | 224.5 | | | | 6.5 | 466 | 1.0 | 0.14 | 5 |

## APPENDIX A2    KHAYINGA PLANT (BS-12)

| Date | Time | Sample | Ferrous ions mg Fe²⁺/l | Total Iron mg Fe/l | Perm. No. mg KmnO₄/l | Nitrate mg NO₃/l | Nitrite mg NO₂/l | Ammonia mg NH₃/l | Dissolved Oxygen mg O₂/l | Carbon Dioxide mg CO₂/l | Colour mg pt/l | Turbidity N.T.U | Conduct. µs/cm | Total Alkalinity mg CaCO₃/l | Total Hardness mg CaCO₃/l | pH Units | Manganese mg Mn/l | Flow Rate l/s | Prod. in lts | Total Coliform Per 100 ml |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | B | A | C | K | | W | A | S | H | E | D | | | | | | | | |
| 28/02/93 01/03/93 | 7.30–8.00am | RAW FILT. | 6.5 0.15 | 16.5 0.38 | | 0.132 0.176 | 0.001 0.042 | 4.5 4.48 | 3.0 4.93 | 145 65 | 190 12 | 62 0.5 | 1630 1640 | 435 439 | 324 320 | 6.55 6.48 | 1.9 1.8 | | 32 | |
| | 8.00–9.00am | RAW FILT. | 6.8 0.1 | 17.2 0.28 | | 0.01 0.165 | 0.005 0.06 | 4.43 4.37 | 3.3 4.6 | | 185 2 | 51 0.7 | 1700 1680 | 457 450 | 340 334 | 6.47 6.36 | 1.8 1.65 | | 60 | |
| | 9.00–11.00am | RAW FILT. | 6.4 0.13 | 12.5 0.15 | | 0.123 0.135 | 0.02 0.08 | 3.96 3.85 | 2.95 1.8 | | 160 5 | 85 2.2 | 1630 1610 | 490 486 | 344 348 | 6.53 6.45 | 1.5 1.3 | | 120 | |
| | 11.00–1.00pm | RAW FILT. | 5.4 0.14 | 14.5 0.13 | | | | | 3.2 2.1 | 132 95 | 170 7 | 110 4.1 | | 430 425 | 360 368 | 6.43 6.33 | 1.1 0.9 | | 180 | |
| | 1.00–3.00pm | RAW FILT. | 6.4 0.16 | 17.0 0.4 | | | | | 3.1 1.4 | | 170 4 | 120 2.4 | | | | 6.6 6.5 | 1.4 1.3 | | 70 | |
| | 3.00–6.00pm | RAW FILT. | 6.3 0.18 | 16.3 0.85 | 13.30 5.40 | 0.14 0.16 | 0.007 0.035 | 3.54 3.51 | 2.85 1.6 | 150 90 | 150 8 | 160 6.6 | | | | 6.40 6.25 | 1.45 1.2 | 0.28 | 250 | 5 12 |
| 03/03/93 | 8.00am | RAW FILT. | 6.9 0.13 | 15.8 0.3 | | | | | 3.43 4.6 | 90 61 | 180 5 | 165 1.2 | | | | 6.0 5.85 | 1.44 1.38 | | | |
| | 11.00am | RAW FILT. | 4.2 0.15 | 16.3 0.3 | | | | | 2.72 2.47 | | 170 1.0 | 190 5.6 | | | | | 1.3 1.2 | | 200 | |
| | 1.00pm | RAW FILT. | 5.5 0.17 | 15.4 0.5 | | | | | 2.82 2.2 | 160 188 | 160 4 | 140 3.4 | | | | 6.25 5.73 | 1.5 1.5 | | 120 | |
| | 2.00–3.00pm | RAW FILT. | 6.2 0.14 | 17.5 0.6 | | | | | 3.33 1.72 | 140 170 | 250 6 | 165 4.2 | 1530 1497 | | | 6.48 6.25 | 1.4 1.4 | | | |
| | 3.00–6.00pm | RAW FILT. | 5.8 0.17 | 18.0 0.65 | 9.50 5.40 | 0.044 0.163 | 0.002 0.008 | 3.32 3.26 | 2.93 1.3 | 140 | 150 7 | 175 7 | | | | 6.53 6.44 | 1.6 1.6 | 0.23 | 260 | 5 13 |
| 05/03/93 | 7.00–8.00am | RAW FILT. | 6.4 0.0 | 15.3 0.0 | | | | | 2.65 1.23 | 163 150 | 200 4 | 150 1.0 | | | | 6.4 6.35 | 1.5 1.5 | | 30 | |
| | 8.00–10.00am | RAW FILT. | 6.7 0.02 | 16.5 0.1 | | | | | 3.37 2.98 | | 150 5 | 140 <1.0 | | | | 6.52 6.4 | 1.7 1.6 | | 80 | |
| | 10.00–12.00pm | RAW FILT. | 4.5 0.04 | 15.9 0.5 | | | | | 2.86 1.76 | | 210 8 | 190 3.4 | | | | 6.2 6.15 | 1.2 1.2 | | 90 | |
| | 12.00–2.00pm | RAW FILT. | 5.3 0.05 | 15.0 0.6 | | | | | 3.30 2.18 | 125 132 | 190 7 | 180 3 | | | | 6.4 5.73 | 1.1 1.2 | | 210 | |
| | 2.00–3.00pm | RAW FILT. | 0.2 0.05 | 15.6 0.7 | | | | | 3.54 1.35 | | 190 6 | 180 3.3 | | | | 6.13 6.0 | 1.6 1.5 | | 60 | |
| | 3.00–6.00pm | RAW FILT. | 6.9 0.04 | 17.0 0.9 | 15.60 8.70 | 0.03 0.143 | 0.001 0.002 | 4.0 3.9 | | 138 120 | 180 10 | 190 9 | | | | | 1.6 1.6 | 0.21 | 300 | 7 10 |

| Date | Time | Sample | Ferrous mg Fe/l | Total Iron mg Fe/l | Perm No. mg KMnO₄/l | Nitrate mg NO₃/l | Nitrite mg NO₂/l | Ammonia mg NH₃/l | Dissolved Oxygen mg O/l | Carbon Dioxide mg CO₂/l | Colour mg Pt/l | Turbidity N.T.U | Conduct. µS/cm | Total Alkalinity mg CaCO₃/l | Total Hardness mg CaCO₃/l | pH Units | Manganese mg Mn/l | Flow Rate l/s | Prod. in lts | Total Coliform Per 100 ml |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 04/03/93 | 7.00- | RAW | 4.3 | 12.5 | | | | | 324 | 135 | 120 | 90 | 1630 | | | 1.7 | | | | 20 |
| | 8.00am | FILT | 0.00 | 0.00 | | | | | 318 | 130 | 3 | 1 | 1635 | | | 1.6 | | 0.18 | | |
| | 8.00- | RAW | 5.4 | 13.5 | | | | | 292 | 150 | 150 | 130 | 1660 | 460 | 378 | 1.3 | 6.63 | | 40 | |
| | 10.00am | FILT | 0.00 | 0.05 | | | | | 1.95 | | 4 | 1.0 | 1640 | 463 | 382 | 1.25 | 6.52 | | | |
| | 10.00- | RAW | 4.5 | 14.5 | 4.60 | 0.044 | 0.005 | 3.4 | 3.37 | 190 | 190 | 170 | 1710 | 420 | 398 | 1.7 | 6.35 | | 70 | |
| | 12.00pm | FILT | 0.04 | 11.5 | 0.17 | 0.06 | 3.35 | | 23 | | 5 | 23 | 1690 | 418 | 420 | 1.72 | 6.3 | | | |
| | 12.00- | RAW | 4.7 | 11.5 | | | | | 210 | 8 | 160 | 454 | | | | 1.3 | 6.29 | | | |
| | 2.00pm | FILT | 0.06 | | | | | | | | | | | | | 1.2 | 6.18 | | 30 | |
| | 2.00- | RAW | 4.8 | 13.2 | | | | | 256 | 190 | 150 | 5 | | | | 1.6 | 6.00 | | | 230 |
| | 3.00pm | FILT | 0.00 | | | | | | 462 | | 7 | 5 | | | | 0.4 | 5.8 | | | |
| | 3.00- | RAW | 5.1 | 14.2 | | | | | 332 | 143 | 240 | 190 | | | | 1.7 | | | | |
| | 6.00pm | FILT | 0.05 | | | | | | 5.23 | 158 | 12 | 5.5 | | | | 1.1 | | 0.18 | | 21 |
| 10/03/93 | 7.30- | RAW | 5.5 | 14.5 | | 0.135 | 0.005 | 4.3 | 3.1 | 104 | 260 | 170 | | 455 | 380 | 6.52 | 1.5 | | | 75 |
| | 8.00am | FILT | 0.02 | 0.1 | 0.136 | 0.026 | 4.27 | | 3.82 | 90 | 4 | 3.5 | | 450 | 385 | 6.35 | 1.2 | | | |
| | 8.00- | RAW | 4.9 | 15.2 | | | | | 255 | 260 | 165 | 4.1 | | 438 | 386 | 6.30 | 1.1 | | 60 | |
| | 9.00am | FILT | 0.00 | 0.2 | | | | | 224 | 5 | | | | 443 | 383 | 6.00 | 0.8 | | | |
| | 9.00- | RAW | 5.3 | 16.5 | | | | | 292 | 240 | 155 | 4 | | | | 6.4 | 1.4 | | 90 | |
| | 11.00am | FILT | 0.00 | 0.4 | | | | | 1.41 | 5 | | | | | | 6.35 | 1.0 | | | |
| | 11.00- | RAW | 5.6 | 15.7 | | | | | 3.17 | 120 | 245 | 160 | | | | 6.47 | 1.3 | | 120 | |
| | 2.00pm | FILT | 0.07 | 0.5 | | | | | 3.59 | 145 | 7 | 5.2 | | | | 6.43 | 0.8 | | | |
| | 2.00- | RAW | 4.3 | 14.6 | | | | | 3.0 | 280 | 160 | | | | | 6.25 | 1.45 | | 35 | |
| | 3.00pm | FILT | 0.07 | 0.4 | | | | | 2.45 | 7 | | 4.5 | | | | 6.25 | 0.9 | | | |
| | 3.00- | RAW | 5.9 | 13.6 | 14.80 | 0.180 | 0.003 | 3.65 | 3.43 | 155 | 290 | 170 | | | | 6.4 | 1.35 | | 260 | 9 |
| | 6.00pm | FILT | 0.04 | 0.45 | 7.80 | 0.180 | 0.008 | 3.56 | 2.9 | 110 | 10 | 9 | | | | 6.3 | 0.7 | 0.17 | | 2 |
| 12/03/93 | 8.00- | RAW | 6.2 | 15.8 | | | | | 290 | 126 | 190 | 130 | 1658 | 442 | | 6.60 | 1.5 | | 50 | |
| | 9.00am | FILT | 0.00 | 0.1 | | | | | 3.67 | 70 | 3 | 3.2 | 1630 | 445 | | 6.45 | 0.6 | | | |
| | 9.00- | RAW | 5.5 | 14.3 | | | | | 3.2 | | 195 | 135 | 1740 | 395 | | 6.35 | 1.4 | | 70 | |
| | 11.00am | FILT | 0.07 | 0.1 | | | | | 2.8 | | 4 | 3.5 | 1705 | 396 | | 6.20 | 0.7 | | | |
| | 11.00- | RAW | 4.5 | 15.7 | | | | | 3.00 | 139 | 190 | 140 | | | | 6.55 | 1.5 | | 160 | |
| | 2.00pm | FILT | 0.04 | 0.1 | | | | | 2.3 | 98 | 7 | 5.2 | | | | 6.44 | 0.6 | | | |
| | 2.00- | RAW | 5.5 | 14.5 | | | | | 2.96 | 190 | 130 | | | | | 6.00 | 1.3 | | 60 | |
| | 3.00pm | FILT | 0.07 | 0.2 | | | | | 2.63 | 6 | | 4.5 | | | | 5.93 | 0.6 | | | |
| | 3.00- | RAW | 4.3 | 13.5 | 18.10 | 0.155 | 0.009 | 4.18 | 3.12 | 110 | 200 | 110 | | | | 6.5 | 1.4 | | 190 | 3 |
| | 6.00pm | FILT | 0.09 | 0.4 | 4.50 | 0.161 | 0.1 | 4.03 | 26 | 105 | 15 | 4.6 | | | | 6.37 | 0.7 | 0.15 | | 17 |

# APPENDIX A2 (Cont.)   KHAYINGA PLANT (BS-12)

| Date | Time | Sample | Ferrous iron mg Fe²⁺/l | Total Iron mg Fe/l | Perm. No. mg KmnO₄/l | Nitrate mg NO₃/l | Nitrite mg NO₂/l | Ammonia mg NH₃/l | Dissolved Oxygen mg O₂/l | Carbon Dioxide mg CO₂/l | Colour mg Pt/l | Turbidity N.T.U | Conduct. µs/cm | Total Alkalinity mg CaCO₃/l | Total Hardness mg CaCO₃/l | pH Units | Manganese mg Mn/l | Flow Rate l/s | Prod. in lts | Total Coliform Per 100 ml |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15/03/93 | 7.30-8.30am | RAW | 6.2 | 14.8 | | | | 3.66 | 2.96 | 87 | 150 | 100 | 1680 | 390 | 350 | 6.31 | 1.5 | | 15 | |
| | | FILT. | 0.02 | 0.2 | | | | 3.42 | 5.2 | 80 | 6 | 4 | 1710 | 395 | 395 | 6.38 | 0.6 | | | |
| | 8.30-11.00am | RAW | 5.4 | 15.2 | | | | | 3.00 | | 155 | 110 | 1740 | 450 | 395 | 6.2 | 1.1 | | 40 | |
| | | FILT. | 0.03 | 0.3 | | | | | 5.73 | | 7 | 4 | 1720 | 415 | 394 | 6.15 | 0.7 | | | |
| | 11.00-2.00pm | RAW | 5.3 | 13.7 | | | | | 2.65 | 165 | 165 | 130 | | | | 6.40 | 1.2 | | 140 | |
| | | FILT. | 0.06 | 0.32 | | | | | 4.76 | 175 | 10 | 6 | | | | 6.25 | 0.4 | | | |
| | 2.00-3.00pm | RAW | 5.7 | 15.5 | | | | | 3.36 | | 166 | 120 | | | | 6.21 | 1.6 | | 50 | |
| | | FILT. | 0.05 | 0.30 | | | | | 5.0 | | 10 | 5 | | | | 6.02 | 0.6 | | | |
| | 3.00-6.00pm | RAW | 5.2 | 14.3 | 12.20 | 0.09 | 0.02 | 3.93 | 2.7 | 130 | 180 | 184 | | | | 6.45 | 1.3 | 0.14 | 280 | 11 |
| | | FILT. | 0.08 | 0.37 | 8.10 | 0.14 | 0.11 | 3.87 | 4.1 | 125 | 15 | 8 | | | | 6.18 | 0.8 | | | 7 |
| 17/03/93 | 7.30-8.30pm | RAW | 5.8 | 16.2 | | | | | 2.8 | 156 | 140 | 90 | 1510 | 370 | 388 | 6.28 | 1.3 | | 30 | |
| | | FILT. | 0.04 | 0.22 | | | | | 5.83 | 86 | 7 | 4 | 1560 | 365 | 379 | 6.17 | 0.5 | | | |
| | 8.30-11.00am | RAW | 4.9 | 15.3 | | | | | 3.13 | | 140 | 95 | 1640 | 430 | 374 | 6.33 | 1.5 | | 50 | |
| | | FILT. | 0.04 | 0.30 | | | | | 4.9 | | 8 | 4 | 1634 | 415 | 372 | 6.26 | 0.7 | | | |
| | 11.00-2.00pm | RAW | 5.6 | 14.8 | | | | | 2.9 | 95 | 160 | 110 | | | | 6.41 | 1.2 | | 175 | |
| | | FILT. | 0.07 | 0.34 | | | | | 4.88 | 178 | 10 | 5.0 | | | | 6.25 | 0.4 | | | |
| | 2.00-3.00pm | RAW | 5.5 | 15.4 | | | | | 3.42 | | 155 | 100 | | | | 6.42 | 0.9 | | 40 | |
| | | FILT. | 0.06 | 0.31 | | | | | 5.2 | | 10 | 4.5 | | | | 6.30 | 0.2 | | | |
| | 3.00-6.00pm | RAW | 4.7 | 15.6 | 8.84 | 0.09 | 0.03 | 4.83 | 2.97 | 108 | 190 | 134 | | | | 6.35 | 1.1 | 0.140 | 230 | 7 |
| | | FILT. | 0.11 | 0.4 | 5.04 | 0.15 | 0.085 | 4.79 | 5.2 | 125 | 15 | 5.7 | | | | 6.45 | 0.5 | | | 2 |
| 19/03/93 | 7.00-8.00am | RAW | 6.0 | 14.4 | | | | | 3.00 | 129 | 120 | 90 | 1645 | 322 | 385 | 6.5 | 1.35 | | 20 | |
| | | FILT. | 0.06 | 0.25 | | | | | 5.94 | 85 | 6 | 4 | 1639 | 320 | 381 | 6.35 | 0.4 | | | |
| | 8.00-11.00am | RAW | 5.9 | 15.1 | | | | | 2.25 | | 125 | 105 | 1725 | 415 | 375 | 6.51 | 1.4 | | 60 | |
| | | FILT. | 0.06 | 0.30 | | | | | 5.7 | | 6.5 | 4 | 1710 | 398 | 371 | 6.25 | 0.6 | | | |
| | 11.00-2.00pm | RAW | 5.4 | 14.9 | | | | | 2.55 | 124 | 150 | 120 | | | | 6.66 | 1.45 | | 190 | |
| | | FILT. | 0.07 | 0.33 | | | | | 4.3 | 195 | 12 | 6.5 | | | | 6.37 | 0.55 | | | |
| | 2.00-3.00pm | RAW | 5.65 | 15.3 | | | | | 3.2 | | 145 | 115 | | | | 6.44 | 1.5 | | 40 | |
| | | FILT. | 0.07 | 0.8 | | | | | 4.8 | | 11 | 4.5 | | | | 6.23 | 0.5 | | | |
| | 3.00-6.00pm | RAW | 5.3 | 13.8 | 10.9 | 0.15 | 0.06 | 3.76 | 3.00 | 145 | 170 | 173 | | | | 6.35 | 1.3 | | 270 | 16 |
| | | FILT. | 0.15 | 0.37 | 5.70 | 0.23 | 0.14 | 3.64 | 5.2 | 120 | 15 | 7 | | | | 6.24 | 0.75 | 0.130 | | 6 |

# APPENDIX A2 (Cont.)   KHAYINGA PLANT (BS-12)

| Date | Time | Sample | Ferrous iron mg Fe²⁺/l | Total Iron mg Fe/l | Perm. No. mg KmnO₄/l | Nitrate mg NO₃/l | Nitrite mg NO₂/l | Ammonia mg NH₃/l | Dissolved Oxygen mg O₂/l | Carbon Dioxide mg CO₂/l | Colour mg Pt/l | Turbidity N.T.U | Conduct. µs/cm | Total Alkalinity mg CaCO₃/l | Total Hardness mg CaCO₃/l | pH Units | Manganese mg Mn/l | Flow Rate l/s | Prod. in ltr | Total Coliform Per 100 ml |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22/03/93 | 7.00–8.00am | RAW | 4.85 | 14.3 | | | | | 3.00 | 109 | 120 | 100 | 1590 | 463 | 453 | 6.35 | 1.75 | | 15 | |
| | | FILT. | 0.07 | 0.22 | | | | | 5.44 | 95 | 75 | 5 | 1587 | 459 | 451 | 6.25 | 0.75 | | | |
| | 8.00–11.00am | RAW | 5.95 | 15.8 | | | | | 2.94 | | 130 | 100 | 1695 | 471 | 383 | 6.38 | 1.6 | | 35 | |
| | | FILT. | 0.07 | 0.25 | | | | | 4.13 | | 8 | 5.3 | 1687 | 475 | 384.2 | 6.23 | 0.85 | | | |
| | 11.00–2.00pm | RAW | 5.25 | 16.3 | | | | | 2.73 | 146 | 180 | 150 | | | | 6.5 | 1.25 | | 130 | |
| | | FILT. | 0.08 | 0.30 | | | | | 4.45 | 163 | 14 | 7.2 | | | | 6.35 | 0.8 | | | |
| | 2.00–3.00pm | RAW | 5.5 | 16.4 | | | | | 2.67 | | 160 | 130 | | | | 6.50 | 1.4 | | 30 | |
| | | FILT. | 0.07 | 0.26 | | | | | 2.0 | | 12 | 6.0 | | | | 6.35 | 0.7 | | | |
| | 3.00–6.00pm | RAW | 4.9 | 14.4 | 7.30 | 0.18 | 0.05 | 3.58 | 2.93 | 150 | 200 | 180 | | | | 6.6 | 1.3 | | 285 | 27 |
| | | FILT. | 0.09 | 0.32 | 5.90 | 0.33 | 0.19 | 3.43 | 2.53 | 155 | 15 | 8.3 | | | | 6.3 | 0.8 | 0.130 | | 9 |
| 24/03/93 | 7.00–8.00am | RAW | 5.2 | 13.7 | | 0.17 | 0.33 | 4.75 | 3.15 | 131 | 130 | 90 | 1735 | 465 | 429 | 6.54 | 1.35 | | 25 | |
| | | FILT. | 0.07 | 0.20 | | 0.30 | 0.16 | 4.65 | 4.74 | 58 | 7.0 | 4.0 | 1729 | 383 | 413 | 6.26 | 0.9 | | | |
| | 8.00–11.00am | RAW | 6.0 | 14.2 | | | | | 2.63 | | 140 | 100 | 1637 | 470 | 395 | 6.45 | 1.43 | | 45 | |
| | | FILT. | 0.08 | 0.27 | | | | | 1.94 | | 9 | 4.4 | 1624 | 410 | 352 | 6.35 | 0.45 | | | |
| | 11.00–2.00pm | RAW | 5.5 | 15.3 | | | | | 3.5 | 128 | 190 | 145 | | | | 6.35 | 1.22 | | 140 | |
| | | FILT. | 0.19 | 0.32 | | | | | 1.5 | 185 | 15 | 5.2 | | | | 6.30 | 0.7 | | | |
| | 2.00–3.00pm | RAW | 5.6 | 15.1 | | | | | 2.9 | | 195 | 150 | | | | 6.35 | 1.35 | | 35 | |
| | | FILT. | 0.17 | 0.28 | | | | | 1.7 | | 15 | 4.0 | | | | 6.20 | 0.6 | | | |
| | 3.00–6.00pm | RAW | 5.4 | 14.85 | 18.40 | 0.14 | 0.66 | 3.85 | 2.73 | 145 | 220 | 120 | | | | 6.30 | 1.55 | | 210 | 5 |
| | | FILT. | 0.22 | 0.36 | 6.32 | 0.31 | 0.24 | 3.7 | 2.35 | 137 | 18 | 5.5 | | | | 6.30 | 0.75 | 0.1 | | 1 |
| 26/03/93 | 7.00–8.00pm | RAW | 6.2 | 15.9 | | 0.12 | 0.05 | 3.66 | 3.00 | 98 | 110 | 80 | 1773 | 433 | 410 | 6.25 | 1.4 | | 10 | |
| | | FILT. | 0.09 | 1.23 | | 0.25 | 0.19 | 3.54 | 3.63 | 39 | 8.0 | 4.3 | 1765 | 425 | 412 | 6.15 | 1.4 | | | |
| | 8.00–11.00am | RAW | 5.75 | 15.2 | | | | | 2.95 | | 120 | 85 | 1530 | 415 | 408 | 6.5 | 1.5 | | 25 | |
| | | FILT. | 0.09 | 0.22 | | | | | 1.38 | | 8 | 4.3 | 1515 | 391 | 323 | 6.35 | 0.5 | | | |
| | 11.00–2.00pm | RAW | 5.4 | 15.5 | | | | | 3.00 | 12 | 195 | 130 | | | | 6.25 | 1.3 | | 90 | |
| | | FILT. | 0.25 | 0.27 | | | | | 1.20 | 85 | 20 | 4.8 | | | | 6.20 | 0.6 | | | |
| | 2.00–3.00pm | RAW | 5.2 | 14.5 | | | | | 3.5 | | 190 | 130 | | | | 6.4 | 1.45 | | 15 | |
| | | FILT. | 0.2 | 0.22 | | | | | 1.22 | | 18 | 4.5 | | | | 6.24 | 0.5 | | | |
| | 3.00–6.00pm | RAW | 5.8 | 15.9 | 8.30 | 0.095 | 0.008 | 4.23 | 2.93 | 133 | 230 | 185 | | | | 6.4 | 1.3 | | 160 | 6 |
| | | FILT. | 0.35 | 0.30 | 7.60 | 0.2 | 0.21 | 8.04 | 1.6 | 111 | 25 | 5.2 | | | | 6.3 | 0.6 | 0.1 | | 2 |
| | | | B | A | C | K | | W | A | S | H | E | D | | | | | | | |

| Date | Time | Sample | Ferrous iron mg Fe²⁺/l | Total iron mg Fe/l | Perm. No. mg KmnO₄/l | Nitrate mg NO₃/l | Nitrite mg NO₂/l | Ammonia mg NH₄/l | Dissolved Oxygen mg O₂/l | Carbon Dioxide mg CO₂/l | Colour mg Pt/l | Turbidity N.T.U | Conduct. µs/m | Total Alkalinity mg CaCO₃/l | Total Hardness mg CaCO₃/l | pH Units | Manganese mg Mn/l | Flow Rate l/s | Prod. in l/s | Total Coliform Per 100 ml |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 27/03/93 | 7.00-8.00am | RAW | 5.4 | 15.6 | | 0.08 | 0.09 | 2.84 | 3.8 | 145 | 115 | 84 | 1632 | 484 | 425 | 6.34 | 1.6 | | 25 | |
| | | FILT. | 0.11 | 0.30 | | 0.30 | 0.14 | 2.76 | 4.5 | 52 | 10 | 4.7 | 1506 | 436 | 412 | 6.23 | 1.45 | | | |
| | 8.00-11.00am | RAW | 5.9 | 16.2 | | 0.11 | 0.07 | 3.32 | 3.5 | 136 | 110 | 70 | 1763 | 465 | 396 | 6.40 | 1.2 | | 45 | |
| | | FILT. | 0.16 | 0.32 | | 0.18 | 0.16 | 3.10 | 4.0 | 74 | 12 | 3.0 | 1680 | 433 | 372 | 6.36 | 0.85 | | | |
| | 11.00-2.00pm | RAW | 5.81 | 15.70 | | | | 3.0 | 3.13 | 134 | 117 | 51 | 1604 | 505 | 450 | 6.14 | 1.55 | | 125 | |
| | | FILT. | 0.175 | 0.35 | | | | 2.82 | 3.90 | 85 | 13 | 3.0 | 1506 | 469 | 422 | 5.95 | 1.34 | | | |
| | 2.00-3.00pm | RAW | 5.2 | 15.9 | | | | | 3.7 | 98 | 113 | 50 | 1570 | 471 | 413 | 6.25 | 1.8 | | 82 | |
| | | FILT. | 0.21 | 0.35 | | | | | 3.4 | 78 | 16 | 3.0 | 1528 | 428 | 382 | 6.17 | 1.7 | | | |
| | 3.00-6.00pm | RAW | 5.45 | 16.5 | 14.30 | 0.14 | 0.04 | 3.42 | 4.2 | 96 | 132 | 195 | 1620 | 450 | 393 | 6.38 | 2.1 | | 269 | |
| | | FILT. | 0.23 | 0.74 | 8.25 | 0.20 | 0.09 | 3.31 | 3.85 | 75 | 20 | 6.0 | 1582 | 431 | 379 | 6.24 | 1.92 | 14.85 | | |
| 30/03/93 | 7.00-8.00am | RAW | 5.71 | 16.8 | | 0.07 | 0.06 | 3.62 | 2.86 | 126 | 110 | 92 | 1585 | 494 | 432 | 6.42 | 1.72 | | 30 | |
| | | FILT. | 0.16 | 0.30 | | 0.13 | 0.10 | 3.50 | 5.2 | 56 | 11 | 4.3 | 1567 | 463 | 412 | 6.36 | 1.60 | | | |
| | 8.00-11.00am | RAW | 5.5 | 17.0 | | | | 3.25 | 2.50 | 104 | 96 | 98 | 1663 | 503 | 460 | 6.35 | 1.82 | | 60 | |
| | | FILT. | 0.172 | 0.32 | | | | 3.13 | 3.84 | 48 | 11.5 | 4.7 | 1629 | 482 | 439 | 6.18 | 1.59 | | | |
| | 11.00-2.00pm | RAW | 5.50 | 14.9 | | 0.13 | 0.15 | 3.36 | 3.66 | 105 | 112 | 84 | 1740 | 420 | 394 | 6.52 | 1.54 | | 94 | |
| | | FILT. | 0.18 | 0.33 | | 0.24 | 0.26 | 3.02 | 3.72 | 65 | 14 | 4.8 | 1718 | 307 | 362 | 6.43 | 1.48 | | | |
| | 2.00-3.00pm | RAW | 5.70 | 15.8 | | | | 2.93 | 3.30 | 90 | 136 | 113 | 1688 | 477 | 395 | 5.96 | 1.95 | | 120 | |
| | | FILT. | 0.183 | 0.36 | | | | 2.76 | 3.70 | 42 | 16.2 | 6.2 | 1651 | 450 | 362 | 5.74 | 1.80 | | | |
| | 3.00-6.00pm | RAW | 5.8 | 15.4 | 15.60 | 0.04 | 0.108 | 3.25 | 3.40 | 91 | 135 | 95 | 1650 | 453 | 429 | 6.34 | 2.0 | | 288 | |
| | | FILT. | 0.25 | 0.75 | 7.90 | 0.23 | 0.151 | 3.13 | 2.82 | 72 | 17 | 7.8 | 1621 | 418 | 383 | 6.27 | 1.91 | 14.3 | | |
| 03/04/93 | 7.00-8.00am | RAW | 4.95 | 15.8 | | 0.0805 | 0.054 | 3.07 | 3.30 | 146 | 118 | 84 | 1594 | 476 | 435 | 6.38 | 1.45 | | 35 | |
| | | FILT. | 0.15 | 0.28 | | 0.22 | 0.130 | 2.81 | 5.5 | 45 | 10 | 4.0 | 1568 | 424 | 406 | 6.27 | 1.30 | | | |
| | 8.00-11.00am | RAW | 5.95 | 16.2 | | | | 2.96 | 3.25 | 134 | 126 | 90 | 1635 | 460 | 415 | 6.39 | 1.66 | | 65 | |
| | | FILT. | 0.16 | 0.33 | | | | 2.73 | 3.20 | 65 | 12 | 4.2 | 1590 | 435 | 386 | 6.26 | 1.52 | | | |
| | 11.00-2.00pm | RAW | 5.43 | 16.90 | | 0.170 | 0.063 | 3.72 | 3.55 | 116 | 103 | 85 | 1586 | 483 | 426 | 6.45 | 1.95 | | 106 | |
| | | FILT. | 0.16 | 0.33 | | 0.20 | 0.180 | 3.49 | 3.48 | 75 | 13 | 5.4 | 1538 | 457 | 390 | 6.37 | 1.84 | | | |
| | 2.00-3.00pm | RAW | | | | | | | | | | | | | | | | | | |
| | | FILT. | | | | | | | | | | | | | | | | | | |
| | 3.00-6.00pm | RAW | 5.75 | 16.4 | 14.40 | 0.12 | 0.06 | 3.40 | 3.80 | 98 | 138 | 80 | 1664 | 463 | 433 | 6.30 | 1.64 | | 300 | |
| | | FILT. | 0.30 | 0.78 | 6.10 | 0.26 | 0.20 | 3.12 | 3.62 | 78 | 14 | 6.0 | 1621 | 429 | 392 | 6.25 | 1.46 | 13.80 | | |

# APPENDIX A2 (Cont.)   KHAYINGA PLANT (BS-12)

| Date | Time | Sample | Ferrous iron mg Fe²⁺/l | Total Iron mg Fe/l | Perm. No. mg KmnO₄/l | Nitrate mg NO₃/l | Nitrite mg NO₂/l | Ammonia mg NH₃/l | Dissolved Oxygen mg O₂/l | Carbon Dioxide mg CO₂/l | Colour mg Pt/l | Turbidity N.T.U | Conduct. µs/cm | Total Alkalinity mg CaCO₃/l | Total Hardness mg CaCO₃/l | pH Units | Manganese mg Mn/l | Flow Rate l/s | Prod. in l/s | Total Coliform Per 100 ml |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 06/04/93 | 7.00–8.00am | RAW | 5.3 | 14.6 | | 0.130 | 0.08 | 4.43 | 3.23 | 153 | 125 | 84 | 1605 | 465 | 416 | 6.35 | 1.6 | | 40 | |
| | | FILT. | 0.16 | 0.20 | | 0.33 | 0.28 | 4.26 | 5.94 | 55 | 5 | 0.9 | 1595 | 452 | 384 | 6.85 | 1.56 | | | |
| | 8.00–11.00am | RAW | 5.6 | 13.0 | | | | | 3.35 | | 137 | 70 | 1687 | 455 | 395 | 6.34 | 1.6 | | 65 | |
| | | FILT. | 0.2 | 0.3 | | | | | 4.85 | | 6 | 3.0 | 1647 | 457 | 277 | 6.30 | 1.5 | | | |
| | 11.00–2.00pm | RAW | 5.2 | 14.5 | | | | | 2.70 | 158 | 189 | 51 | 1626 | | | 6.50 | 1.8 | | 143 | |
| | | FILT. | 0.23 | 0.35 | | | | | 4.30 | 172 | 8 | 3.0 | 1602 | | | 6.30 | 1.8 | | | |
| | 2.00–3.00pm | RAW | 0.52 | 13.5 | | | | | 2.66 | 160 | 71 | 50 | 1621 | | | 6.36 | 1.7 | | 30 | |
| | | FILT. | 0.05 | 0.14 | | | | | 3.54 | 120 | 14 | 3.0 | 1630 | | | 6.30 | 1.6 | | | |
| | 3.00–6.00pm | RAW | 5.00 | 13.0 | 12.64 | 0.22 | 0.11 | 3.65 | 3.00 | 162 | 72 | 195 | 1567 | | | 6.50 | 1.8 | | 320 | 7 |
| | | FILT. | 0.1 | 0.77 | 8.10 | 0.39 | 0.34 | 3.45 | 3.59 | 80 | 12 | 8.0 | 1496 | | | 6.44 | 1.6 | 0.25 | | 18 |
| 08/04/93 | 7.00–8.00am | RAW | 4.65 | 13.3 | | | | | 3.21 | 112 | 230 | 67 | 1435 | | | 6.3 | 1.54 | | 45 | |
| | | FILT. | 0.00 | 0.1 | | | | | 3.35 | 60 | 3 | 2.0 | 1430 | | | 6.25 | 1.48 | | | |
| | 8.00–11.00am | RAW | 4.3 | 15.8 | | | | | 2.94 | | 193 | 70 | 1530 | 463 | 348 | 6.35 | 1.76 | | 28 | |
| | | FILT. | 0.05 | 0.17 | | | | | 2.77 | | 4 | 2.0 | 1531 | 467 | 334 | 6.35 | 1.71 | | | |
| | 11.00–2.00pm | RAW | 5.00 | 15.9 | | | | | 3.18 | 139 | 270 | 90 | 1636 | 474 | 358 | 6.2 | 1.2 | | 205 | |
| | | FILT. | 0.07 | 0.35 | | | | | 1.40 | 170 | 6 | 4.0 | 1593 | 446 | 266 | 6.45 | 1.25 | | | |
| | 2.00–3.00pm | RAW | 5.4 | 15.3 | | | | | 2.73 | | 180 | 95 | 1480 | 445 | 330 | 6.45 | 1.6 | | 57 | |
| | | FILT. | 0.06 | 0.3 | | | | | 1.32 | | 5 | 20 | 1467 | 448 | 335 | 6.4 | 1.58 | | | |
| | 3.00–6.00pm | RAW | 4.4 | 12.7 | 13.58 | 0.190 | 0.09 | 4.24 | 3.00 | 142 | 189 | 178 | 1659 | 450 | 335 | 6.34 | 1.6 | | 276 | 8 |
| | | FILT. | 0.16 | 0.19 | 7.80 | 0.49 | 0.38 | 3.96 | 1.64 | 78 | 7 | 6.5 | 1650 | 450 | 330 | 6.26 | 1.2 | 0.22 | | 17 |
| 13/04/93 | 7.00–8.00am | RAW | 6.00 | 15.4 | | | | | 3.0 | 143 | 160 | 60 | 1681 | 465 | 400 | 6.4 | 1.4 | | 32 | |
| | | FILT. | 0.00 | 0.08 | | | | | 5.64 | 54 | 3 | 1.0 | 1624 | 367 | 385 | 6.36 | 0.8 | | | |
| | 8.00–11.00am | RAW | 6.2 | 15.4 | | | | | 3.43 | | 140 | 68 | 1536 | 421 | 425 | 6.25 | 1.5 | | 60 | |
| | | FILT. | 0.03 | 0.11 | | | | | 4.34 | | 3 | 1.0 | 1490 | 423 | 400 | 6.40 | 1.49 | | | |
| | 11.00–2.00pm | RAW | 6.8 | 15.0 | | | | | 3.72 | 140 | 190 | 60 | 1685 | 460 | 350 | 6.62 | 1.4 | | 120 | |
| | | FILT. | 0.07 | 0.2 | | | | | 4.15 | 170 | 4 | 1.9 | 1642 | 427 | 316 | 6.5 | 1.3 | | | |
| | 2.00–3.00pm | RAW | 5.8 | 14.5 | | | | | 3.50 | | 140 | 75 | 1650 | | | 6.30 | 1.6 | | 45 | |
| | | FILT. | 0.07 | 0.3 | | | | | 4.20 | | 4 | 2.0 | 1625 | | | 6.20 | 1.4 | | | |
| | 3.00–6.00pm | RAW | 4.7 | 15.5 | 15.50 | 0.15 | 0.071 | 3.82 | 3.93 | | 150 | 116 | 1635 | | | 6.45 | 1.7 | | | 5 |
| | | FILT. | 0.08 | 0.3 | 6.35 | 0.36 | 0.044 | 3.54 | 4.65 | | 5 | 4.2 | 1605 | | | 6.30 | 1.2 | 0.20 | 200 | 11 |

# APPENDIX A2 (Cont.)   KHAYINGA PLANT (BS-12)

| Date | Time | Sample | Ferrous iron mg Fe²⁺/l | Total Iron mg Fe/l | Perm. No. mg KmnO₄/l | Nitrate mg NO₃/l | Nitrite mg NO₂/l | Ammonia mg NH₄/l | Dissolved Oxygen mg O₂/l | Carbon Dioxide mg CO₂/l | Colour mg Pt/l | Turbidity N.T.U | Conduct. μs/cm | Total Alkalinity mg CaCO₃/l | Total Hardness mg CaCO₃/l | pH Units | Manganese mg Mn/l | Flow Rate l/s | Prod. in hr | Total Coliform Per 100 ml |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 14-04-93 | 7.30–9.00pm | RAW | 5.6 | 14.2 | | | | | 2.95 | 163 | | 110 | 1590 | 423 | 333 | 6.30 | 1.3 | | 45 | |
| | | FILT | 0.00 | 0.07 | | | | | 5.75 | 65 | 5 | 5 | 1565 | 425 | 206 | 6.15 | 0.07 | | | |
| | 9.00–11.00am | RAW | 5.30 | 15.7 | | | | | 2.90 | | 130 | 75 | 1615 | 415 | 375 | 6.2 | 1.6 | | 56 | |
| | | FILT | 0.035 | 0.4 | | | | | 5.80 | | 3 | 2 | 1585 | 430 | 267 | 6.15 | 1.00 | | | |
| | 11.00–2.00pm | RAW | 6.0 | 16.6 | | | | | 3.20 | 193 | | 72 | 1634 | 461 | 460 | 6.35 | 1.15 | | | |
| | | FILT | 0.07 | 0.18 | | | | | 4.46 | | 6 | 3 | 1600 | 457 | 428 | 6.34 | 1.20 | | | |
| | 2.00–3.00pm | RAW | 5.5 | 13.9 | | | | | 2.80 | | 170 | 80 | | | | 6.60 | 1.1 | | 47 | |
| | | FILT | 0.05 | 0.14 | | | | | 3.57 | | 5 | 3 | | | | 6.45 | 0.45 | | | |
| | 3.00–6.00pm | RAW | 5.8 | 14.2 | 16.20 | 0.130 | 0.09 | 3.67 | | 120 | 185 | 210 | | | | | 1.4 | | 365 | 13 |
| | | FILT | 0.09 | 0.95 | 9.30 | 0.35 | 0.31 | 3.46 | | 138 | 6 | 10 | | | | | 0.8 | 0.17 | | 4 |
| 15-04-93 | 7.00–8.00pm | RAW | 4.1 | 15.4 | | | | | 2.09 | 162 | 136 | 105 | 1583 | 574 | 393 | 6.1 | 1.7 | | 53 | |
| | | FILT | 0.02 | 0.06 | | | | | 4.15 | 90 | 2.5 | 2 | 1566 | 468 | 353 | 6.15 | 0.9 | | | |
| | 8.00–11.00am | RAW | 4.3 | 16.4 | | | | | 3.15 | 136 | | 95 | 1636 | 403 | 377 | 6.2 | 1.2 | | 62 | |
| | | FILT | 0.02 | 0.05 | | | | | 2.60 | | 3.0 | 2.0 | 1594 | 409 | 350 | 6.0 | 0.5 | | | |
| | 11.00–2.00pm | RAW | 5.7 | 14.7 | | | | | 2.73 | 167 | 154 | 109 | | | | 6.3 | 1.66 | | 282 | |
| | | FILT | 0.06 | 0.16 | | | | | 1.45 | 180 | 5 | 1 | | | | 6.24 | 0.7 | | | |
| | 2.00–3.00pm | RAW | 5.6 | 16.8 | | | | | 2.85 | | 150 | 97 | | | | 6.4 | 1.35 | | 79 | |
| | | FILT | 0.04 | 0.13 | | | | | 1.16 | | 4 | 1 | | | | 6.28 | 0.6 | | | |
| | 3.00–6.00pm | RAW | 5.90 | 14.7 | 9.90 | 0.18 | 0.12 | 4.85 | 3.22 | 140 | 163 | 217 | | | | 6.50 | 1.9 | | 578 | 14 |
| | | FILT | 0.04 | 1.27 | 9.80 | 0.43 | 0.3 | 4.51 | 1.35 | 120 | 7.5 | 12 | | | | 6.35 | 1.5 | 0.14 | | 6 |
| 16-04-93 | 7.00–8.00pm | RAW | 6.35 | 14.5 | | | | | 3.16 | 133 | 180 | 62 | 1640 | 420 | 440 | 6.25 | 1.75 | | 59 | |
| | | FILT | 0.04 | 0.05 | | | | | 5.75 | 52 | 4 | 2.5 | 1625 | 377 | 433 | 6.35 | 0.9 | | | |
| | 8.00–11.00am | RAW | 4.5 | 15.4 | | | | | 2.90 | | 154 | 60 | 1715 | 403 | 377 | 6.45 | 1.33 | | 53 | |
| | | FILT | 0.05 | 0.06 | | | | | 5.70 | | 5.5 | 3 | 1620 | 388 | 386 | 6.30 | 0.8 | | | |
| | 11.00–2.00pm | RAW | 5.20 | 15.2 | | | | | 2.56 | 130 | 160 | 70 | 1689 | | | 6.43 | 1.6 | | 293 | |
| | | FILT | 0.07 | 0.25 | | | | | 3.25 | 95 | 6.7 | 4 | 1665 | | | 6.32 | 1.2 | | | |
| | 2.00–3.00pm | RAW | 5.8 | 14.35 | | | | | 3.3 | | 150 | 65 | | | | 6.6 | 1.8 | | 64 | |
| | | FILT | 0.06 | 0.25 | | | | | 3.55 | | 7 | 4 | | | | 6.45 | 0.7 | | | |
| | 3.00–6.00pm | RAW | 5.4 | 15.9 | 19.60 | 0.20 | 0.15 | 3.7 | 3.15 | 142 | 170 | 185 | | | | 6.5 | 1.2 | | 316 | 17 |
| | | FILT | 0.1 | 10 | 8.90 | 0.53 | 0.45 | 1.39 | 3.58 | 189 | 9 | 9.5 | | | | 6.45 | 0.6 | 0.13 | | 5 |

| Date | Time | Sample | Ferrous iron mg $Fe^{2+}$/l | Total Iron mg Fe/l | Perm. No. mg $KmnO_4$/l | Nitrate mg $NO_3$/l | Nitrite mg $NO_2$/l | Ammonia mg $NH_3$/l | Dissolved Oxygen mg $O_2$/l | Carbon Dioxide mg $CO_2$/l | Colour mg Pt/l |
|------|------|--------|------|------|------|------|------|------|------|------|------|
| 19/04/95 | 7.00–8.00am | RAW | 5.20 | 15.30 | | | | | 3.35 | 144 | 125 |
| | | FILT. | 0.06 | 0.08 | | | | | 3.2 | 68 | 6.0 |
| | 8.00–11.00am | RAW | 5.75 | 16.5 | | | | | 2.80 | | 120 |
| | | FILT. | 0.05 | 0.07 | | | | | 1.83 | | 6 |
| | 11.00–2.00pm | RAW | 5.30 | 15.4 | | | | | 2.75 | 105 | 140 |
| | | FILT. | 0.08 | 0.35 | | | | | 0.9 | 178 | 7.5 |
| | 2.00–3.00pm | RAW | 6.5 | 15.5 | | | | | 3.13 | | 130 |
| | | FILT. | 0.07 | 0.30 | | | | | 1.65 | | 7 |
| | 3.00–6.00pm | RAW | 4.7 | 14.9 | 17.80 | 0.33 | 0.10 | 4.35 | 2.85 | 126 | 150 |
| | | FILT. | 0.09 | 0.84 | 9.50 | 0.59 | 0.43 | 4.04 | 0.85 | 90 | 9 |
| 21/04/95 | 7.00–8.00pm | RAW | 5.6 | 12.8 | | | | | 3.11 | 120 | 158 |
| | | FILT. | 0.05 | 0.07 | | | | | 3.75 | 50 | 6.5 |
| | 8.00–10.00am | RAW | 5.30 | 13.2 | | | | | 2.95 | | 162 |
| | | FILT. | 0.05 | 0.08 | | | | | 1.65 | | 7 |
| | 10.00–2.00pm | RAW | 5.8 | 15.4 | | | | | 2.58 | 150 | 170 |
| | | FILT. | 0.15 | 0.4 | | | | | 0.8 | 159 | 8.5 |
| | 2.00–3.00pm | RAW | 6.3 | 15.5 | | | | | 3.33 | | 160 |
| | | FILT. | 0.10 | 0.35 | | | | | 1.1 | | 6.5 |
| | 3.00–6.00pm | RAW | 6.0 | 15.3 | 7.90 | 0.28 | 0.15 | 3.94 | 2.98 | 130 | 160 |
| | | FILT. | 0.2 | 0.5 | 6.50 | 0.58 | 0.48 | 3.61 | 1.43 | 197 | 10 |

| Turbidity N.T.U | Conduct. µs/cm | Total Alkalinity mg CaCO$_3$/l | Total Hardness mg CaCO$_3$/l | pH Units | Manganese mg Mn/l | Flow Rate l/s | Prod. in lts | Total Coliform Per 100 ml |
|---|---|---|---|---|---|---|---|---|
| 95 | 1575 | 460 | 424 | 6.55 | 1.4 | | 68 | |
| 4 | 1570 | 456 | 413 | 6.25 | 0.6 | | | |
| 100 | 1644 | 510 | 387 | 6.20 | 1.30 | | 48 | |
| 4 | 1570 | 412 | 379 | 6.35 | 0.70 | | | |
| 116 | 1580 | | | 6.4 | 1.5 | | 258 | |
| 6 | 1582 | | | 6.4 | 1.00 | | | |
| 110 | | | | 6.30 | 1.0 | | 32 | |
| 6 | | | | 6.15 | 0.3 | | | |
| 195 | | | | 6.35 | 1.7 | | 312 | 18 |
| 8.5 | | | | 6.25 | 1.1 | 0.12 | | 5 |
| 98 | 1640 | 522 | 455 | 6.40 | 1.3 | | 23 | |
| 4 | 1605 | 384 | 433 | 6.25 | 0.4 | | | |
| 108 | 1560 | 398 | 423 | 6.3 | 1.8 | | 52 | |
| 4.8 | 1530 | 384 | 375 | 6.2 | 0.6 | | | |
| 115 | 1656 | | | 6.4 | 1.55 | | 210 | |
| 6.6 | 1604 | | | 6.4 | 0.8 | | | |
| 138 | 1538 | | | 6.5 | 1.9 | | 60 | |
| 6.0 | 1500 | | | 6.2 | 0.5 | | | |
| 115 | 1636 | | | 6.3 | 1.6 | | 308 | 7 |
| 4.7 | 1586 | | | 6.3 | 0.8 | 0.12 | | 1 |

# APPENDIX A3    SHIVANGA PLANT (C-5467)

| Date | Time | Sample | Ferrous iron mg Fe²⁺/l | Total Iron mg Fe/l | Colour mg Pt/l | Turbidity N.T.U | Ammonia mg NH₄/l | Nitrate mg NO₃/l | Nitrite mg NO₂/l | Manganese mg Mn/l | Dissolved Oxygen mg O₂/l | Perm. No. mg KmnO₄/l | pH Units | Conduct µs/cm | Carbon Dioxide mg CO₂/l | Total Alkalinity mg CaCo₃/l | Total Hardness mg CaCo₃/l | Prod. in ltr | Total Coliform Per 100 ml | Flow Rate l/sec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 28/06/95 | 7.00–9.00am | RAW | 1.4 | 4.8 | 65 | 30 | 0.28 | 0.41 | 0.15 | 0.33 | 0.85 | | 6.11 | 217 | 48.8 | 136 | 106 | 73 | | |
| | | FILT. | 0.01 | 0.08 | 1.00 | 0.6 | 0.20 | 0.46 | 0.152 | 0.29 | 5.75 | | 6.82 | 235 | 25.4 | 153 | 119 | | | |
| | 9.00–11.00am | | | | | | | | | | | | | | | | | | | |
| | 11.00–12.30pm | RAW | 0.84 | 1.58 | 47 | 12 | 0.09 | 0.36 | 0.003 | 0.2 | 0.35 | | 6.64 | 190 | 51.2 | 120 | 135 | | | |
| | | FILT. | 0.02 | 0.07 | 2.0 | 1.5 | 0.04 | 0.39 | 0.005 | 0.18 | 4.3 | | 6.80 | 200 | 22.5 | 135 | 120 | 15 | | |
| | 12.30–2.30pm | RAW | 1.10 | 2.45 | 55 | 1.5 | | | | | 0.20 | - | 6.20 | | | | | | | |
| | | FILT. | 0.025 | 0.15 | 2.0 | 1.0 | | | | | 3.8 | - | 6.75 | | | | | 55 | | |
| | 2.30–3.00pm | | | | | | | | | | | | | | | | | | | |
| | 5.00–5.30pm | RAW | 1.830 | 3.84 | 60 | 25 | 0.122 | 0.290 | 0.07 | 0.13 | 0.18 | 7.20 | 5.30 | | 65.7 | | | 195 | 0 | |
| | | FILT. | 0.03 | 0.18 | 3 | 1.0 | 0.084 | 0.32 | 0.085 | 0.07 | 3.40 | 5.0 | 6.73 | | 34.3 | | | | 0 | 0.36 |
| 06/07/95 | 7.00–8.00am | RAW | 1.23 | 2.95 | 54 | 32 | 0.23 | 4.4 | 0.016 | - | 0.80 | | 6.35 | 151 | 43.6 | 97 | 145 | | | |
| | | FILT. | 0.00 | 0.10 | 1.0 | 0.4 | 0.02 | 5.28 | 0.18 | - | 4.50 | | 6.88 | 234 | 18.3 | 152 | 195 | 90 | | |
| | 8.00–11.00am | RAW | 0.9 | 4.2 | 64 | 33 | 0.52 | 0.28 | 0.13 | 0.62 | 0.35 | | 6.15 | 174 | 65 | 114.5 | 98 | | | |
| | | FILT. | 0.05 | 0.10 | 1.2 | 0.3 | 0.14 | 0.36 | 0.25 | 0.51 | 2.73 | | 6.86 | 196 | 17.5 | 126 | 121 | 10 | | |
| | 11.00–12.30pm | RAW | | | | | | | | | | | | | | | | | | |
| | | FILT. | | | | | | | | | | | | | | | | 15 | | |
| | 12.30–2.00pm | RAW | 1.30 | 3.6 | 59 | 45 | 0.54 | - | | 0.75 | 0.95 | | 6.5 | | | 147 | 164 | | | |
| | | FILT. | 0.08 | 0.2 | 1.0 | 0.5 | 0.26 | | | 0.56 | 3.2 | | 6.93 | | | 153 | 171 | 60 | | |
| | 2.00–3.00pm | RAW | 0.69 | 2.35 | 108.0 | 18.0 | 0.11 | | | 0.00 | 1.0 | | 6.48 | 197 | | 115 | 92 | | | |
| | | FILT. | 0.00 | 0.02 | 3.0 | 3.0 | 0.16 | | | 0.00 | 3.80 | | 6.76 | 209 | | 130 | 118 | 0 | | |
| | 3.00–5.30pm | RAW | 2.3 | 3.5 | 70 | 23 | 0.27 | 1.32 | 0.02 | | | 9.48 | 6.05 | | 68 | | | 175 | 0 | |
| | | FILT. | 0.05 | 0.15 | 3.0 | 1.2 | 0.19 | 1.38 | 0.02 | | | 3.2 | 6.30 | | 30 | | | | 0 | 0.36 |
| 07/07/95 | 8.00–10.00am | RAW | 1.85 | 3.25 | 48 | 25 | 0.20 | 0.132 | 0.005 | 0.00 | 11.0 | 8.35 | 6.51 | 236 | 64 | 177 | 108 | | | |
| | | FILT. | 0.00 | 0.053 | 2.5 | 1.0 | 0.15 | 0.136 | 0.045 | 0.00 | 5.20 | 3.30 | 6.70 | 253 | 15 | 192 | 144 | 35 | | |
| | 10.00–12.30pm | | | | | | | | | | | | | | | | | | | |
| | 12.30–2.00pm | RAW | 0.75 | 2.28 | 57 | 38 | 0.33 | 0.24 | 0.09 | | | | 6.22 | | 46 | | | | | |
| | | FILT. | 0.03 | 0.10 | 3.0 | 1.5 | 0.29 | 0.24 | 0.11 | | | | 6.54 | | 22 | | | 55 | | |
| | 2.00–3.00pm | RAW | | | | | | | | | | | | | | | | 15 | | |
| | | FILT. | | | | | | | | | | | | | | | | | | |
| | 3.00–5.30pm | RAW | 2.02 | 4.40 | 25.0 | 25 | 0.26 | 0.088 | 0.002 | 0.32 | 8.35 | 7.40 | 6.24 | 191 | 61.4 | 133 | 140 | 145 | 0 | |
| | | FILT. | 0.00 | 0.13 | 4.0 | 1.1 | 0.20 | 0.092 | 0.063 | 0.2 | 3.3 | 5.34 | 6.60 | 231 | 38.3 | 126 | 143 | | 0 | 0.30 |

| Date | Time | Sample | Ferrous iron mg Fe²/l | Total Iron mg Fe/l | Colour mg pt/l | Turbidity N.T.U | Ammonia mg NH₃/l | Nitrate mg NO₃/l | Nitrite mg NO₂/l | Manganese mg Mn/l | Dissolved Oxygen mg O₂/l | Perm. No. mg KmnO₄/l | pH Units | Conduct. µs/cm | Carbon Dioxide mg CO₂/l | Total Alkalinity mg CaCo₃/l | Total Hardness mg CaCo₃/l | Prod. in ltr | Total Coliform Per 100 ml | Flow Rate l/sec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 08/07/95 | 7.00–9.00am | RAW | 2.01 | 2.26 | 37 | 30 | 2.14 | 1.76 | 0.004 | 0.00 | 1.80 | | 6.74 | 47 | 54 | 125 | 97 | | | |
| | | FILT. | 0.02 | 0.07 | 0.8 | 0.2 | 2.02 | 1.87 | 0.100 | 0.00 | 5.50 | | 6.86 | 56 | 15 | 135 | 115 | 75 | | |
| | 9.00–11.00am | RAW | 2.3 | 3.12 | 60 | 20 | 0.07 | 0.00 | 0.007 | 2.1 | 1.50 | | 6.60 | 89 | | 127 | 88 | | | |
| | | FILT. | 0.01 | 0.10 | 4 | 2 | 0.04 | 0.036 | 0.028 | 2.1 | 4.70 | | 6.86 | 131 | | 127 | 160 | 20 | | |
| | 11.00–12.30pm | RAW | 2.5 | 4.2 | 70.0 | 46 | 1.62 | 1.33 | 0.009 | 0.30 | 1.30 | | 6.50 | 115 | | 134 | 117 | | | |
| | | FILT. | 0.05 | 0.11 | 3.0 | 2.0 | 1.53 | 1.40 | 0.15 | 0.32 | 5.2 | | 6.75 | 142 | | 142 | 122 | 30 | | |
| | 12.30–2.30pm | RAW | 1.85 | 3.55 | 65.0 | 34 | 0.185 | 0.00 | 0.03 | 0.52 | 0.65 | | 6.30 | | 62 | | | | | |
| | | FILT. | 0.07 | 0.12 | 3.5 | 2.5 | 0.180 | 0.004 | 0.025 | 0.49 | 4.85 | | 6.70 | | 38 | | | 100 | | |
| | 2.30–3.00pm | RAW | 2.20 | 2.95 | 75 | 10 | 0.14 | 0.02 | 0.09 | 0.55 | 1.77 | | 6.45 | | 47 | | | | | |
| | | FILT. | 0.04 | 0.08 | 2.5 | 2.0 | 0.09 | 0.08 | 0.085 | 0.57 | 5.3 | | 6.88 | | 19 | | | 15 | | |
| | 3.00–5.30pm | RAW | 2.85 | 3.60 | 80 | 23 | 0.109 | 2.30 | 0.04 | 0.77 | 0.45 | 10.48 | 6.2 | | 55.6 | | | 170 | 0 | 0.26 |
| | | FILT. | 0.03 | 0.14 | 2.0 | 1.3 | 0.08 | 2.34 | 0.04 | 0.72 | 7.5 | 7.42 | 6.55 | | 24.7 | | | | 0 | |
| 14/07/95 | 7.00–8.00am | RAW | 1.52 | 3.36 | 70 | 40 | 0.13 | 0.044 | 0.00 | 0.10 | 0.70 | | 6.74 | 153 | 57.0 | 105 | 112 | 95 | | |
| | | FILT | 0.00 | 0.05 | 2 | 1.0 | 0.08 | 0.046 | 0.003 | 0.00 | 5.60 | | 7.82 | 180 | 28 | 174 | 126 | | | |
| | 8.00–11.00am | RAW | 1.32 | 5.00 | 97 | 58 | 0.34 | 0.044 | 0.095 | 0.20 | 0.55 | | 6.70 | 150 | 51 | 80 | 94 | 0 | | |
| | | FILT. | 0.00 | 0.06 | 3 | 1.0 | 0.09 | 0.051 | 0.100 | 0.20 | 4.8 | | 7.15 | 176 | 16 | 169 | 102 | | | |
| | 11.00–12.30pm | RAW | 1.88 | 4.73 | 80 | 63 | 0.25 | 0.185 | 0.160 | | 0.63 | | 6.8 | 153 | | 98 | 128 | 25 | | |
| | | FILT. | 0.01 | 0.11 | 3.5 | 2.0 | 0.15 | 0.275 | 0.163 | | 5.30 | | 7.13 | 185 | | 122 | 136 | | | |
| | 12.30–2.30pm | RAW | 0.95 | 2.80 | 63 | 15 | 0.162 | 0.35 | 0.082 | 0.18 | 0.30 | | 6.34 | 110 | | 143 | 82 | | | |
| | | FILT. | 0.02 | 0.13 | 2.0 | 1.0 | 0.10 | 0.32 | 0.15 | 0.13 | 5.85 | | 6.75 | 130 | | 165 | 85 | 55 | | |
| | 2.00–3.00pm | | | | | | | | | | | | | | | | | | | |
| | 3.00–5.30pm | RAW | 1.28 | 3.42 | 93 | 27 | 0.35 | 0.22 | 0.096 | 0.11 | 0.20 | 12.50 | 6.55 | 176 | 65 | 115 | 138 | 175 | 0 | 0.26 |
| | | FILT. | 0.025 | 0.15 | 3.5 | 1.2 | 0.28 | 0.26 | 0.12 | 0.095 | 4.90 | 8.5 | 7.25 | 195 | 28 | 133 | 142 | | 0 | |
| 19/07/95 | 8.00–10.00am | RAW | 1.24 | 3.13 | 131 | 15 | 0.14 | 1.76 | 0.154 | 2.2 | 0.7 | | 6.51 | 180 | 43 | 119 | 92 | | | |
| | | FILT. | 0.00 | 0.07 | 5 | 2.0 | 0.00 | 1.90 | 0.153 | 0.00 | 5.7 | | 7.02 | 210 | 21.6 | 150 | 137 | 70 | | |
| | 10.00–12.00pm | RAW | 4.62 | 8.40 | 129 | 20 | 0.34 | 0.00 | 0.000 | 2.2 | 0.2 | | 6.48 | 140 | | 86 | 88 | | | |
| | | FILT. | 0.02 | 0.05 | 2.0 | 0.00 | 0.00 | 4.4 | 0.003 | 0.00 | 4.5 | | 6.93 | 200 | | 150 | 125 | 5 | | |
| | 12.00–2.00pm | RAW | 1.4 | 2.10 | 65 | 14 | 0.35 | 2.12 | 0.072 | 0.2 | 0.35 | | 6.50 | 188 | | 114 | 113 | | | |
| | | FILT. | 0.00 | 0.07 | 3.0 | 1.0 | 0.29 | 2.16 | 0.90 | 0.00 | 5.2 | | 6.86 | 195 | | 114 | 83 | 30 | | |
| | 2.00–3.00pm | | | | | | | | | | | | | | | | | | | |
| | 3.00–5.30pm | RAW | 0.93 | 3.3 | 72 | 26 | 0.17 | 0.154 | 0.87 | 0.12 | 0.40 | 6.32 | 6.30 | | 56.8 | 154 | 113 | 190 | 0 | 0.22 |
| | | FILT. | 0.03 | 0.16 | 3.0 | 1.15 | 0.108 | 0.184 | 0.90 | 0.12 | 3.3 | 4.6 | 6.95 | | 27.5 | 163 | 83 | | 0 | |

# APPENDIX A3 (Cont.)   SHIVANGA PLANT (C-5467)

| Date | Time | Sample | Ferrous Iron mg Fe²⁺/l | Total Iron mg Fe/l | Colour mg Pt/l | Turbidity N.T.U | Ammonia mg NH4/l | Nitrate mg NO3/l | Nitrite mg No2/l | Manganese mg Mn/l | Dissolved Oxygen mg O2/l | Perm. No. mg KmnO4/l | pH Units | Conduct. µs/cm | Carbon Dioxide mg CO2/l | Total Alkalinity mg CaCo3/l | Total Hardness mg CaCo3/l | Prod. in ls | Total Coliform Per 100 µl | Flow Rate l/sec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25/07/95 | 7.00–9.00am | RAW | 1.90 | 2.9 | 65 | 31 | 0.035 | 0.2 | 0.001 | 0.5 | 0.7 | | 6.74 | | 43 | | | 91 | | |
| | | FILT. | 0.01 | 0.1 | 0.6 | 0.2 | 0.005 | 0.22 | 0.012 | 0.18 | 5.8 | | 6.99 | | 23 | | | | | |
| | 9.00–11.00am | RAW | | | | | | | | | | | | | | | | 13 | | |
| | | FILT. | | | | | | | | | | | | | | | | | | |
| | 11.00–12.30pm | RAW | 2.46 | 3.60 | 40 | 28 | 0.073 | 0.133 | 0.07 | 0.38 | 0.4 | | 6.00 | | | | | 30 | 0 | |
| | | FILT. | 0.021 2 | 0.08 | 0.5 | 1.0 | 0.00 | 0.165 | 0.025 | 0.24 | 3.70 | 6.4 | 6.44 | | | | | | 0 | |
| | 12.30–2.30pm | RAW | 0 | 4.30 | 38 | 39 | 0.034 | 1.5 | 0.016 | 0.5 | 0.2 | | 6.77 | 66 | | 75 | 84 | 56 | | |
| | | FILT. | 0.04 | 0.07 | 1.0 | 0.7 | 0.024 | 1.505 | 0.01 | 0.41 | 5.4 | | 7.08 | 73 | | 97 | 91 | | | |
| | 2.30–3.00pm | RAW | | | | | | | | | | | | | | | | 22 | | |
| | | FILT. | | | | | | | | | | | | | | | | | | |
| | 3.00–5.30pm | RAW | 2.08 | 3.85 | 57 | 22 | 0.66 | 0.38 | 0.11 | 0.75 | | 11.60 | 5.56 | | 38.3 | | | 125 | 0 | 0.19 |
| | | FILT. | 0.08 | 0.11 | 1.5 | 1.0 | 0.45 | 0.49 | 0.01 | 0.61 | | 6.8 | 6.30 | | 17.9 | | | | 0 | |
| 27/07/95 | 7.00–8.00am | RAW | 1.76 | 6.0 | 124 | 23 | 0.08 | 0.25 | 0.01 | 0.3 | 0.5 | | 5.95 | 171 | 50 | 86 | 147 | | | |
| | | FILT. | 0.01 | 0.05 | 1.0 | 0.2 | 0.00 | 0.28 | 0.06 | 0.2 | 4.1 | | 6.5 | 185 | 29 | 165 | 197 | 66 | | |
| | 8.00–11.00am | RAW | 0.99 | 5.0 | 73 | 24 | 0.09 | 0.2 | 0.001 | 0.2 | 0.3 | | | | | 98 | 163 | 27 | | |
| | | FILT. | 0.02 | 0.1 | 1.0 | 0.5 | 0.05 | 0.028 | 0.000 | 0.190 | 3.65 | | | | | 135 | 172 | | | |
| | 11.00–12.30pm | RAW | | | | | | | | | | | | | | | | | | |
| | | FILT. | | | | | | | | | | | | | | | | | | |
| | 12.30–2.30pm | RAW | 1.50 | 4.6 | 46 | 21 | 0.160 | 0.2 | 0.03 | 0.2 | 0.2 | | 6.1 | 198 | 62 | 117 | 89 | 45 | | |
| | | FILT. | 0.03 | 0.15 | 1.5 | 1.0 | 0.05 | 0.28 | 0.06 | 0.183 | 3.7 | | 7.0 | 215 | 40 | 125 | 91 | | | |
| | 2.30–3.00pm | RAW | | | | | | | | | | | | | | | | | | |
| | | FILT. | | | | | | | | | | | | | | | | 15 | | |
| | 3.00–5.30pm | RAW | 1.25 | 3.5 | 65 | 27 | 0.33 | 1.5 | 0.002 | 0.20 | 0.25 | 4.30 | 5.5 | – | 54 | 122 | 91 | | 0 | 0.19 |
| | | FILT. | 0.04 | 0.18 | 3.0 | 1.3 | 0.22 | 1.55 | 0.006 | 0.120 | 3.3 | 3.90 | 6.5 | – | 25.8 | 133 | 93 | 192 | 0 | |
| 28/07/95 | 6.00–9.00am | RAW | 1.90 | 4.6 | 74 | 17 | 0.06 | 0.02 | 0.12 | 0.2 | 1.3 | | 6.57 | | 56.2 | 134 | 98 | 80 | | |
| | | FILT. | 0.01 | 0.07 | 1.6 | 0.4 | 0.00 | 0.16 | 0.001 | 0.00 | 7.2 | | 6.70 | | 24.4 | 145 | 100 | | | |
| | 9.00–12.30pm | | | | | | | | | | | | | | | | | | | |
| | 12.30–2.30pm | RAW | 1.76 | 4.2 | 53 | 24 | | | | – | 0.4 | | 6.18 | | | 88 | 95 | | | |
| | | FILT. | 0.01 | 0.08 | 1.0 | 0.7 | | | | – | 4.3 | | 6.27 | | | 159 | 98 | 25 | | |
| | 2.30–3.00pm | | | | | | | | | | | | | | | | | | | |
| | 3.00–5.30pm | RAW | 1.4 | 3.8 | 64 | 28 | 0.14 | 0.25 | 0.15 | 0.42 | 0.3 | 5.6 | | | 46 | | | 175 | 0 | 0.18 |
| | | FILT. | 0.03 | 0.17 | 2.8 | 1.25 | 0.00 | 0.32 | 0.005 | 0.33 | 3.5 | 4.8 | | | 24.2 | | | | 0 | |

| Date | Time | Sample | Ferrous iron mg $Fe^{2+}$/l | Total iron mg Fe/l | Colour mg Pt/l | Turbidity N.T.U | Ammonia mg $NH_3$/l | Nitrate mg $NO_3$/l | Nitrite mg $NO_2$/l | Manganese mg Mn/l | Dissolved Oxygen mg $O_2$/l | Perm. No. mg $KmnO_4$/l | pH Units | Conduct. µs/cm | Carbon Dioxide mg $CO_2$/l | Total Alkalinity mg $CaCo_3$/l | Total Hardness mg $CaCo_3$/l | Prod. in lts | Total Coliform Per 100 ml | Flow Rate l/s |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 29/07/93 | 6.00–10.00am | RAW | 2.5 | 5.4 | 80 | 45 | 0.28 | 0.2 | 0.2 | 0.1 | 0.6 | 5.60 | 6.5 | 218 | 1 | – | – | 57 | | |
| | | FILT. | 0.00 | 0.02 | 1.00 | 0.6 | 0.18 | 0.28 | 0.05 | 0.00 | 5.9 | 4.80 | 6.9 | 223 | 26.6 | – | – | | | |
| | 10.00–12.00pm | RAW | | | | | | | | | | | | | | | | 0 | | |
| | | FILT. | | | | | | | | | | | | | | | | | | |
| | 12.00–2.00pm | RAW | 3.60 | 4.7 | 50 | 20 | 0.140 | | | 0.12 | 0.3 | | 6.59 | 206 | – | – | – | | | |
| | | FILT. | 0.01 | 0.03 | 1.0 | 0.4 | 0.00 | | | 0.00 | 6.4 | | 7.0 | 236 | – | – | – | 20 | | |
| | 2.00–3.00pm | RAW | | | | | | | | | | | | | | | | | | |
| | | FILT. | | | | | | | | | | | | | | | | 0 | | |
| | 3.00–5.30pm | RAW | 2.66 | 3.30 | 30 | 25 | 0.31 | 0.14 | 0.180 | | 0.2 | 5.00 | 5.8 | – | 54 | – | – | | 0 | |
| | | FILT. | 0.03 | 0.20 | 2 | 1.3 | 0.11 | 0.25 | 0.03 | 0.03 | 6.2 | 4.4 | 6.70 | – | 33 | – | – | 195 | 0 | 0.18 |
| 30/07/93 | 6.00–8.00am | RAW | 2.05 | 4.4 | 178 | 36 | 0.43 | 0.22 | 0.05 | 0.2 | 0.7 | 5.4 | 5.9 | 187 | 49 | 94 | 66 | 72 | | |
| | | FILT. | 0.00 | 0.03 | 1.00 | 0.09 | 0.38 | 0.28 | 0.004 | 0.1 | 5.8 | 5.0 | 6.5 | 214 | 24 | 144 | 97 | | | |
| | 8.00–11.00am | RAW | 1.6 | 3.8 | 95 | 23 | 0.15 | 0.12 | 0.15 | 0.1 | 0.3 | | 5.5 | 234 | | 98 | 72 | | | |
| | | FILT. | 0.01 | 0.05 | 61.0 | 0.08 | 0.06 | 0.26 | 0.00 | 0.00 | 4.5 | | 6.1 | 241 | | 150 | 107 | 0 | | |
| | 11.00–12.30pm | RAW | | | | | | | | | | | | | | | | | | |
| | | FILT. | | | | | | | | | | | | | | | | 0 | | |
| | 12.00 2.30pm | RAW | 1.3 | 5.1 | 70 | 30 | – | – | – | – | – | – | 6.0 | 200 | | | | | | |
| | | FILT. | 0.02 | 0.07 | 20 | 1.00 | – | – | – | – | – | – | 6.6 | 240 | | | | 42 | | |
| | 2.30–3.00pm | RAW | | | | | | | | | | | | | | | | | | |
| | | FILT. | | | | | | | | | | | | | | | | 0 | | |
| | 3.00–5.30pm | RAW | 1.8 | 3.3 | 65 | 28 | 0.28 | 0.16 | 0.14 | 0.17 | 0.3 | 5.4 | 5.75 | 195 | 52 | 86 | 68 | | 0 | |
| | | FILT. | 0.01 | 0.12 | 2.0 | 1.0 | 0.12 | 0.07 | 0.04 | 0.06 | 3.3 | 5.0 | 6.5 | 220 | 46 | 120 | 94 | 110 | 0 | 0.18 |

# APPENDIX A3 (Cont.)   SHIVANGA PLANT (C-5467)

| Date | Time | Sample | Ferrous iron mg Fe²⁺/l | Total Iron mg Fe/l | Colour mg Pt/l | Turbidity N.T.U | Ammonia mg NH₄/l | Nitrate mg NO₃/l | Nitrite mg No₂/l | Manganese mg Ma/l | Dissolved Oxygen mg O₂/l | Perm. No. mg KmnO₄/l | pH Units | Conduct. μs/cm | Carbon Dioxide mg CO₂/l | Total Alkalinity mg CaCo₃/l | Total Hardness mg CaCo₃/l | Prod. in ltr | Total Coliform Per 100 ml | Flow Rate l/s |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 31/7/93 | 8.00–9.00am | RAW | 2.7 | 4.25 | 50 | 35 | 0.23 | 1.2 | 0.003 | 0.4 | 0.2 | | 6.36 | 212 | 65 | 142 | 117 | 83 | | |
| | | FILT. | 0.07 | 0.06 | 2 | 1.0 | 0.10 | 1.24 | 0.055 | 0.23 | 3.7 | | 6.7 | 206 | 38 | 149 | 108 | | | |
| | 9.00–11.00am | RAW | | | | | | | | | | | | | | | | 10 | | |
| | | FILT. | | | | | | | | | | | | | | | | | | |
| | 11.00–12.30pm | RAW | | | | | | | | | | | | | | | | 30 | | |
| | | FILT. | | | | | | | | | | | | | | | | | | |
| | 12.30–2.30pm | RAW | 2.2 | 4.2 | 63 | 30 | 0.42 | 3.8 | 0.002 | | 0.3 | | 5.9 | 226 | | 168 | 145 | 60 | | |
| | | FILT. | 0.05 | 0.10 | 2.5 | 1.0 | 0.33 | 4.4 | 0.062 | | 3.3 | | 6.5 | 217 | | 163 | 127 | | | |
| | 2.30–3.00pm | RAW | | | | | | | | | | | | | | – | | 15 | | |
| | | FILT. | | | | | | | | | | | | | | – | | | | |
| | 3.00–5.30pm | RAW | 1.87 | 3.20 | 56 | 26 | 0.255 | 2.64 | 0.05 | 0.3 | 0.2 | 4.2 | 6.0 | – | 44 | – | | | 0 | |
| | | FILT. | 0.04 | 0.13 | 3.5 | 1.2 | 0.126 | 2.94 | 0.11 | 0.2 | 4.4 | 3.8 | 6.5 | | 33 | | | 105 | 0 | 0.18 |
| 01/08/93 | 7.00–9.00am | RAW | 1.2 | 5.4 | 239 | 52 | 0.54 | 3.73 | 0.008 | 0.3 | 0.2 | 6.54 | 5.75 | 231 | 58 | 140 | 60 | 86 | | |
| | | FILT. | 0.01 | 0.08 | 3 | 1.55 | 0.41 | 3.87 | 0.13 | 0.4 | 5.7 | 3.16 | 6.60 | 215 | 35 | 129 | 53 | | | |
| | 9.00–12.00pm | RAW | 2.5 | 5.0 | 99 | 18 | 0.360 | 2.95 | 0.09 | 0.16 | 0.25 | 3.8 | 6.25 | – | | 98 | 94 | | | |
| | | FILT. | 0.00 | 0.1 | 4.5 | 0.5 | 0.17 | 3.65 | 0.15 | 0.10 | 4.8 | 3.0 | 7.1 | – | | 116 | 90 | 20 | | |
| | 12.00–2.30pm | RAW | 2.0 | 4.6 | 75 | 15 | | | | | 0.2 | | – | 223 | | – | – | | | |
| | | FILT. | 0.03 | 0.16 | 3.0 | 1.0 | | | | | 4.2 | | – | 189 | | | | 45 | | |
| | 2.30–3.00pm | RAW | | | | | | | | | | | | | | | | 15 | | |
| | | FILT. | | | | | | | | | | | | | | | | | | |
| | 3.00–5.30pm | RAW | 0.95 | 3.90 | 80 | 27 | 0.48 | 5.0 | 0.008 | 0.3 | 0.3 | 3.8 | 5.95 | 203 | 48 | 133 | 118 | | 0 | |
| | | FILT. | 0.05 | 0.20 | 3.0 | 1.5 | 0.26 | 5.21 | 0.013 | 0.19 | 3.7 | 3.2 | 6.85 | 192 | 36 | 125 | 103 | 190 | 0 | 0.18 |
| 02/08/93 | 6.00–9.00am | RAW | 2.30 | 6 | 44 | 13 | 0.36 | 0.70 | 0.110 | 0.2 | 0.36 | | 6.82 | 224 | 53 | 180 | 119 | 40 | | |
| | | FILT. | 0.00 | 0.09 | 0.3 | 0.6 | 0.20 | 0.75 | 0.20 | 0.00 | 4.2 | | 7.15 | 217 | 38 | 131 | 86 | | | |
| | 9.00–11.00am | RAW | | | | | | | | | | | | | | | | | | |
| | | FILT. | | | | | | | | | | | | | | | | | | |
| | 11.00–12.30pm | RAW | | | | | | | | | | | | | | | | | | |
| | | FILT. | | | | | | | | | | | | | | | | | | |
| | 12.30–2.30pm | RAW | 1.3 | 4.8 | 193 | 37 | 0.550 | 0.22 | 0.13 | 0.10 | 2.4 | | 6.5 | 215 | | 156 | 109 | | | |
| | | FILT. | 2.0 | 0.12 | 2.0 | 1.3 | 0.430 | 0.39 | 0.15 | 0.00 | 4.8 | | 6.8 | 208 | | 144 | 106 | 29 | | |
| | 2.30–3.00pm | | | | | | | | | | | | | | | | | | | |
| | 3.00–5.30pm | RAW | 2.20 | 3.6 | 173 | 25 | 0.220 | 0.12 | 0.29 | 0.12 | 3 | 5.3 | 6.52 | 230 | 66 | | | | 0 | |
| | | FILT. | 0.05 | 0.16 | 3 | 1.4 | 0.01 | 0.35 | 0.004 | 0.16 | 4.6 | 4.9 | 6.73 | 218 | 50 | – | – | 172 | 0 | 0.17 |

# APPENDIX A3 (Cont.)   SHIVANGA PLANT (C-5467)

| Date | Time | Sample | Ferrous iron mg Fe²/l | Total Iron mg Fe/l | Colour mg Pt/l | Turbidity N.T.U | Ammonia mg NH₃/l | Nitrate mg NO₃/l | Nitrite mg No₂/l | Manganese mg Ma/l | Disolved Oxygen mg O₂/l | Perm. No. Mg KMNO₄/l | pH Units | Conduct. µs/cm | Carbon Dioxide mg CO₂/l | Total Alkalinity mg CaCo₃/l | Total Hardness mg CaCo₃/l | Prod. in ltr | Total Coliform Per 100 ml | Flow Rate l/sec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 03/08/93 | 6.00-10.00am | RAW | 1.50 | 3.8 | 44 | 8 | 0.030 | 5.2 | 0.028 | 0.6 | 1.2 | 6.30 | 6.4 | 226 | 55 | 132 | 108 | 90 | | - |
| | | FILT. | 0.03 | 0.05 | 0.00 | 0.00 | 0.13 | 6.6 | 0.52 | 0.4 | 2.4 | 5.70 | 6.7 | 230 | 44 | 153 | 121 | | | - |
| | 10.00-12.00pm | RAW | 1.30 | 2.90 | 75 | 23 | 0.30 | 0.05 | 0.20 | 0.6 | 0.6 | | 6.5 | 190 | | 108 | 61 | | | |
| | | FILT. | 0.05 | 0.05 | 2.0 | 1.0 | 0.04 | 0.26 | 0.54 | 0.2 | 3.3 | | 7.2 | 200 | | 140 | 81 | 60 | | |
| | 12.00-2.00pm | RAW | 1.70 | 2.70 | 55 | 14 | 0.80 | 0.5 | 0.60 | 0.30 | 0.3 | | 6.53 | 207 | | 92 | 73 | 32 | | - |
| | | FILT. | 0.03 | 0.05 | 2.0 | 0.71 | 0.35 | 0.73 | 6.82 | 0.1 | 4.8 | | 6.7 | 215 | | 158 | 99 | | | - |
| | 2.00-3.00pm | RAW | 1.1 | 2.1 | 44 | 8 | 0.23 | 4.4 | 0.25 | 0.5 | 0.4 | | 6.0 | 220 | | - | - | 20 | | |
| | | FILT. | 0.01 | 0.06 | 0.93 | 4.0 | 0.02 | 4.6 | 0.018 | 0.3 | 4.3 | | 6.5 | 236 | | - | - | | | |
| | 3.00-5.30pm | RAW | 0.9 | 3.8 | 52 | 25 | 0.11 | 0.25 | 0.16 | 0.5 | 0.5 | 6.3 | 6.52 | 210 | 68 | - | - | | 0 | |
| | | FILT. | 0.1 | 0.15 | 2.0 | 1.35 | 0.04 | 0.132 | 0.018 | 0.4 | 3.6 | 5.7 | 6.6 | 230 | 63 | - | - | 140 | 0 | 0.17 |
| 05/08/93 | 6.00-9.00am | RAW | 3.23 | 5.6 | 90 | 16 | 0.38 | 0.38 | 0.18 | 0.6 | 0.6 | 4.60 | 6.2 | 225 | 42 | | | 75 | | |
| | | FILT. | 0.02 | 0.04 | 1.6 | 0.90 | 0.27 | 0.43 | 0.55 | 0.4 | 4.4 | 3.80 | 6.8 | 230 | 38 | | | | | |
| | 9.00-11.00am | RAW | 1.60 | 3.00 | 48 | 30 | 0.18 | 1.4 | 0.78 | 0.6 | 0.35 | | 5.80 | 191 | | | | 15 | | |
| | | FILT. | 0.02 | 0.00 | 1.0 | 0.5 | 0.00 | 2.30 | 18 | 0.35 | 5.0 | | 5.95 | 231 | | | | | | |
| | 11.00-12.30pm | RAW | 1.13 | 3.09 | 40 | 25 | 0.27 | 0.4 | 0.275 | 0.4 | 0.6 | | 6.67 | 197 | | | | 35 | | |
| | | FILT. | 0.02 | 0.10 | 1.0 | 0.00 | 0.05 | 0.52 | 0.360 | 0.1 | 4.7 | | 6.90 | 209 | | | | | | |
| | 12.30-2.30pm | RAW | 2.20 | 4.5 | 17 | 8 | 0.37 | 0.78 | 0.44 | 0.8 | 0.2 | | 5.9 | - | | | | 60 | | |
| | | FILT. | 0.06 | 0.14 | 1.0 | 0.70 | 0.09 | 0.92 | 0.52 | 0.5 | 5.4 | | 6.3 | | | | | | | |
| | 2.30-3.00pm | | | | | | | | | | | | | | | | | | | |
| | 3.00-5.30pm | RAW | 1.30 | 3.90 | 34 | 22 | 0.25 | 0.05 | 0.33 | 0.30 | 0.2 | 4.6 | 6.0 | | 50 | | | 185 | 0 | |
| | | FILT. | 0.03 | 0.2 | 2.0 | 1.4 | 0.03 | 0.15 | 0.41 | 0.10 | 5.8 | 3.8 | 6.9 | - | 46 | | | | 0 | 0.17 |
| 10/08/93 | 7.00-9.00am | RAW | 2.05 | 4.67 | 52 | 8 | 0.16 | 0.22 | 0.16 | 0.00 | 0.7 | 3.6 | 6.40 | 216 | 54 | 138 | 100 | 75 | | |
| | | FILT. | 0.02 | 0.18 | 1.0 | 0.3 | 0.10 | 0.27 | 0.19 | 0.00 | 5.7 | 3.2 | 6.76 | 230 | 46 | 150 | 105 | | | |
| | 9.00-12.30pm | RAW | 1.91 | 3.76 | 52 | 18 | 0.29 | 0.22 | 0.33 | 0.30 | 0.3 | | 6.42 | 212 | | 126 | 76 | 26 | | |
| | | FILT. | 0.02 | 0.07 | 1.0 | 0.6 | 0.07 | 0.65 | 0.11 | 0.10 | 5.3 | | 6.72 | 220 | | 145 | 103 | | | |
| | 12.30-2.30pm | RAW | 1.68 | 4.74 | 31 | 21 | 0.163 | 0.132 | 0.153 | 0.3 | 0.2 | | 6.56 | 204 | | 118 | 93 | | | |
| | | FILT. | 0.04 | 0.18 | 1.5 | 0.5 | 0.010 | 0.202 | 0.24 | 0.00 | 6.0 | | 6.75 | 209 | | 141 | 98 | 40 | | |
| | 2.30-3.00pm | RAW | | | | | | | | | | | | | | | | 10 | | |
| | | FILT. | | | | | | | | | | | | | | | | | | |
| | 3.00-5.30pm | RAW | 1.85 | 3.63 | 35 | 29 | - | - | - | 0.12 | 0.3 | 3.6 | 6.00 | - | 58 | - | - | 180 | 0 | |
| | | FILT. | 0.1 | 0.22 | 2.00 | 1.35 | - | - | - | 0.04 | 5.0 | 3.2 | 7.10 | | 50 | - | - | | 0 | 0.17 |

| Date | Time | Sample | Ferrous iron mg Fe³⁺/l | Total Iron mg Fe/l | Colour mg Pt/l | Turbidity N.T.U | Ammonia mg NH₄/l | Nitrate mg NO₃/l | Nitrite Mg No₂/l | Manganese mg Mn/l | Dissolved Oxygen mg O₂/l | Perm. No. mg KmnO₄/l | pH Units | Condut. µs/cm | Carbon Dioxide mg CO₂/l | Total Alkalinity mg CaCo₃/l | Total Hardness mg CaCo₃/l | Prod. in ltr | Total Coliform Per 100 ml | Flow Rate l/sec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11/08/93 | 7.00–9.00am | RAW | 1.99 | 4.8 | 35 | 25 | 0.19 | 0.176 | 0.06 | – | 0.5 | | 6.57 | 176 | 45 | 134 | 97 | 50 | | |
| | | FILT. | 0.02 | 0.10 | 1.0 | 0.2 | 0.09 | 0.22 | 0.03 | – | 6.2 | | 6.67 | 189 | 35 | 141 | 102 | | | |
| | 9.00–11.00am | RAW | 2.91 | 3.5 | 42 | 27 | 0.15 | 0.088 | 0.352 | – | 0.3 | 4.50 | 6.57 | 193 | | 136 | 85 | 30 | | |
| | | FILT. | 0.02 | 0.15 | 1.0 | 0.3 | 0.10 | 0.42 | 0.02 | – | 5.3 | 4.10 | 6.76 | 218 | | 131 | 95 | | | |
| | 11.00–12.30pm | RAW | 2.21 | 5.2 | 9.0 | 10 | 0.11 | | | – | 0.4 | | 6.48 | 213 | | 132 | 83 | 65 | | |
| | | FILT. | 0.04 | 0.15 | 1.5 | 1.00 | 0.00 | | | | 3.90 | | 6.56 | 227 | | 148 | 93 | | | |
| | 12.30–2.30pm | RAW | 0.94 | 2.30 | 65 | 15 | 0.22 | 0.088 | 0.155 | 0.35 | 0.2 | | 5.60 | – | 63 | – | – | 150 | 0 | 0.17 |
| | | FILT. | 0.03 | 0.23 | 2.0 | 1.45 | 0.15 | 0.27 | 0.03 | 0.11 | 4.3 | | 6.5 | – | 57 | – | – | | 0 | |
| | 2.30–3.00pm | RAW | | | | | | | | | | | | | | | | 15 | | |
| | | FILT. | | | | | | | | | | | | | | | | | | |
| | 3.00–5.30pm | RAW | 1.10 | 3.16 | 50 | 24 | 0.22 | 0.088 | 0.155 | 0.35 | 0.15 | 4.5 | 5.95 | – | 52 | – | – | | 0 | |
| | | FILT. | 0.02 | 0.23 | 2.5 | 1.45 | 0.15 | 0.27 | 0.03 | 0.11 | 3.8 | 4.1 | 6.35 | | 47 | | | 170 | 0 | 0.17 |
| 12/08/93 | 7.00–9.00am | RAW | 1.79 | 4.39 | 51 | 19 | 0.07 | 4.4 | 0.29 | 0.5 | 0.5 | | 6.52 | 209 | 62 | 132 | 117 | 93 | | |
| | | FILT. | 0.03 | 0.1 | 0.5 | 0.09 | 0.00 | 4.65 | 0.004 | 0.14 | 4.6 | | 6.70 | 218 | 55 | 146 | 119 | | | |
| | 9.00–11.00am | RAW | 1.02 | 4.5 | 47 | 4 | 0.03 | 2.64 | 0.30 | 0.75 | 0.3 | | 6.74 | 206 | | 143 | 116 | 26 | | |
| | | FILT. | 0.02 | 0.08 | 1.0 | 0.06 | 0.00 | 2.2 | 0.002 | 0.24 | 5.8 | | 6.80 | 234 | | 148 | 119 | | | |
| | 11.00–12.30pm | RAW | 1.77 | 3.78 | 97 | 16 | 2.10 | 0.00 | 1.56 | 0.45 | 0.3 | | 6.63 | 207 | | 148 | 117 | 4 | | |
| | | FILT. | 0.02 | 0.1 | 0.8 | 1.00 | 0.06 | 1.8 | 1.06 | 0.19 | 5.2 | | 6.75 | 236 | | 160 | 131 | | | |
| | 12.30–2.30pm | RAW | 2.2 | 2.90 | 82 | 15 | | | | – | | | 5.6 | 178 | | 152 | 118 | 50 | | |
| | | FILT. | 0.06 | 0.2 | 1.5 | 1.00 | | | | – | | | 6.30 | 195 | | 161 | 123 | | | |
| | 2.30–3.00pm | RAW | | | | | | | | | | | | | | | | 15 | | |
| | | FILT. | | | | | | | | | | | | | | | | | | |
| | 3.00–5.30pm | RAW | 1.65 | 3.75 | 48 | 26 | 1.84 | 3.8 | 2.2 | 0.65 | | 4.7 | 6.3 | – | 57 | – | – | | 0 | 0.17 |
| | | FILT. | 0.1 | 0.25 | 2.0 | 1.35 | 0.03 | 4.2 | 3.5 | 0.18 | | 3.9 | 7.3 | | 52 | | | 165 | 0 | |
| 16/08/93 | 6.00–8.00am | RAW | 1.10 | 1.77 | 74 | 10 | 0.06 | 2.64 | 0.09 | 0.3 | 0.4 | | 6.67 | 214 | 43 | 133 | 133 | 68 | | |
| | | FILT. | 0.02 | 0.13 | 1.0 | 0.60 | 0.00 | 2.82 | 0.05 | 0.26 | 5.4 | | 6.92 | 218 | 38 | 166 | 140 | | | |
| | 8.00–11.00am | RAW | 1.50 | 2.5 | 17 | 116 | N/D | 44 | 0.003 | 0.22 | 0.30 | | 5.96 | 215 | | 123 | 158 | 25 | | |
| | | FILT. | 0.03 | 0.10 | 2.0 | 21.0 | 0.02 | 4.4 | 0.003 | 0.1 | 4.8 | | 7.03 | 234 | | 139 | 181 | | | |
| | 11.00–12.30pm | RAW | 1.60 | 3.3 | 47 | 70 | 0.03 | 2.64 | 0.002 | 0.4 | 0.60 | | 6.73 | 175 | | 129 | 123 | 30 | | |
| | | FILT. | 0.02 | 0.15 | 2.0 | 1.0 | 0.00 | 2.65 | 0.002 | 0.1 | 5.0 | | 7.11 | 206 | | 157 | 144 | | | |
| | 12.30–2.30pm | RAW | 0.80 | 2.40 | 63 | 32 | 0.36 | 2.64 | 0.03 | 0.2 | 0.55 | | 6.20 | 201 | | – | – | 45 | | |
| | | FILT. | 0.04 | 0.22 | 1.5 | 1.0 | 0.12 | 2.76 | 0.18 | 0.10 | 3.6 | | 7.40 | 233 | | | | | | |
| | 2.30–3.00pm | | | | | | | | | | | | | | | | | | | |
| | 3.00–5.30pm | RAW | 2.60 | 3.20 | 70 | 23 | 0.40 | 1.20 | 0.01 | 0.5 | 0.25 | 3.5 | 6.0 | – | 48 | – | – | 160 | 0 | 0.16 |
| | | FILT. | 0.08 | 0.26 | 2.0 | 1.30 | 0.25 | 1.22 | 0.14 | 0.3 | 3.2 | 3.3 | 6.5 | – | 46 | – | – | | 0 | |

| Date | Time | Sample | Ferrous iron mg $Fe^{2+}$/l | Total Iron mg Fe/l | Colour mg Pt/l | Turbidity N.T.U | Ammonia mg $NH_3$/l | Nitrate mg $NO_3$/l | Nitrite mg $NO_2$/l | Manganese mg Mn/l | Dissolved Oxygen mg $O_2$/l | Perm. No. mg $KmnO_4$/l | pH Units | Conduct. μs/cm | Carbon Dioxide g $CO_2$/l | Total Alkalinity mg $CaCo_3$/l | Total Hardness mg $CaCo_3$/l | Prod. in lts | Total Coliform Per 100 ml | Flow rate l/s |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 28/7/93 | 7.00–9.00am | RAW | 0.70 | 1.8 | 90 | 30 | 0.27 | 0.9 | 0.03 | 0.00 | 1.90 | 4 | 6.50 | 146 | 63 | 62.2 | 57 | 35 | | |
| | | FILT. | 0.01 | 0.06 | 3.5 | 0.8 | 0.19 | 1.10 | 0.43 | 0.00 | 6.75 | | 6.75 | 195 | 15 | 93.4 | 86 | | | |
| | 9.00–12.30am | RAW | 0.82 | 1.65 | 80 | 33 | | | | 0.16 | 2.0 | | 6.43 | 115 | – | 83.8 | 55 | 10 | | |
| | | FILT. | 0.01 | 0.1 | 4.2 | 0.91 | | | | 0.08 | 6.3 | | 6.80 | 152 | | 97.3 | 78 | | | |
| | 12.30–2.30pm | RAW | 0.53 | 3.2 | 96 | 29 | 0.18 | 1.63 | 0.04 | 0.22 | 2.4 | | | | 400 | | | 185 | | |
| | | FILT. | 0.05 | 0.12 | 4.4 | 1.1 | 0.07 | 1.65 | 0.21 | 0.13 | 5.6 | | | | 13 | | | | | |
| | 2.30–4.00pm | RAW | 0.82 | 2.0 | 86 | 24 | | | – | | – | | | | | | | 16 | | |
| | | FILT. | 0.05 | 0.14 | 4.0 | 0.7 | | | – | | | | | | | | | | | |
| | 4.00–6.30pm | RAW | 0.65 | 1.95 | 77 | 50 | 0.20 | 1.82 | 0.00 | 0.35 | 2.8 | 4.8 | 6.13 | 102 | 36 | 53.4 | 48 | 278 | 25 | |
| | | FILT. | 0.04 | 0.14 | 4.5 | 2.3 | 0.15 | 1.89 | 0.03 | 0.26 | 4.5 | 3.2 | 6.70 | 141 | 16 | 75.3 | 62 | | 5 | 0.108 |
| 02/08/93 | 7.00–9.00am | RAW | 0.71 | 1.80 | 110 | 29 | 0.31 | 2.6 | 0.07 | 0.18 | 2.7 | | 6.3 | 113 | 44 | 86 | 67 | 50 | | |
| | | FILT. | 0.01 | 0.07 | 2.0 | 0.6 | 0.23 | 2.73 | 0.52 | 0.06 | 6.5 | | 6.75 | 123 | 10 | 112 | 89 | | | |
| | 9.00–11.00am | RAW | 0.56 | 2.1 | 82 | 30 | 0.17 | 0.116 | 0.092 | 0.28 | 3.2 | | 5.5 | 125 | | 93 | 46 | 18 | | |
| | | FILT. | 0.01 | 0.10 | 1.5 | 0.5 | 0.06 | 0.21 | 0.12 | 0.10 | 5.7 | | 6.6 | 145 | | 116 | 76 | | | |
| | 11.00–12.30pm | RAW | 0.63 | 1.90 | 93 | 37 | 0.35 | 0.19 | 0.075 | 0.34 | 3.0 | | 6.0 | | | 78 | 52 | 168 | | |
| | | FILT. | 0.012 | 0.11 | 2.5 | 0.7 | 0.21 | 0.26 | 0.120 | 0.12 | 5.0 | | 6.5 | | | 96 | 72 | | | |
| | 12.30–2.30pm | RAW | | | | | | | | | | | | | | | | | | |
| | | FILT. | | | | | | | | | | | | | | | | | | |

| Date | Time | Sample | Ferrous iron mg $Fe^{2+}$/l | Total Iron mg Fe/l | Colour mg Pt/l | Turbidity N.T.U | Ammonia mg $NH_3$/l | Nitrate mg $NO_3$/l | Nitrite mg $NO_2$/l | Manganese mg Mn/l | Dissolved Oxygen mg $O_2$/l | Perm. No. mg $KmnO_4$/l | pH Units | Conduct. μs/cm | Carbon Dioxide $CO_2$/l | Total Alkalinity mg $CaCo_3$/l | Total Hardness mg $CaCo_3$/l | Prod. in lts | Total Coliform Per 100 ml | Flow rate l/s |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12/7/93 | 6.00–9.00am | RAW | 0.6 | 1.50 | 190 | 62 | 0.26 | 5.4 | 0.30 | 0.30 | 2.90 | | 6.1 | 98 | 46.3 | 78 | 53 | 30 | | |
| | | FILT. | 0.00 | 0.2 | 12.0 | 0.72 | 0.19 | 5.46 | 0.047 | 0.10 | 6.30 | | 6.6 | 136 | 7.5 | 110 | 72 | | | |
| | 9.00–12.30am | RAW | 0.9 | 1.50 | 180 | 54 | 0.62 | 1.51 | 0.04 | 0.2 | 3.0 | | 6.2 | | – | – | | | 70 | | |
| | | FILT. | 0.03 | 0.1 | 15 | 0.8 | 0.50 | 1.92 | 0.02 | 0.15 | 5.8 | | 6.7 | | | | | | | |
| | 12.30–2.30pm | RAW | 0.4 | 1.30 | 70 | 18 | 0.41 | | 0.042 | 0.4 | 2.5 | | 5.59 | 120 | 53.8 | 60 | 50.0 | 180 | | |
| | | FILT. | 0.00 | 0.15 | 20 | 1.3 | 0.32 | | 0.07 | 0.18 | 4.6 | | 6.17 | 168 | 5.5 | 86 | 77 | | | |
| | 2.30–4.00pm | RAW | 0.5 | 1.4 | 85 | 18 | 0.33 | 5.72 | – | 0.28 | 3.1 | | 6.2 | | | | | 0 | | |
| | | FILT. | 0.02 | 0.05 | 9 | 0.6 | 0.28 | 5.50 | – | 0.26 | 5.4 | | 7.0 | | | | | | | |

# APPENDIX A4 (Cont.)    LUGUSI PLANT (KA-69)

| Date | Time | Sample | Ferrous iron mg Fe²⁺/l | Total Iron mg Fe/l | Colour mg P/l | Turbidity N.T.U | Ammonia mg NH₃/l | Nitrate mg NO₃/l | Nitrite mg NO₂/l | Manganese mg Mn/l | Dissolved Oxygen mg O₂/l | Perm. No. mg KmnO₄/l | pH Units | Conduct. µs/cm | Carbon Dioxide mg CO₂ | Total Alkalinity mg CaCo₃/l | Total Hardness mg CaCo₃/l | Prod. in ltr | Total Coliform Per 100 ml | Flow rate l/s |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16/08/93 | 8.00–10.00am | RAW | 0.54 | 2.2 | 94 | 42 | 1.84 | 0.93 | 0.05 | 0.14 | 2.1 | | 5.92 | 142 | 62 | 73 | 39 | 62 | | |
| | | FILT. | 0.03 | 0.05 | 1.5 | 0.7 | 0.3 | 1.20 | 0.23 | 0.04 | 6.2 | | 7.2 | 190 | 18 | 86 | 65 | | | |
| | 10.00–12.30pm | RAW | 0.80 | 1.63 | 64 | 51 | | | | 0.41 | 2.6 | | 5.66 | | | 56 | 56 | 28 | | |
| | | FILT. | 0.02 | 0.07 | 1.8 | 0.6 | | | | 0.13 | 6.0 | | 6.56 | | | 63 | 84 | | | |
| | 12.30–2.00pm | RAW | 0.67 | 1.65 | 68 | 38 | | | | 0.06 | 3.1 | | 5.70 | | 35 | 76 | 60 | 168 | | |
| | | FILT. | 0.04 | 0.14 | 2.0 | 1.2 | | | | 0.00 | 5.2 | | 6.80 | | 11 | 92 | 63 | | | |
| | 2.00–4.00pm | RAW | 0.82 | 1.10 | 75 | 38 | | | | | 2.8 | | | 131 | | | 30 | 42 | | |
| | | FILT. | 0.03 | 0.08 | 1.9 | 1.0 | | | | | 4.8 | | | 150 | | | 71 | | | |
| | 4.00–6.30pm | RAW | 1.3 | 1.4 | 80 | 48 | 3.53 | 1.68 | 0.034 | 0.36 | 3.5 | 5.4 | 6.0 | | 58 | 71 | 43 | 279 | 17 | |
| | | FILT. | 0.05 | 0.14 | 2.3 | 2.4 | 1.82 | 2.55 | 0.28 | 0.15 | 4.3 | 3.9 | 6.90 | | 27 | 88 | 87 | | 3 | 0.116 |
| 24/08/93 | 7.00–9.00am | RAW | 0.75 | 1.5 | 63 | 41 | 2.26 | 1.43 | 0.133 | 0.23 | 2.4 | | 6.3 | | 25 | 83 | 50 | 28 | | |
| | | FILT. | 0.02 | 0.06 | 2.0 | 0.7 | 0.65 | 2.10 | 0.52 | 0.08 | 6.0 | | 7.15 | | 0 | 120 | 68 | | | |
| | 9.00–11.00am | RAW | 0.94 | 1.25 | 75 | 45 | | | | 0.42 | 2.70 | | 5.80 | 75 | | 58 | 68 | 154 | | |
| | | FILT. | 0.026 | 0.13 | 2.4 | 1.5 | | | | 0.16 | 5.90 | | 6.70 | 107 | | 75 | 95 | | | |
| | 11.00–12.30pm | RAW | 0.48 | 1.94 | 54 | 36 | | | | 0.27 | 2.6 | | | | | 70 | 38 | 17 | | |
| | | FILT. | 0.020 | 0.09 | 2.0 | 1.0 | | | | 0.05 | 5.9 | | | | | 98 | 72 | | | |
| | 12.30–2.00pm | RAW | 0.68 | 1.7 | 87 | 48 | | | | 0.48 | 3.0 | | 5.4 | | | 90 | 76 | 67 | | |
| | | FILT. | 0.03 | 0.11 | 2.5 | 2.0 | | | | 0.130 | 5.3 | | 6.5 | | | 136 | 103 | | | |
| | 2.00–4.00pm | RAW | | | | | | | | | | | | | | | | 0 | | |
| | | FILT. | | | | | | | | | | | | | | | | | | |
| | 4.00–6.30pm | RAW | 0.81 | 1.45 | 102 | 50 | 1.36 | 1.56 | 0.026 | 0.25 | 3.4 | 3.6 | 5.54 | 112 | 76 | 104 | 84 | 285 | 19 | |
| | | FILT. | 0.06 | 0.13 | 4.0 | 2.4 | 0.035 | 1.78 | 0.45 | 0.04 | 5.0 | 3.1 | 6.65 | 138 | 36 | 85 | 120 | | 4 | 0.11 |
| 30/08/93 | 7.00–8.00am | RAW | 0.50 | 2.0 | 110 | 57 | 0.38 | 1.75 | 0.012 | 0.19 | 1.75 | | 6.0 | 122 | 41 | 73 | 60 | 25 | | |
| | | FILT. | 0.02 | 0.08 | 1.8 | 0.7 | 0.03 | 1.92 | 0.084 | 0.00 | 6.6 | | 6.4 | 140 | 11 | 112 | 97 | | | |
| | 8.00–11.00am | RAW | 0.95 | 1.20 | 86 | 39 | | | | 0.28 | 2.5 | | 5.45 | | | 55 | 36 | 50 | | |
| | | FILT. | 0.032 | 0.10 | 2.6 | 0.9 | | | | 0.075 | 5.6 | | 6.5 | | | 89 | 54 | | | |
| | 11.00–12.30pm | RAW | 0.75 | 1.54 | 67 | 29 | | | | 0.32 | 2.4 | | 6.1 | 110 | | | | 25 | | |
| | | FILT. | 0.03 | 0.08 | 2.0 | 0.95 | | | | 0.070 | 5.4 | | 6.90 | 126 | | | | | | |
| | 12.30–2.30pm | RAW | 0.64 | 1.62 | 98 | 53 | 0.58 | 1.64 | 0.044 | 0.22 | 3.6 | | 5.85 | | 65 | | | 190 | | |
| | | FILT. | 0.08 | 0.11 | 3.8 | 1.3 | 0.02 | 1.82 | 0.156 | 0.09 | 4.7 | | 6.3 | | 50 | | | | | |
| | 4.00–6.30pm | RAW | 1.3 | 1.86 | 77 | 36 | | | | 0.34 | 3.2 | 5.8 | | 121 | 62 | 87 | 70 | 255 | 15 | |
| | | FILT. | 0.05 | 0.12 | 3.5 | 2.2 | | | | 0.03 | 4.9 | 3.3 | | 159 | 34 | 124 | 114 | | 2 | 0.11 |

# APPENDIX A4 (Cont.)    LUGUSI PLANT (KA-69)

| Date | Time | Sample | Ferrous Iron mg Fe/l | Total Iron mg Fe/l | Colour mg PM | Turbidity N.T.U | Ammonia mg NH4/l | Nitrate mg NO3/l | Nitrite mg No2/l | Manganese mg Mn/l | Dissolved Oxygen mg O2/l | Perm. No. mg Kmn/l | pH Units | Conduct. μs/cm | Carbon Dioxide mg CO2/l | Total Alkalinity mg CaCo3/l | Total Hardness mg CaCo3/l | Prod. in No | Total Coliform Per 100 ml | Flow rate l/s |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01/09/93 | 6.00–9.00am | RAW FILT. | 0.63 0.03 | 1.55 0.08 | 67 2 | 8 0.9 | 0.16 0.00 | 3.48 4.28 | 0.089 0.089 | 0.17 0.06 | 1.68 6.4 | | 6.15 6.6 | 74 128 | 55 15 | 74 110 | 57 85 | 22 | | |
| | 9.00–11.00am | RAW FILT. | 0.74 0.03 | 1.65 0.08 | 47 2.6 | 12 1.4 | | | | | 1.83 5.8 | | 5.83 6.65 | | | | | 35 | | |
| | 11.00–12.30pm | | | | | | | | | | | | | | | | | – | | |
| | 12.30–2.30pm | RAW FILT. | 0.80 0.04 | 1.24 0.10 | 78 3.0 | 10 1.5 | | | | | 2.6 5.4 | | 5.80 6.45 | 83 150 | | | | 144 | | |
| | 2.30–4.00pm | RAW FILT. | | | | | | | | | | | | | | | | – | | |
| | 4.00–6.30pm | RAW FILT. | 0.78 0.06 | 1.75 0.11 | 56 3.2 | 40 1.9 | 0.12 0.05 | 3.76 4.16 | 0.028 0.026 | 0.34 0.10 | 3.4 4.9 | 3.8 3.6 | 6.0 6.50 | | 43 34 | 79 113 | 64 83 | 262 | 12 3 | 0.105 |
| 14/09/93 | 6.00–9.00am | RAW FILT. | 0.86 0.02 | 1.40 0.05 | 69 4 | 20 2.0 | | | | 0.23 0.03 | 1.73 6.2 | | 5.94 6.70 | 91 121 | 20 8 | 70 83 | 99 96 | 18 | | |
| | 9.00–11.00am | RAW FILT. | 0.67 0.04 | 1.85 0.07 | 57 3.5 | 22 1.5 | 0.07 0.02 | 1.76 3.96 | 0.076 0.075 | | 1.92 5.8 | | 6.35 6.80 | | | | | 54 | | |
| | 11.00–12.30pm | | | | | | | | | | | | | | | | | – | | |
| | 12.30–2.30pm | RAW FILT. | 0.52 0.035 | 2.4 0.11 | 75 4.0 | 18 2.5 | | | | | 2.6 5.3 | | 5.90 6.44 | 80 138 | 48 22 | | | 175 | | |
| | 2.30–4.00pm | RAW FILT. | | | | | | | | | | | | | | | | – | | |
| | 4.00–6.30pm | RAW FILT. | 0.58 0.04 | 1.60 0.11 | 66 3.8 | 43 2.6 | 0.15 0.012 | 2.18 2.70 | 0.062 0.04 | 0.30 0.05 | 2.9 5.0 | 5.9 5.7 | 5.71 6.40 | | | 56 90.3 | 80 103 | 263 | 8 1 | 0.107 |
| 21/09/93 | 6.00–9.00am | RAW FILT. | 0.64 0.01 | 1.95 0.03 | 58 1.5 | 17 0.6 | | | | 0.06 0.0 | 2.2 6.3 | | 5.88 6.50 | 84 144 | 25 10 | 76 86.5 | 62 115 | 32 | | |
| | 9.00–11.00am | | | | | | | | | | | | | | | | | – | | |
| | 11.00–12.30pm | RAW FILT. | 0.76 0.03 | 1.50 0.11 | 82 2.3 | 37 1.3 | 0.036 0.013 | 3.42 3.88 | 0.088 0.052 | 0.0 0.0 | 3.4 5.5 | | 5.81 6.50 | | | 65 103 | 59 83 | 150 | | |
| | 12.30–2.30pm | RAW FILT. | 0.39 0.02 | 2.30 0.08 | 48 2.0 | 19 1.4 | | | | | 3.0 5.2 | | 6.14 6.74 | | | 70 125 | 57 92 | 20 | | |
| | 2.30–4.00pm | | | | | | | | | | | | | | | | | – | | |
| | 4.00–6.30pm | RAW FILT. | 0.45 0.06 | 1.90 0.14 | 86 3.0 | 45 2.5 | 0.05 0.00 | 2.4 3.2 | 0.045 0.163 | 0.18 0.02 | 3.3 4.8 | 6.3 4.5 | 5.96 6.55 | 95 146 | 29.0 10.2 | 83 105 | 58 85 | 280 | 7 2 | 0.106 |

# APPENDIX A4 (Cont.)  LUGUSI PLANT (KA-69)

| Date | Time | Sample | Ferrous iron mg Fe²⁺/l | Total Iron mg Fe/l | Colour mg Pt/l | Turbidity N.T.U | Ammonia mg NH₄/l | Nitrate mg NO₃/l | Nitrite mg No₂/l | Manganese mg Mn/l | Dissolved Oxygen mg O₂/l | Perm. No. mg KmnO₄/l | pH Units | Conduct. µs/cm | Carbon Dioxide mg CO₂/l | Total Alkalinity mg CaCo₃/l | Total Hardness Mg CaCo₃/l | Prod. in hrs | Total Coliforms Per 100 ml | Flow Rate l/s |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 29/09/93 | 7.00-9.00am | RAW FILT | 0.77 0.02 | 1.35 0.09 | 74 1.0 | 24 0.8 | 0.085 0.025 | 3.6 4.2 | 0.14 0.07 | 0.15 0.04 | 2.3 6.5 | | 5.35 6.63 | | 42.8 13.5 | 57 80 | 73 122 | 45 | | |
| | 9.00-12.30pm | | | | | | | | | | | | | | | | | - | | |
| | 12.30-2.50pm | RAW FILT | 0.35 0.03 | 1.75 0.12 | 61 2.0 | 26 1.3 | 0.15 0.03 | 2.6 2.7 | 0.08 0.13 | 0.12 0.0 | 3.2 5.4 | | 6.17 6.22 | 80.9 125 | | | | 67 | | |
| | 2.30-4.00pm | RAW FILT | | | | | | | | | | | | | | | | - | | |
| | 4.00-6.30pm | RAW FILT | 0.44 0.012 | 1.45 0.13 | 55 2.7 | 38 2.3 | 0.12 0.04 | 1.72 2.6 | 0.09 0.15 | 0.26 0.08 | 3.4 4.4 | 3.79 4.1 | 5.63 6.02 | 78.3 135 | 83.7 16.2 | 50 77 | 88 133 | 245 | 13 2 | 0.11 |
| 04/10/93 | 7.00-9.00am | RAW FILT | 0.28 0.01 | 2.6 0.06 | 40 1.7 | 18 0.82 | | | | 0.0 0.0 | 2.0 5.9 | | 5.52 6.25 | | 28.8 9.7 | 75 98 | 64 93 | 58 | | |
| | 9.00-11.00am | | | | | | | | | | | | | | | | | - | | |
| | 11.00-12.30pm | RAW FILT | 0.65 0.03 | 1.49 0.09 | 75 3.0 | 33 1.6 | 0.17 0.05 | 2.0 2.11 | 0.19 0.16 | 0.31 0.07 | 2.2 5.3 | | 6.05 6.85 | 69 116 | | | | 148 | | |
| | 12.30-2.30pm | RAW FILT | 0.74 0.04 | 1.55 0.05 | 48 2.4 | 16 1.2 | | | | | 2.1 5.0 | | 5.90 6.58 | 82 140 | | | | 17 | | |
| | 2.30-4.00pm | RAW FILT | | | | | | | | | | | | | | | | - | | |
| | 4.00-6.30pm | RAW FILT | 0.80 0.06 | 1.24 0.14 | 68 3.4 | 36 2.0 | 0.14 0.06 | 1.5 1.64 | 0.25 0.21 | 0.29 0.09 | 2.7 4.7 | 5.3 3.5 | 5.45 6.92 | | 43.3 20.5 | 70 90 | 65 80 | 250 | 17 4 | 0.11 |
| 13/10/93 | 11.00-1.30pm | RAW FTTL. | 0.76 0.068 | 1.60 0.6 | 75 4.0 | 38 1.5 | | | | 0.34 0.10 | 3.5 5.1 | | 6.01 6.75 | 97 125 | 55 30 | 67 82 | 58 70 | 125 | | |
| | 4.00-6.30pm | RAW FTTL. | 0.86 0.08 | 1.30 0.1 | 70 4.5 | 34 1.8 | 0.17 0.05 | 2.6 2.75 | 0.13 0.10 | 0.20 0.05 | 3.0 4.85 | 3.8 4.6 | 5.81 6.8 | 84 116 | 39 20 | 78 93 | 60 83 | 193 | 21 0 | 0.11 |
| 19/10/93 | 11.30-2.00pm | RAW FTTL. | 0.64 0.07 | 1.65 0.10 | 80 5 | 45 1.0 | | | | 0.18 0.03 | 2.65 5.40 | | 5.6 6.71 | 81 108 | 60 37 | 99 131 | 75 90 | 145 | | |
| | 4.00-6.30pm | RAW FTTL. | 0.88 0.069 | 1.40 0.12 | 74 4.7 | 35 1.2 | 0.2 0.08 | 3.4 3.54 | 0.16 0.20 | 0.22 0.08 | 2.85 4.6 | 5.70 5.6 | 5.4 6.5 | 94 120 | 65 38 | 80 135 | 70 100 | 170 | 10 3 | 0.11 |
| 29/10/93 | 11.00-1.30pm | RAW FTTL. | 0.80 0.075 | 1.50 0.12 | 70 4.3 | 35 1.2 | | | | 0.30 0.09 | 3.3 5.2 | | 5.70 6.9 | 97 132 | 57 21 | 98 106 | 84 98 | 138 | | |
| | 4.00-6.30pm | RAW FTTL. | 0.9 0.84 | 1.10 0.14 | 85 4.8 | 38 1.8 | 0.13 0.03 | 2.3 2.4 | 0.21 0.11 | 0.33 0.11 | 2.9 4.4 | 3.8 5.10 | 5.5 6.6 | 88 120 | 45 29 | 42 122 | 87 109 | 236 | 16 5 | 0.10 |

**APPENDIX B**

# APPENDIX B    STANDARDS FOR CHEMICAL AND PHYSICAL QUALITY OF DRINKING WATER

| Nª | Water Classification and Substances | Unit | Acceptable | Standards of Water International (a) Allowable |
|----|-------------------------------------|------|------------|-----------------------------------------------|
| | Water causing toxic effects | | | |
| 1. | lead Pb | mg/l | n.m | 0.05 |
| 2. | Arsenic, As, | mg/l | n.m | 0.05 |
| 3. | Selenium, Sc | mg/l | n.m | 0.01 |
| 4. | Chromium (b.) Cr | mg/l | n.m | 0.05 |
| 5. | Cyanide, CN | mg/l | n.m | 0.20 |
| 6. | Cadnium Cd | mg/l | n.m | 0.01 |
| 7. | Barium Ba | mg/l | n.m | 1.00 |
| 8. | Mercury Hg | mg/l | n.m | n.m |
| 9. | Silver Ag | mg/l | n.m | n.m |
| | Water affecting human health | | | |
| 10. | Fluoride | mg/l | n.m | 1.5 |
| 11. | Nitrate | mg/l | n.m | 30.0 |
| | Water for general domestic use | | | |
| | Water being organo-septic | | | |
| 12. | Colour | mgPt/l | 5 | 50 |
| 13. | Turbidity | mgSiO$_2$/l | 5 | 25 |
| 14. | Taste | – | n.o | n.o |
| 15. | Odour | – | n.o | n.o |
| | Water of Salinity and hardness | | | |
| 16. | pH | – | 7.0-8.5 | 6.5-9.2 |
| 17. | Total filtrable residue | mg/l | 500 | 1500 |
| 18. | Total hardness | mgCaCo$_3$/l | n.m | n.m |
| 19. | Calcium Ca | mg/l | 75 | 200 |
| 20. | Magnesium Mg | mg/l | 50 | 150 |
| 21. | Magnesium-Sodium Sulphate | mg/l | 500 | 1000 |
| 22. | Sulphate SO$_4$ | mg/l | 200 | 400 |
| 23. | Chloride Cl | mg/l | 200 | 600 |
| | Water with non toxic metals | | | |
| 24. | Iron Fe | mg/l | 0.3 | 1.0 |
| 25. | Manganese Mn | mg/l | 0.1 | 0.5 |
| 26. | Copper Cu | mg/l | 1.0 | 1.5 |
| 27. | Zinc Zn | mg/l | 5.0 | 15.0 |
| | Water with organic pollution of natural origin | | | |
| 28. | BOD 5 | mgO$_2$/l | n.m | 6.0 |
| 29. | PV (Oxygen abs. KMnO$_4$) | mgO$_2$/l | n.m | 10 |
| 30. | Ammonium NH$_3$ | mg/l | n.m | 0.5 |
| 31. | Total Nitrogen, exclusive Nitrate | mg/l | n.m | 0.1 |

**STANDARDS FOR CHEMICAL AND PHYSICAL QUALITY OF DRINKING WATER**

| Nº | Water Classification and Substances | Unit | Acceptable | Standards of Water International (a) Allowable |
|----|-------------------------------------|------|------------|---------------------------------------|
| | <u>Water with organic pollution introduced artificially</u> | | | |
| 32. | Surfactants ABS | mg/l | 0.5 | 1.0 |
| 33. | Organic matter as carbon in chloroform extract | mg/l | 0.2 | 0.5 |
| 34. | Phenolic substances as phenol | mg/l | 0.001 | 0.002 |

**Notes:**

| | |
|---|---|
| n.m | = not mentioned |
| n.o | = Unobjectionable |
| (a) | = Intern. Standards for Drinking Water, WHO, Geneva, 1963 |
| (b) | = Proposed temporary standards for Rural Water supplies by RWSHSC, 1973 |
| * | = Tentative figures |

# APPENDIX C — THE COST OF THE THREE IRON-REMOVAL PLANT MODELS AND MATERIAL AVAILABILITY

| No. | ITEM DESCRIPTION | QUANTITY | | | RATE | COST | | | Availability |
|---|---|---|---|---|---|---|---|---|---|
| | | OPT 1 | OPT 2 | OPT 3 | | OPT 1 | OPT 2 | OPT 3 | |
| 1 | Concrete culvert 500mm dia. x 500mm | 2 | 4 | 1 | 1200 | 2400 | 800 | — | Local |
| 2 | Concrete culvert 1000mm dia x 500mm | — | — | 1 | 1600 | — | — | 1000 | Local |
| 3 | Concrete cover slab | — | 2 | 1 | 1200 | — | 2400 | 1200 | Local |
| 4 | Ordinary portland cement | 3 bags | 5 bags | 1½ bags | 420 | 1260 | 2100 | 630 | General |
| 5 | Building mud | ½ ton | 1 ton | ¼ ton | 400 | 200 | 400 | 100 | Local |
| 6 | Graded sand | 4 bags | 7 bags | 7 bags | 100 | 450 | 700 | 700 | " |
| 7 | Ballast (or gravel) ¾" | 1/8 ton | ¼ ton | 1/16 ton | 650 | 82 | 161 | 41 | " |
| 8 | Ballast (or gravel) ¾" | ¼ ton | ½ ton | ¼ ton | 650 | 163 | 325 | 163 | " |
| 9 | BRC or weldmesh 1m x 1m | 1 Pc | 1 Pc | 1 Pc | 500 | 500 | 500 | 279 | General |
| 10 | Plasticord (water seal) | 1 roll | 2 rolls | ½ roll | 500 | 500 | 1000 | 250 | Imported |
| 11 | Polyfilt (fibre reinforcement) | — | — | 1 | 500 | — | — | 500 | " |
| 12 | Glass yarn fibre | 2L | 2L | 1L | 125 | 250 | 250 | 125 | External |
| 13 | PVC pipe 100mm dia | 3m | — | — | 400 | 1200 | — | — | " |
| 14 | PVC tee 100mm dia | 1 Pc | — | — | 1000 | 1000 | — | — | " |
| 15 | PVC endcap 100mm dia | 1 Pc | — | — | 700 | 700 | — | — | " |
| 16 | GI pipe 25mm dia | 2m | 4m | 6m | 100 | 200 | 400 | — | " |
| 17 | Gate valve 25mm dia | 1 Pc | 1 Pc | 1 Pc | 300 | 300 | 300 | 300 | " |
| 18 | GI elbow 25mm dia | 2 Pc | 2 Pc | 2 Pc | 100 | 200 | 200 | 200 | " |
| 19 | PVC reducer 100mm x 50mm | 1 Pc | — | — | 350 | 350 | — | — | " |
| 20 | GI pipe 50mm dia | 1m | 3m | 3m | 170 | 170 | 210 | 210 | " |
| 21 | GI pipe 50mm dia | 1 Pc | 1 Pc | 2 Pc | 450 | 450 | 450 | 900 | " |
| 22 | PVC adaptor 50mm dia | 1 Pc | — | — | 200 | 200 | — | — | " |
| 23 | GI nipple 50mm dia | 1 Pc | — | 1 Pc | 100 | 100 | — | 100 | " |
| 24 | GI reducer 50mm x 25mm dia | — | 1 Pc | 1 Pc | 100 | — | 170 | 150 | " |
| 25 | GI elbow 50mm dia | 2 Pc | 2 Pc | 2 Pc | 150 | 300 | 300 | 300 | " |
| 26 | GI plug 50mm dia | — | — | 1 Pc | 75 | — | — | 75 | " |

# APPENDIX C  THE COST OF THE THREE IRON-REMOVAL PLANT MODELS AND MATERIAL AVAILABILITY

| No. | ITEM DESCRIPTION | QUANTITY | | | RATE | COST | | | REMARKS |
|-----|------------------|----------|-------|-------|------|------|------|------|---------|
| | | OPT 1 | OPT 2 | OPT 3 | | OPT 1 | OPT 2 | OPT 3 | |
| 1 | Concrete culvert 800mm dia. x 500mm | 2 | 8 | 1 | 1200 | 2400 | 600 | – | Local |
| 2 | Concrete culvert 1000mm dia x 500mm | – | – | 1 | 1600 | – | – | 1600 | Local |
| 3 | Concrete cover slab | – | 2 | 1 | 1200 | – | 2400 | 1200 | Local |
| 4 | Ordinary portland cement | 3 bags | 6 bags | 1½ bags | 420 | 1260 | 2100 | 630 | External |
| 5 | Building sand | ½ ton | 1 ton | ¼ ton | 400 | 200 | 400 | 100 | Local |
| 6 | Graded sand | 4 bags | 7 bags | 2 bags | 100 | 400 | 700 | 200 | " |
| 7 | Ballast (or gravel) 3/4" | 1/8 ton | ¼ ton | 1/16 ton | 650 | 82 | 160 | 41 | " |
| 8 | Ballast (or gravel) ½" | ¼ ton | ½ ton | ¼ ton | 650 | 163 | 325 | 163 | " |
| 9 | BRC or weldmesh 1m x 1m | 1 Pc | 1 Pc | 1 Pc | 500 | 500 | 500 | 250 | External |
| 10 | Flexoband (water seal) | 1 roll | 2 rolls | ½ roll | 500 | 500 | 1000 | 250 | Imported |
| 11 | Polyfelt (filter membrane) | – | – | 1 | 500 | – | – | 500 | " |
| 12 | Gloss paint blue | 2L | 2L | 1L | 125 | 250 | 250 | 125 | External |
| 13 | PVC pipe 100mm dia | 3m | – | – | 400 | 1200 | – | – | " |
| 14 | PVC tee 100mm dia | 1 Pc | – | – | 1000 | 1000 | – | – | " |
| 15 | PVC endcap 100mm dia | 1 Pc | – | – | 700 | 700 | – | – | " |
| 16 | GS pipe 25mm dia | 2m | 4m | ½m | 100 | 200 | 400 | – | " |
| 17 | Gate valve 25mm dia | 1 Pc | 1 Pc | 1 Pc | 300 | 300 | 300 | 300 | " |
| 18 | GS elbow 25mm dia | 2 Pc | 2 Pc | 2 Pc | 100 | 200 | 200 | 200 | " |
| 19 | PVC reducer 100mm x 50mm | 1 Pc | – | – | 350 | 350 | – | – | " |
| 20 | GS pipe 50mm dia | 1m | 3m | 3m | 170 | 170 | 510 | 510 | " |
| 21 | GI pipe 50mm dia | 1 Pc | 1 Pc | 2 Pc | 450 | 450 | 450 | 900 | " |
| 22 | PVC adaptor 50mm dia | 1 Pc | – | – | 200 | 200 | – | – | " |
| 23 | GS nipple 50mm dia | 1 Pc | – | 1 Pc | 100 | 100 | – | 100 | " |
| 24 | GS reducer 50mm x 25mm dia | – | 1 Pc | 1 Pc | 100 | – | 150 | 150 | " |
| 25 | GS elbow 50mm dia | 2 Pc | 2 Pc | 2 Pc | 150 | 300 | 300 | 300 | " |
| 26 | GS plug 50mm dia | – | – | 1 Pc | 75 | – | – | 75 | " |

**THE COST OF THE THREE IRON–REMOVAL PLANT MODELS AND MATERIAL AVAILABILITY**

| NO | ITEM DESCRIPTION | QUANTITY | | | RATE | COST | | | REMARKS |
|---|---|---|---|---|---|---|---|---|---|
| | | OPT 1 | OPT 2 | OPT 3 | | OPT 1 | OPT 2 | OPT 3 | |
| 27 | GS tee 50mm dia | – | – | 2 Pc | 100 | – | – | 150 | External |
| 28 | GS tee 25mm dia | 1 Pc | – | – | 75 | 75 | – | – | • |
| 29 | GS cross 25mm dia | – | 1 | – | 150 | – | 150 | – | • |
| | TOTAL MATERIAL COST | | | | | 11,000 | 19,898 | 7,644 | |
| | LABOUR AND ADMINISTRATION | | | | | 4,500 | 8,000 | 3,000 | |
| | TOTAL PROJECT COST | | | | | 15,000 | 26,898 | 10,644 | |
| | SAY | | | | | 16,000 | 27,000 | 11,000 | |

**NB:**

1) Options:   Option 1:   One tank type (e.g. C–5467, Shivanga)
                      Option 2:   Two tank type (e.g. KA 69, Lugusi)
                      Option 3:   Single culvert type (e.g.BS–9, Siginga and BS–12, Khayinga)

2)   **Local** – Means item can be obtained (or made) at site or at least within Programme area.
     **External** – Means item obtainable outside Programme area but made in Kenya.
     **Imported** – Means item manufactured outside the country.

# APPENDIX C THE COST OF THE THREE IRON-REMOVAL PLANT MODELS AND MATERIAL AVAILABILITY

| No. | ITEM DESCRIPTION | QUANTITY | | | RATE | COST | | | REMARKS |
|---|---|---|---|---|---|---|---|---|---|
| | | OPT 1 | OPT 2 | OPT 3 | | OPT 1 | OPT 2 | OPT 3 | |
| 1 | Concrete culvert 800mm dia. x 500mm | 2 | 8 | 1 | 1200 | 2400 | 600 | – | Local |
| 2 | Concrete culvert 1000mm dia x 500mm | – | – | 1 | 1600 | – | – | 1600 | Local |
| 3 | Concrete cover slab | – | 2 | 1 | 1200 | – | 2400 | 1200 | Local |
| 4 | Ordinary portland cement | 3 bags | 6 bags | 1½ bags | 420 | 1260 | 2100 | 630 | External |
| 5 | Building sand | ½ ton | 1 ton | ¼ ton | 400 | 200 | 400 | 100 | Local |
| 6 | Graded sand | 4 bags | 7 bags | 2 bags | 100 | 400 | 700 | 200 | * |
| 7 | Ballast (or gravel) 3/4" | 1/8 ton | ¼ ton | 1/16 ton | 650 | 82 | 160 | 41 | * |
| 8 | Ballast (or gravel) ½" | ¼ ton | ½ ton | ¼ ton | 650 | 163 | 325 | 163 | * |
| 9 | BRC or weldmesh 1m x 1m | 1 Pc | 1 Pc | 1 Pc | 500 | 500 | 500 | 250 | External |
| 10 | Flexoband (water seal) | 1 roll | 2 rolls | ½ roll | 500 | 500 | 1000 | 250 | Imported |
| 11 | Polyfelt (filter membrane) | – | – | 1 | 500 | – | – | 500 | * |
| 12 | Gloss paint blue | 2L | 2L | 1L | 125 | 250 | 250 | 125 | External |
| 13 | PVC pipe 100mm dia | 3m | – | – | 400 | 1200 | – | – | * |
| 14 | PVC tee 100mm dia | 1 Pc | – | – | 1000 | 1000 | – | – | * |
| 15 | PVC endcap 100mm dia | 1 Pc | – | – | 700 | 700 | – | – | * |
| 16 | GS pipe 25mm dia | 2m | 4m | ½m | 100 | 200 | 400 | – | * |
| 17 | Gate valve 25mm dia | 1 Pc | 1 Pc | 1 Pc | 300 | 300 | 300 | 300 | * |
| 18 | GS elbow 25mm dia | 2 Pc | 2 Pc | 2 Pc | 100 | 200 | 200 | 200 | * |
| 19 | PVC reducer 100mm x 50mm | 1 Pc | – | – | 350 | 350 | – | – | * |
| 20 | GS pipe 50mm dia | 1m | 3m | 3m | 170 | 170 | 510 | 510 | * |
| 21 | GI pipe 50mm dia | 1 Pc | 1 Pc | 2 Pc | 450 | 450 | 450 | 900 | * |
| 22 | PVC adaptor 50mm dia | 1 Pc | – | – | 200 | 200 | – | – | * |
| 23 | GS nipple 50mm dia | 1 Pc | – | 1 Pc | 100 | 100 | – | 100 | * |
| 24 | GS reducer 50mm x 25mm dia | – | 1 Pc | 1 Pc | 100 | – | 150 | 150 | * |
| 25 | GS elbow 50mm dia | 2 Pc | 2 Pc | 2 Pc | 150 | 300 | 300 | 300 | * |
| 26 | GS plug 50mm dia | – | – | 1 Pc | 75 | – | – | 75 | * |

**THE COST OF THE THREE IRON-REMOVAL PLANT MODELS AND MATERIAL AVAILABILITY**

| NO | ITEM DESCRIPTION | QUANTITY | | | RATE | COST | | | REMARKS |
|----|------------------|----------|----------|----------|------|----------|----------|----------|---------|
| | | OPT 1 | OPT 2 | OPT 3 | | OPT 1 | OPT 2 | OPT 3 | |
| 27 | GS tee 50mm dia | – | – | 2 Pc | 100 | – | – | 150 | External |
| 28 | GS tee 25mm dia | 1 Pc | – | – | 75 | 75 | – | – | • |
| 29 | GS cross 25mm dia | – | 1 | – | 150 | – | 150 | – | • |
| | TOTAL MATERIAL COST | | | | | 11,000 | 19,898 | 7,644 | |
| | LABOUR AND ADMINISTRATION | | | | | 4,500 | 8,000 | 3,000 | |
| | TOTAL PROJECT COST | | | | | 15,000 | 26,898 | 10,644 | |
| | SAY | | | | | 16,000 | 27,000 | 11,000 | |

NB:

1) Options:    Option 1:    One tank type (e.g. C-5467, Shivanga)
             Option 2:    Two tank type (e.g. KA 69, Lugusi)
             Option 3:    Single culvert type (e.g. BS-9, Siginga and BS-12, Khayinga)

2)    Local – Means item can be obtained (or made) at site or at least within Programme area.
     External – Means item obtainable outside Programme area but made in Kenya.
     Imported – Means item manufactured outside the country.

PLATES

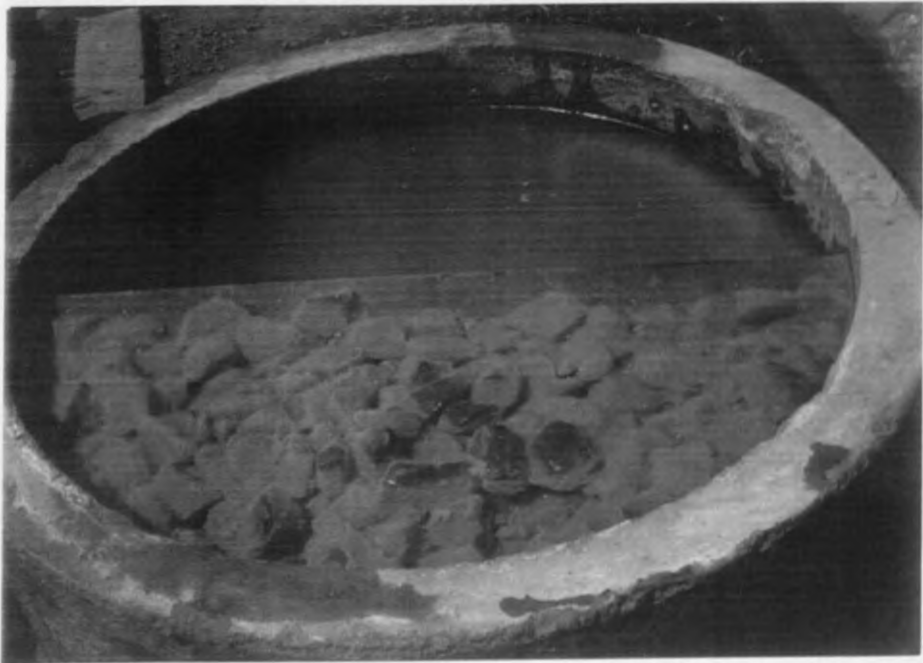**PLATE 1    Khayinga Plant immediately after backwashing**



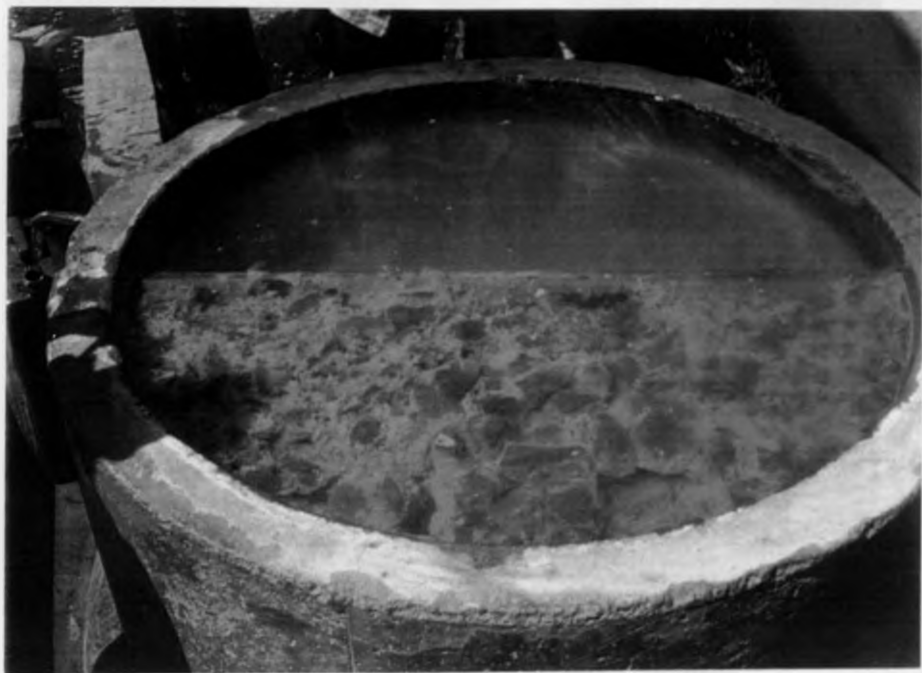**PLATE 2    Khayinga Plant one day after backwashing**
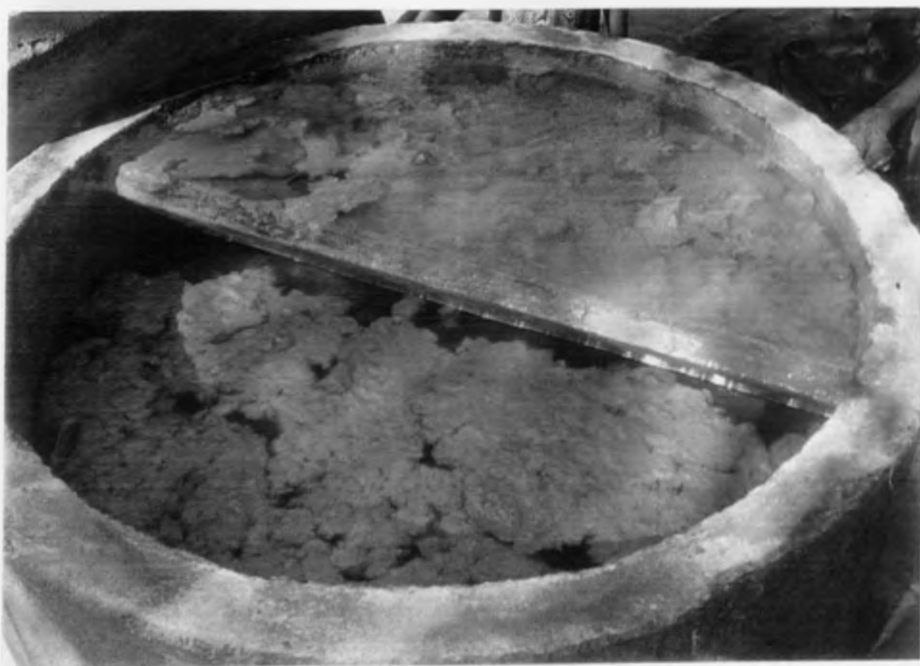
**PLATE 3    Khayinga Plant second day after backwashing**



**PLATE 4    Khayinga Plant after clogging up**

**PLATE 5    Siginga Plant two days after backwashing**



**PLATE 6    Khayinga Plant in operation**

PLATE 7 Siginga Plant in operation



PLATE 8 Siginga Plant after clogging up

**PLATE 9**      **Lugusi Plant in operation**



**PLATE 10**    **Shivanga Plant in operation**

PLATE 11  Lutaso iron removal plant (C–5480)



PLATE 12  Handiti iron removal plant (C–5462)