Effectiveness Of Slow Sand Filtration For Improvement Of Surface Reservoir Waters For Rural Water Supply

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EFFFECTIVENESS OF SLOW SAND FILTRATION FOR IMPROVEMENT OF SURFACE RESERVOIR WATERS FOR RURAL WATER SUPPLY

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CERTIFICATION

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DEDICATION

This report is dedicated to my darling wife Sarah and my two beautiful daughters Yaa Asantewaa and Abena Badu Dwomoh

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ABSTRACT

In parts of the rural areas of northern Ghana where groundwater is generally inaccessible for exploitation, resort is made to streams, ponds, and constructed surface water reservoirs for drinking water. These sources of water are unprotected and highly susceptible to faecal and agro-chemical contamination. The exposed nature of such waters also creates ample breeding grounds for parasitic disease agents. The potential health risks of such sources are therefore quite substantial.

Since a large percentage (about 30%) of common diseases is attributable to ingestion of unsafe water, there is a need to improve drinking water quality especially for community water supplies.

The low technology and income status of most rural areas dictate that any intervention must be low-cost and simplified (appropriate technology).

Bearing the above considerations in mind it is imperative that research into simplified treatment possibilities be intensified to provide information for the design, construction and operation of full-scale plants.

This particular research activity involved the design, construction and operation of a pilot slow sand filter plant to generate data about the actual performance of a simplified slow sand filtration system within the typical rural setting of the selected study area. Samples were taken from the effluents of the different filter components and analysed for concentrations of some selected water quality parameters. The percentage reductions in the concentrations of the selected parameters, due to the actions of the various filter units, were then determined and the effectiveness of the unit operations analysed for the different parameters.

The progressive improvement in the quality of the final water was monitored during the period of the filter run to determine the ripening period of the slow sand filter.

The final water quality parameters were compared to the stated WHO guideline values for drinking water to determine the acceptability of the final product.

A series arrangement was adopted for the roughing filters to enable an estimation of a suitable filter length.

Protective measures were incorporated in the design to safeguard the quality of the final water against contamination during the fetching process.

Interactions with the members of the user community yielded some interesting information about certain conditions that would compel them to abandon the whole facility.

Based on the field experiences and analysis of laboratory tests, recommendations have been proposed for better design and operation of future village-scale plants. Serious attention has also been drawn to the importance of training for sustainable use of the filter system.

The conclusion drawn from the analysis of the results of this research is that slow sand filtration is a feasible and appropriate water treatment technology for village-level surface reservoir water improvement in the Northern Region of Ghana.

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LIST OF ABBREVIATIONS

GWSC: Ghana Water and Sewerage Corporation

CWSA Community Water and Sanitation Agency

VWR: Village Water Reservoir Project

UDS: University for Development Studies

VRF: Vertical Roughing Filter

SSF: Slow Sand Filter

IHE: International Institute for Infrastructural Hydraulic & Environmental Engineering

WHO: World Health Organisation

TADO: Tamale Archdiocese Development Office

VRF: Vertical roughing filter

N/R: Northern Region

1.0 INTRODUCTION

1.1 Background to the study

Rural water supply systems in Northern Ghana normally produce water in the natural or raw state, meaning the water that reaches the consumer does not undergo any form of organised treatment before consumption. The consumption of raw water however, is advisable only when the source is a ground water source. Such waters have been naturally purified during their transport through the various aquifer systems. However, for supply systems dependent on impoundment of surface flows there is virtually no quality improvement prior to the impoundment. Since the users normally fetch the raw water either directly from the reservoir or from wells linked to the reservoir by pipes, the full impact of whatever constituent pollutants are present are transferred directly to the consumer.

The potential health risks of consuming such raw waters cannot be over-emphasised since the catchment areas of the reservoirs contain cultivated agricultural lands, grazing fields for livestock, some arable lands and human settlements. It is storm runoff through these areas that is intercepted and stored in the reservoirs for later use.

The exposed nature of these raw waters also creates an environment for the easy breeding of the guinea worm cyclops, especially when infected persons wade into the water during fetching. This situation has resulted in the prevalence of the guineaworm disease in certain parts of the Northern Region where ponds and open surface reservoirs are the main sources of domestic water. The combination of these described factors tend to portray the utilisation of these untreated raw waters for human consumption as hazardous to health and an eventual setback to the original objectives which prompted provision of the infrastructure.

The history of the rural water supply effort in the Northern Region[1], reveals that the complete absence of water of any type, for most of the dry season, within the central portion of the region, was the major problem that confronted most of the inhabitants of the area. The main efforts of the major NGO active in these dam constructions (Village Water Reservoirs Project) were thus primarily concentrated on ensuring sufficient quantities of raw water. Some attempts were made to treat the raw water, prior to fetching, through the use of infiltration galleries and roughing filters. The water quality improvements however were not satisfactory[2]. The local people also found it difficult to operate the filters. The provision of treatment units within the supply schemes was thus dropped from the designs that were built. Due to the extremely high costs of constructing such surface water reservoirs and the pressure to meet numerous communities' demands for greater quantities of raw water, research into more appropriate treatment technologies were suspended. In fact quantity and convenience have dominated the design efforts of small-scale dam constructions in the northern region.
With the recent increased availability of reservoir waters (30 schemes now in place) , there is now the need to put improvement of water quality on the agenda and harness the available appropriate technologies for the purposes of developing affordable and sustainable local water supply schemes that produce water safe for human consumption.
In recent times, a number of researches have been undertaken on simplified water treatment technologies applicable in Ghana (eg. Damongo and Salaga pilot plant trials).The intention, I believe, has been to assess the suitability of the tested technologies for application to local circumstances. Most of these activities however have been directed at small to large town water supplies (populations from 5000 and above). The main reason being that the main promoter of these researches has been the Ghana Water and Sewerage Corporation, which has traditionally, concentrated on urban and town water supply. The recommendations arising out of these researches are thus structured to suit towns with characteristics similar to the research sites.

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[1] Jan Ubels, Frits van den Steen van Ommeren, Rural Water Supply in the Archdiocese of Tamale: evaluation and project proposals, 1985, SAWA, Utrecht, the Netherlands.

Wegelin and Dorcoo provide such a set of typical recommendations on the potential of slow sand filtration in the northern region of Ghana[3]. Unfortunately the vast majority of communities in rural Ghana have demographic, spatial and infrastructural characteristics far removed from the situations in towns. Their socio-economic environment also militates against the normally recommended operation and maintenance procedures involved in daily operation and control of systems designed on the basis of such research results. The blanket application of the recommendations of researches based on communities of such different characteristics may therefore not yield the desired benefits.

The design of water treatment systems to be operated in small villages should be based rather on information obtained from research activities undertaken in communities with characteristics similar to the target communities. The conclusions that could be drawn from such researches would then be more relevant to the problem areas.

In arguing for the choice of a suitable treatment technology to be employed in less developed countries, Wagner and Lanoix [4] in 1981 suggested that water supply control agencies should oppose the use of treatment processes which communities can ill-afford to procure, operate and maintain with their meagre financial resources. This presupposes encouragement of the use of technology which has been researched, and found adequate, economical, socially acceptable, and hopefully, environmentally compatible (ie. appropriate technology). To enable such technological choices to be made a body of knowledge would have to be available to serve as the reference material to guide such decisions. Hence the need for research into the various identified possible treatment options within the suitable local context.

This report presents the findings of a pilot plant test to determine the possibility of introducing slow sand filters into the existing numerous village

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[2] Akari et al, VWR Project Monitoring and Evaluation Baseline Mission, 1995 pp 23-25.

[3] Martin Wegelin & Kolly Dorcoo, Potential of slow sand filters in the northern region of Ghana, Field report on evaluation mission,1992

[4] Droste R.L. and McJunkin E. "Simplified Water Treatment Methods",pp.102, Water Supply and Sanitation in Developing Countries, Ann Arbor Science Publishers, 1982

surface water supply schemes scattered throughout northern Ghana. It incorporates results from other researches within the region for small town water supplies and an earlier filter trial at the same site but with a modified design. This research particularly focuses on slow sand filtration plants for small village (populations of 200-1000) schemes, dependant on gravity flow from a reservoir to a central fetching point.

1.2 The Research Problem

One of the most important sectoral activities for development has been the provision of safe drinking water supplies to the urban and rural communities. Water supply is a fundamental building block in the development process directly influencing health, economic development, employment and the position of women in the society. Progress in this sector in conjunction with improved sanitation, has been most instrumental for reducing infant mortality and morbidity, and for overall improvement in health[5].
The continued use of raw water polluted with faecal and other domestic waste matter from human and animal activities remains a big problem in most of the rural areas of the Northern Region of Ghana where surface water, stored in built reservoirs, are the main sources of water. The absence of any technical facilities for treatment purposes within the designed water schemes prohibits the on-site improvements of the raw water prior to fetching. In order to rectify this situation it will be necessary to identify an appropriate treatment that may be included in these supply schemes to purify the water prior to consumption. Biological treatment of the water is desirable but the raw water in the reservoirs is characterised by seasonal high turbidity and fluctuation in the water quality. Pretreatment, mainly to reduce the suspended particle load, is required prior to application of slow sand filtration. Roughing filtration is an emerging pretreatment technology, which has been researched in several developing countries and field-tested to develop practical guidelines[6].

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[5] Process Analysis and Optimisation of Direct Horizontal-Flow Roughing Filtration, doctoral dissertation, IHE-Delft, 1995, pp1. A.A.Balkema, Rotterdam.
[6] Martin Wegelin, Surface Water Treatment by Roughing Filters, A design construction and operation manual, 1996, pp VII-3 &VII-4.

In Ghana research has been undertaken in slow sand filtration preceded by roughing filters for small town water supply. The results may be considered directly for small to medium sized town water supply. The sustainable application of this technology to small village water supply, especially in northern Ghana, is yet to be established.
Against this background the main hypotheses of this study are:

- slow sand filtration preceded by roughing filtration is a feasible treatment technology for improving raw water quality in surface reservoirs in northern Ghana,
- small scale plants can be designed, built and operated within the typical village settings and,
- the final treated water will pass the quality standards test, and will be acceptable to normal consumers within the villages.

1.3 Objectives Of Study

The primary objective of this study was to assess the performance of a simplified filtration plant comprising roughing and slow sand filtration units, for the purpose of improving raw water quality from rural surface water reservoirs located throughout northern Ghana.
The secondary objective was to assess the acceptability of this treatment scheme to the potential user communities in terms of their willingness to operate, manage, maintain and benefit from the technology.

1.4 Significance of the Study

In parts of the rural areas of northern Ghana where groundwater is generally inaccessible for exploitation, resort is made to natural streams and ponds, and man-made surface water reservoirs for drinking water. These sources of water are unprotected and highly susceptible to faecal and agro-chemical contamination. The exposed nature of such waters also creates ample breeding grounds for parasitic disease agents. Unfortunately even in the circumstances where man constructs the water sources there are no technical provisions for improving the raw water quality prior to fetching by the users. The potential health risks of such sources are therefore quite substantial.

Since a large percentage (about 30%) of common diseases is attributable to ingestion of unsafe water, there is a need to attempt the improvement of drinking water quality especially for community water supplies.

The low technology and income status of most rural areas dictate that any intervention must be low-cost and simplified (appropriate technology).

Bearing the above-listed considerations in mind it is imperative that research into simplified treatment possibilities be intensified to provide information for the design, construction and operation of full-scale plants. It is thus the intention of this author to contribute meaningfully to the body of knowledge on simplified water treatment in such a way that, improvement of surface impoundment waters within, especially, the rural north of Ghana becomes a reality.

1.5 Scope of the Study

Geographical location and extent:

The general study area is defined as the Northern Region of Ghana.

An appropriate test site within the Tolon-Kumbungu was selected for the project in the village of Gizaa-Gundaa. This district has been chosen because of the proliferation of small-scale dams and dugouts for domestic water needs. A total of thirty was counted in May 1999. Data from some of these 30 dams/dugouts were used to provide background information on the raw water quality characteristics within the study area.

Pilot plant

The emphasis of this research was on the technical feasibility of a simplified treatment plant design for improving water of the quality encountered within the study area at the end of the dry season. Due to time constraints, the requirements for changing raw water qualities and periodic maintenance were not researched.

Sampling and testing

Samples were taken and tested, from selected points of the plant at selected time intervals. No attempt was made to determine the quality of water actually consumed at household level. The improvements in quality over the various units were evaluated and the values obtained compared to prescribed guidelines.

The analysis of results were restricted to factors which directly affected colour, taste and health considerations since these are directly observable by consumers and will greatly influence their appreciation and acceptance of the filter plant.

Community involvement

The only issues addressed here concerned the acceptance of the technology by users of the water and appreciation of improved water quality for improved health.

1.6 Background Information On Northern Region Of Ghana

1.6.1 Geographical Setting

The Northern region of Ghana lies approximately between latitudes 8 and 10 degrees.

It has the Upper East and Upper West regions as its northern boundaries whilst the south is bounded by the Brong-Ahafo and Volta regions. It shares international borders with Cote d'Ivoire and Togo in the west and East respectively. The total surface area is 70,390 km2, which is about 30% of the total land area of Ghana. The regional capital is the Tamale municipality and there are 13 other district capitals. The region is currently estimated to have a population 2,168,730.

The central portion of the region depicts a plateau-like landscape slightly dissected by valleys with intermittent streams. This area has a radius of about 50 km and extends from Tamale southwards towards Kpandai in the east and New Buipe in the west. This area is an inverted-U shape and is referred to as the "Horse-shoe" area. Impermeable sedimentary rocks with very low groundwater potential that has rendered groundwater abstraction and usage unfeasible in most areas underlie it. On the higher grounds the soils are imperfectly drained whereas in the lowlands there is flooding during the rains.

The 3 administrative districts which are principally covered by the "Horse-shoe area are the Tolon-Kunbungu, Savelugu-Nanton and East Gonja districts.

From the 1984 census report it is estimated that population dwelling in this area is about 405,000.

1.6.2 Physical characteristics

The main physical characteristics of the study area that have a direct influence on the storm runoff which is intercepted and stored for use are the topography, geology and soils and climate.

- The topography is generally flat to moderately rolling. The valleys are wide without deep riverbeds. There are large floodplains, which are waterlogged during the rainy season.
- Geology and soils

  The Voltaian Sedimentary Basin underlies the entire area; The bedrock of the Voltaian Basin consists of sandstone, mudstones, siltstones and shales, found in various alternating layers. In the Voltaian sediments, the groundwater is mainly found in the joints, fractures and weak zones of the rock. Shallow groundwater is not available in most of the area. Either the bedrock is impermeable (shales) and does not have sand layers on top (except in the larger rivers) or the water disappears through the well-jointed and rather permeable sandstones.

  Throughout the horse-shoe area, lateritic soils are extensively found, covering the imperfectly drained flat areas. They are extremely wet in the rainy season and very dry in the dry season. A thin sandy layer covers clayey and silty impermeable subsoil with a high content of laterite iron concretions. Over large areas an ironpan has been developed which is frequently exposed at the surface. These marginal soils are poor in nutrients and are generally unsuitable for cultivation. Many of the other types of soil in the region contain also laterite concretionary layers in their profile and have exposures of ironpan in eroded areas (summits).

Climate

One dry season from October to April/May and a wet season, starting in May/June and ending in October characterize the tropical climate. Real dry months are December, January and February. In the dry season, air masses come from a northeasterly direction over the Sahara. This dry and hot wind is called the Harmattan. Mean daily temperatures are high, about 32°C, reaching a peak in April. In January the nights can by very cool. In the rainy season, the monsoon winds are prevailing, coming form a southwesterly direction. After having passed the Atlantic Ocean, they are cool and humid and the source of rainfall for agricultural production.

The main characteristics of the rainfall pattern in the district are its seasonal nature and its variability from place to place and year to year. In the transition from the dry to the wet season (March/April), the rains fall only in a few local showers. June and July have fairly similar rainfall amounts and then the amount increases to its maximum in September. At the end of the rainy season, the rainfall shows a sharp decrease.

The mean annual rainfall in the region varies from 1000 mm in the north to 1300 mm in the southeast. The rainfall totals vary widely from year to year.

Economic activities

The main economic activity in the villages of the Northern Region is agriculture and the production is in the first place aimed at the subsistence needs of the compound. Main crops are guinea-corn, millet, yams, groundnuts, maize and rice. Minor crops include beans, cassava and vegetables (okra).
About 80% of the people in the region depend on farming for their livelihood. The men grow the staple crops (grains), while the women grow the vegetables and ingredients for the sauce. The only tools used in subsistence agriculture are the hoe and the cutlass. Recently bullock-ploughing has been introduced at some places. Some fertilizer is used.

Usually the farmers rotate their fields as the soil is poor and easily exhausted. Marketing of surpluses is also important. Especially in the Bimbilla-Salaga area, commercial growing of yams for the markets in the south is important. The area is known as the best and most important yam-producing area of Ghana.

Sheanut, a tree-nut collected in the bush, is an important marketing product. The nuts are either sold raw or processed as butter for cooking.

1.6.3 WATER SUPPLY SITUATION

District Capitals Water Supply

The 13 district capitals and small towns are served by either PCI package plants (10 no.) or conventional plants(3no.) which depend on surface water sources. According to Wegelin and Dorcoo[7], in 1992 most of the package plants were not functioning well and the conventional plants were only partly in operation . Since then the Ghana Water and Sewerage Corporation has undertaken some rehabilitation and expansion on some of these systems and improved the supply situation in 4 towns. The GWSC regional distribution Engineer reports an average service coverage of 15.% of the design population. The percentage of the region's population which have access to the urban\town water supply however is only 2.7%.

Recommendations have been made for the eventual construction of full-scale slow sand filtration plants in Salaga, Damongo and Zabzugu townships. The Zabzugu SSF treatment plant is currently under construction.

It has been planned that all 13 water supply systems will eventually be passed on for community ownership and management.

Community Water Supply (Village Level)

The sources of water for human consumption in the rural areas vary according to the prevailing climatic season. All the numerous rural communities in the region depend on one or a combination of several sources. During the rainy season water is obtained from direct interception of rainfall, shallow local wells, deep hand-dug wells, boreholes, streams, ponds and dugout reservoirs. Most of these sources however normally dry up within 2 to 3 months after the last rains. At the peak of the dry season the rural inhabitants have to contend with stored water in the deeper hand-dug wells and boreholes and the larger dugouts. Unfortunately only a small percentage of the population have access

[7] Potential of slow sand filters in the northern region of Ghana, Martin Wegelin & Kolly Dorcoo, Field report on evaluation mission,1992, pp 1.

to these water sources. It is estimated that a maximum of 25% of the total population relies mainly on the groundwater systems whiles the remaining 75% have to resort to the surface water sources.

Apart from the borehole systems (1306 systems serving 11.8% of the population), the other sources are generally unprotected, both from the design point of view and the daily usage of the facilities. The principal causes of this current predicament being the former NGO and user-community preoccupation with providing large quantities of water to the neglect of water quality. Improved collaboration and networking amongst the various sector participants, and introduction of a national policy have contributed significantly to an improvement in the general approach to rural water provision. Source protection for groundwater supplies is thus gradually being improved at the construction stage through better design of the wellheads and fetching facilities. These measures unfortunately cannot be applied to surface waters. Definite treatment steps however have to be introduced between the surface raw water sources and the fetching points if improvement in water quality is desired.

1.6.4 Drinking Water Quality Characteristics

Monitoring of drinking water quality by the Village Water Reservoirs Project[8], and University for Development Studies[9], indicate that untreated water of unacceptable quality is being consumed in the rural communities, which rely on impounded water in the northern region. Appendix B depicts the trends in several water quality parameters measured at different times of the year. All the indications are that the untreated waters generally used for domestic purposes are unsafe for human consumption.

Local Water Treatment Methods

In most of the village communities within the Northern Region which utilise surface water for drinking purposes, treatment is limited to straining through calico cloth to screen out guineaworm cyclops. Boiling prior to the screening is normally not considered because of the scarcity of fuelwood.

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[8] VWR Project quarterly reports 1994,1995.

[9] UDS/GWSC Laboratory test results on 3 selected reservoirs

2.0 RESEARCH APPROACH AND METHODOLOGY

2.1 Literature review/Desk study

The methodology adopted for the study involved a critical review of literature related to the development of simplified water treatment technologies in the developing world. Reports on research conducted within the Northern region involving slow sand filtration were also studied. Reference was also made to design manuals for roughing filtration and slow sand filtration to provide guidance on setting up the pilot plant. International conference proceedings, national policy documents and programme planning documents were referred to in developing the framework for justifying the need for such a research topic. Internal project implementation reports of some development agencies (eg. Village Water Reservoirs Project) involved in the provision of the raw water sources also yielded some vital information on history of the water sources and characterisation of the water quality. Consultations were also held with officials of governmental agencies responsible for different aspects of water supply, quality assurance and public health.

2.2 Pilot Plant Trials

The field component of the study involved the construction and operation of a pilot plant to observe the actual behaviour of the designed system within the peculiar environment of the study area.

A series of laboratory tests were conducted on samples according to standard testing procedures to generate data for meaningful analysis of the system's performance.

2.3 Community Interviews

The community's perceptions about the introduction, operation and future maintenance of the filter system were sampled from a cross-section of the population.

2.4 Limitations to The Study

The main limitation was the short time allowed for implementing the project.
The issue of limited funds for undertaking research work also constrained the extent of laboratory analysis.
The design of the pilot plant was greatly restricted by the nature of the existing structure, which was modified and used.
The travel distance to pilot plant site (25km) limited the frequency of monitoring visits.

2.5 Analysis of Results

The combination of results from the literature review, community discussions and the pilot plant runs, forms the bulk of data for analysis, interpretation and recommendations.

2.6 Organisation of the report

In chapter 1 the objectives of the study are outlined and the scope of the research clearly stated.
Chapter 2 presents the methodology adopted for the various aspects of the study.
Chapter 3 is basically a review of the available literature on water quality and standards, simplified water treatment, background information on general study area, existing water supply situation and previous research findings in this area.
Chapter 4 provides detailed information on the actual test plant, and describes the sampling and testing procedure.
Chapter 5 presents an analysis of the test results
Chapter 6 is devoted to the social considerations involved in introducing and operating such a treatment into the community water supply scheme.
Chapter 7 presents the cost calculations for the construction of the infrastructure.
In chapter8 recommendations are made for design, operation and maintenance of such systems for better results, and highlights points for future research.
Finally chapter 9 then presents the conclusions of the study.

The report is concluded with a series of appendices presenting details of test results, sample of questionnaire, and graphical presentations of data trends observed during the research.

3.0 LITERATURE REVIEW

3.1 Framework of the literature review

The literature review seeks to highlight the justifications and scientific basis for application of slow sand filtration technology in developing countries. It presents information on nature of raw surface water sources, assessment of water quality parameters, purification of water, simplified water treatment technology, filtration theory and practice, and the history of slow sand filters in the northern region. The analysis of the pilot plant results and subsequent recommendations rely heavily on the bulk of information presented in this literature review.

3.2 Water quality improvement

3.2 1 The need for improvement of raw water

Water consumed by human beings must be safe and not cause the incidence of any disease. Water that contains pathogens is not fit for human consumption. Unfortunately due to lack of alternative sources, large volumes of such unsafe water is copiously consumed, especially during the dry season in many parts of the developing world. The persistent prevalence of certain water-related diseases in most of the villages that depend on open sources is an indictment on the untreated water sources and should draw attention to the plight of those whose only choice is such sources. The importance of water related interventions for infectious disease control is presented in following table.

Table 1: The importance of water related interventions for infectious disease control

Disease	Intervention	
	Water quality	Water quantity/convenience
Diarrhoea		
- Viral	++	+++
- Bacterial	+++	+++
- Protozoal	+	+++
Poliomyelitis and hepatitis A	+	+++
Worm infections		
- ascaris,trichuris	+	+
- hookworm	+	+
- pinworm, dwarf tapeworm	o	+++
- other tapeworms		
- schistosomiasis	o	+
- guineaworm	+	+
- other worms with aquatic	+++	o
hosts	o	o
Skin infections	O	+++
Eye infections	O	+++
Insect-transmitted diseases		
- malaria	O	O
- urban yellow fever, dengue	O	O
- bancroftian filariasis		
- onchocerciasis	O	O
	O	O

*degree of importance of intervention: +++ high, ++ medium, + low, o negligible
(after IRC source[10])

Cairncross and Feacham[11] state that it would be almost inconceivable to find any untreated water supply in any village in any developing country in which

[10]Visscher et al, Slow Sand Filtration for Community Water Supply ,IRC Technical paper no.24 , 1987, pp.5, IRC The Hague.

one could not detect faecal coliforms and other faecal bacteria. This is because untreated water sources are almost invariably contaminated with faecal matter and contain faecal coliforms and other indicator bacteria.

Table 2.0 (next page) presents figures of some measured concentrations of faecal coliforms in untreated water sources in some developing countries. Although these figures are not necessarily typical of the domestic water supplies of those countries, they still present some pointers as to how bad the situation can get if no intervention is introduced.

Untreated water sources in Ghana and for that matter in the northern region are no different from others in the developing world. It is thus to be expected that they would also require treatment before consumption. Water quality test results of some raw water reservoirs within the study area under consideration clearly highlight the need for improvement (Appendix B1 to B10).

TABLE 2.0:MEASURED FAECAL COLIFORM IN SOME WATER SOURCES

Source	*Escherichia coli* per 100 ml
Gambia:	
- open handdug well (15-18m)	Up to 100000
Indonesia:	
Canals in central Jakarta	3100-3100000
Kenya:	
- springs	0
- dam	0-2
- waterhole	11-350
- large river	10-100000
Lesotho:	
- unprotected springs	900
- waterholes	860
- small dams	260
- streams	5000
- protected springs	200
- tap water (springs)	9
- tap water (boreholes)	1
Nigeria:	
- Ponds	1300-1900
- Open handug wells	200-580
- Tap water (borehole)	up to 35
Papua New Guinea:	
- streams	0-10000
Tanzania:	
- rainwater	3
- waterholes	61
- ponds	163
- streams	128
- unprotected springs	20
- protected springs	15
- open wells	343
- protected wells	7
- boreholes	1
- treated tap water	3
Uganda:	
- rivers	500-8000
- streams	2-1000
- unprotected springs	0-2000
- protected springs	0-200
- handdug wells	8-200
- boreholes	0-60

Note: single values represent the geometric mean

Source: Sandy Cairncross & Richard Feacham; Environmental Health Engineering in the Tropics:An Introductory Text, 1991,John Wiley & Sons, pp 32.

Tropics:An Introductory Text, 1991,John Wiley & Sons, pp 31.

3.2.2 Surface Water Sources

Surface water is seldom of a quality that can be used without some form of treatment. It is likely to have been affected by nature and by man[12]. The most common pollutants are basically;

- Humus from plant decomposition which result in unacceptable odour or taste.
- Mineral particles which cloud water, increasing turbidity
- Organic pollutants from either humus, pesticides, or waste products
- Microorganisims from natural sources or faecal pollution

Since the ingestion of certain concentrations of some or all of these could result in diseases in human beings, the treatment of such waters for drinking purposes seeks to ensure that the pollution levels are reduced to safe limits.

3.2.3 Chemical Characteristics of Water

The chemistry of water can lead to disease either if there is an absence of a necessary constituent or more commonly an excess of a harmful chemical[13]. The characteristics of water consumed should not cause disease and should make consumers want to continue using it because of agreeable taste and appearance.

The excess of potentially harmful chemicals in water may be disease causing or cause the rejection of a particular source due to unpleasant taste, colour or odour.

The two main categories of chemical pollutants of concern are the organics and the inorganics. Some organic compounds are known to be either toxic or carcinogenic. The main sources are pesticides used for agricultural purposes. In water sources, which depend on storm runoff for replenishment, there is a possibility of higher pesticide levels and permissible limits may be exceeded. The equipment and manpower requirements for detecting these micro-pollutants are quite stringent and specialised laboratories are required for monitoring therefore most community water projects in developing countries do not place too much importance on these types of pollutants.

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[12] Handbook on Water Treatment, Kemira Kemi AB, Water Treatment,1990 pp82.
[13] Sandy Cairncross & Richard Feacham; Environmental Health Engineering in the Tropics:An Introductory Text, 1991,John Wiley & Sons, pp 21.

A number of metallic ions are known to cause metabolic disturbances in man by upsetting the production and function of certain enzymes, or to cause a variety of other toxic effects[14]. Arsenic, barium, lead and mercury are examples of such compounds.

A more noticeable problem in developing countries is the effect of salts in the groundwater ,mainly chlorides and sulphates, which make the water unpalatable and cause people to opt for other sources of drinking water even when they are polluted.

3.2.4 Microbiological Quality

The presence of pathogens in water could create health hazards and eventually lead to infectious diseases. These diseases which are related to impurities in water are termed water-related diseases. They are of prime importance to designers of water supply projects because of the public health risk.

The main pathogenic microbes of general interest are bacteria, viruses, protozoa, and helminthes. Since the routine identification and enumeration of all pathogens in water is too complex, it is normal practice to identify indicator bacteria. "These are bacteria which are always excreted in large numbers by warm-blooded animals irrespective of whether they are healthy or sick. The presence of indicator bacteria in water is therefore indicative of faecal contamination of that water. If a sample is faecally contaminated it may contain any pathogen which is being excreted by the animal. Thus indicator bacteria indicate the presence of faecal contamination and faecal contamination suggests the potential presence of pathogens, and thus a health hazard.

The most commonly used indicator bacteria are the coliforms. Water is tested either for the presence of the total coliform group or for the presence of faecal coliforms only. Faecal coliforms mainly comprising E*scherichia coli,* are a subgroup of the total coliform group and they occur almost entirely in faeces. By contrast, other members of the coliform group can be free-living in nature and therefore their presence in water is not necessarily evidence of faecal contamination. *Escherichia coli* are always present in faeces; most are not

[14] Sandy Cairncross & Richard Feacham; Environmental Health Engineering in the

pathogenic, although some strains are a major cause of childhood diarrhoea throughout the world" [15].

The World Health Organisation[16] suggests the following bacteriological standards for treated drinking water:

Table 3: Recommended coliform levels in drinking water (WHO)

	Water entering the distribution system	Water in the distribution system
Percentage of samples without coliforms/100 ml.	98%	95%
Maximum no. of coliform organisms/ 100 ml.	3*	3*
No. of samples with faecal coliforms	0	0

* in occasional samples only, but not in consecutive samples.

According to Cairncross and Feacham[17] to apply these stringent standards would be to condemn the water supplies used by the great majority of the populations of most developing countries especially for untreated water supplies. They recommend that a good deal of common sense be exercised in the interpretation and use of bacteriological water quality standards for untreated water in developing countries. Standards or goals should be set realistic and national authorities must decide themselves what are reasonable levels to aim for, given the particular environmental and economic circumstances of the country. An overall assessment of needs, costs, diseases prevalent and hygienic practice is needed before deciding upon tolerable indicator levels[18]. Bacteriological water testing is expensive and should only

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Tropics:An Introductory Text, 1991,John Wiley & Sons, pp 24.

15 Sandy Cairncross & Richard Feacham; Environmental Health Engineering in the Tropics:An Introductory Text, 1991,John Wiley & Sons, pp 28-29.

16 WHO (1985) Guidelines for drinking water quality. Vol . 3: drinking water quality control in small community supplies. Geneva, Switzerland, World Health Organization.

17 Sandy Cairncross & Richard Feacham; Environmental Health Engineering in the Tropics: An Introductory Text, 1991,John Wiley & Sons, pp 31.

18 Droste R.L. and McJunkin E. "Simplified Water Treatment Methods",pp.104, Water Supply and Sanitation in Developing Countries, Ann Arbor Science Publishers, 1982

be undertaken when practical decisions can be taken on the basis of the results.

3.3 Assessment Of Water Quality Parameters

This discussion on the assessment of water quality parameters relies mainly on the information provided by Chapman[19]. Consideration is given to selected parameters, which ensure effective monitoring and easy evaluation of the performance system.

Conductivity

The conductivity or specific conductance is a measure of the ability of water to conduct an electric current. It is related to the concentrations of total dissolved solids and major ions and provides an indication of the extent of mineralisation. It is sensitive to variations in dissolved solids. Conductivity is expressed in microsiemens per centimetre (*u*/cm) and for a given water is related to the concentrations of total dissolved salts and major ions. The conductivity of most fresh waters ranges from 10μs/cm to 1000 μs/cm but may exceed 1000 μs/cm especially in polluted waters, or those receiving large quantities of land run-off. In addition to being a rough indicator of mineral content when other methods cannot be easily used, conductivity can be measured to establish a pollution zone.

pH

The pH of water influences many biological and chemical processes within a water body and processes associated with water supply and treatment. It is a measure of the acid balance of the water. In unpolluted water, pH is primarily controlled by the balance between the carbon dioxide, carbonate, and bicarbonate ions as well as other natural compounds such as humic and fulvic acids. Changes in pH can indicate the presence of certain effluents, particularly when the continuously monitored and recorded together with the conductivity. The pH of most natural waters is between 6 and 8.5.

Temperature

[19] Chapman Deborah (editor) Water Quality Assessments, a guide to the use of biota, sediments, water in envirnmental monitoring, Chapman & Hall, 1992 pp 57-88.

The temperature of water affects physical, chemical and biological processes and consequently the concentrations of many variables. Increases in temperature prompt the rates chemical reactions, decreases solubility of gases in water, increases respiration rates of aquatic organisms and decomposition of organic matter. Surface waters are usually within the temperature range of 0°C to 30° C. Temperature should be measured in-situ using a thermometer.

Colour

The visible colour of water is the result of the different wavelengths not absorbed by the water itself or the result of the dissolved and particulate substances present. True colour can only be measured in a sample after filtration or centrifugation. Coloured particulates and the refraction and reflection of light on suspended particles cause apparent colour. Colour can be measured by use of a standardised comparator.

Alkalinity

Alkalinity is the acid neutralising capacity of the water. When the water has no buffering capacity it is inter-related with pH. However as most natural waters contain weak acids or bases, alkalinity or acidity is usually determined in addition to pH. The alkalinity of water is controlled by the sum of titrable bases. It is mostly taken as an indication of the concentration of carbonate, bicarbonate and hydroxide but may include contributions from borate phosphates, silicates and other basic compounds. Waters of low alkalinity (< 2ml/l as $CaC0_3$) have a low buffering capacity and can therefore be susceptible to alterations in pH for example from atmospheric acidic deposition. Alkalinity is determined by titration. The amount of strong acid needed to lower the pH of a sample to pH 4 gives the total alkalinity.

Total Hardness

Hardness of natural water is caused by polyvalent metallic cations especially calcium and magnesium. The total content of the salts of these cations is known as total hardness, which can be further divided into carbonate hardness (from calcium and magnesium hydrocarbonates) and non-carbonate hardness (from calcium and magnesium salts of strong acids). Hardness may vary over a wide range. Calcium hardness is usually prevalent (up to 70%) although in processes, usually under anaerobic conditions. The nitrite ion is rapidly oxidised to nitrate. Natural sources of nitrate to surface waters include igneous rocks, land drainage and plant and animal debris. Municipal and industrial wastewaters and use of inorganic nitrate fertilisers may enhance natural levels, which seldom exceed 0.1 mg/l NO3-N.

When influenced by man's activities, surface waters usually contain nitrate concentrations up to 5mg/l NO_3^-N, but often less than 1mg/l NO_3^-N. Levels in excess of 5mg/l NO_3^-N usually indicate pollution by human or animal waste or fertiliser run-off. In cases of extreme pollution, concentrations may reach 200mg/l NO_3^-N. The WHO maximum guideline limit for drinking water is 10mg/l NO_3^-N indicating that waters with a higher concentration represent a significant health risk. In lakes, levels of nitrate in excess of 0.2mg/l NO_3 tend to stimulate algal growth and indicate possible eutrophic conditions.

Nitrite conditions in fresh waters are usually very low, 0.001mg/l NO_2^-N and rarely higher than 1mg/l NO_2^-N. High nitrite concentrations are generally indicative of industrial effluents and are often associated with unsatisfactory microbiological quality of water.

Determination of nitrate and nitrite in surface waters gives a general indication of the nutrient status and level of organic pollution. Spectrophotometric methods may be used for analysis of the water samples.

3.4 The Purification of Water

The purification of water generally involves changing the state of the raw water to a state acceptable for human consumption and other domestic purposes. The treatment processes normally involve a sequence of activities aimed at removing progressively smaller foreign matter present in the water. It starts with the physical separation of coarser particles and ends with the destruction of dissolved organics and pathogenic microorganisms. The main objectives of all the intermediate processes are the removal of suspended particles from the water.

The key steps in the conventional treatment process are outlined as follows:

1. coarse screening
2. pretreatment
3. coagulation

4. flocculation
5. sedimentation
6. filtration
7. disinfection

This application of subsequent treatment barriers reduces the disease potential of the water and hence ensures the safety of public health. The supply of purified water is thus a very important aspect of disease prevention and public health engineering.

The following table describes the common treatment processes for suspended solids removal. It distinguishes the different pretreatment options and filtration options for final treatment.

Table 4: Common and emerging processes for particle (ss) removal

Options	Influent Conc. Upper limit (mg/l)	removal efficiency (%)	stage of acceptance	supervision level	comments
A. PRETREATMENT					
Sedimentation/flotation based					
Prolonged Storage	No restriction	50-70	Established	low	Removes only settleable particles Algal growth risk
Plain Sedimentation	No restriction	30-50	Established	low	Only mineral >20µm removed
Clari-Flocculation	No restriction	90-98	Established	Medium	Coagulants required; Sensitive to water quality changes
Flotation	20-100	90-98	Established	High	Coagulants and dissolved air required; sensitive to water quality changes
Roughing filtration					
Vertical-flow Up or down	20-150	80-95	Emerging	Medium	Moderate deposit storage capacity; Filter cleaning problem
Horizontal-flow	200-400	80-95	emerging	Low	High deposit storage capacity; Requires large filter volume; Filter cleaning problem
B . FINAL TREATMENT					
Slow sand filtration	10-20	90-98	established	Low	Manual cleaning typically after 1 month; large area required
Rapid sand filtration	20-50	90-98	established	Medium	Backwashing duration typically 6-12hrs
Direct filtration	20-50	90-99	established	High	Coagulants to be added; backwashing typically after 12-48hrs

Observations from this table indicate that the low chemical and manpower requirements coupled with the higher removal efficiencies of roughing filtration and slow sand filtration make a combination of these technologies suitable for rural water supply.

3.5 Simplified Water Treatment Technology

The design of water supply facilities for communities in developing countries should be based upon the proper application of current technology. The social and economic differences between the developed and the developing world explain why conventional approaches for designing water systems in the industrialised countries are not appropriate in developing countries. In industrialised countries, water projects use capital intensive designs with a high degree of mechanisation and automation in order to reduce the need for labour, which is high in cost. The prevailing economies in developing countries, however, are labour – intensive. This implies that a facility which can be built and operated with local labour will likely be more economical and more easily operated than a facility utilising extensive technology (Schulz & Okun 1994)[20].

A technology should not only be 'low-investment' so that its construction is within the financial possibilities of the developing countries, it should also satisfy operational and socio-economic considerations for effective operation and maintenance. The following considerations are generally accepted for a technology to be suitable in a particular situation[21]:

- the technology should be conceptually and physically within the capabilities of the persons responsible for operation and maintenance,
- spare-parts and equipment must be available,
- operating costs should be within the financial means, and
- the technology should be attractive and produce a good standard of service.

Droste & Mc Junkin[22] claim that the production of treated water is a function of raw water quality, the treatment processes, and plant operation. Too often many designers fail to evaluate the capability and the resources of the operators or they assume that operators can and will adjust to the demand of their design. Given the availability and skill of operators and other constraints

[20] Schulz C. R. and Okun D. A. Surface Water Treatment for Communities in Developing Countries, 1984, J. Wiley, New York.
[21] Ahsan T. Process Analysis and Optimisation of Direct Horizontal-Flow Roughing Filtration, doctoral dissertation, IHE-Delft, 1995, pp17-18. A.A.Balkema, Rotterdam.

there are only a few unit processes that are generally feasible for small rural water supplies.

They go on to state further that adding a water treatment plant to a rural water supply increases its complexity by an order of magnitude. They observed that in many, if not most, developing countries, operation and maintenance of water treatment plants was necessarily the responsibility of national or regional governments, not of villages. The required level of infrastructural and manpower support does not exist in normal rural communities.

Wegelin and Dorcoo[23], during an evaluation of water treatment plants in the Northern region of Ghana, observed that due to the unavailability of chemicals (foreign exchange and transport problems) and inadequate dosage (defective equipment and lack of trained staff) the chemical treatment of water often fails in rural areas of developing countries.

To combat similar problems in other parts of the world alternative pretreatment methods have been developed over the past ten years for the removal of the solid matter to permit efficient slow sand filtration operation. Details of such methods and where they have been tried are presented in " The Decade of Roughing Filters" (Wegelin et al, 1991). Pescod et al[24], also present some information on processes available for pretreatment suitable for low cost water treatment in developing countries.

Sedimentation and roughing filtration may be combined with SSF to form an efficient and reliable treatment scheme for turbid and faecally polluted surface water. Wegelin and Dorcoo state emphatically that the treated water of such schemes is safe for human consumption. Chlorination is however recommended to prevent a deterioration of the quality as the water moves through the distribution system.

[22] Droste R.L. and McJunkin E. "Simplified Water Treatment Methods",pp.107, Water Supply and Sanitation in Developing Countries, Ann Arbor Science Publishers, 1982

[23] Martin Wegelin & Kolly Dorcoo, Potential of Slow Sand Filters in the Northern Region of Ghana , Field Report on Evaluation Mission, pp 2, April 1992.

[24] Pescod M.B. et al, Slow Sand Filtration: A low cost treatment for water supplies in developing countries. Published by WRC(UK) & IRC for WHO European Regional Office pp 4-5.

The IRC also shares this view and states in its Technical paper no.24[25] that "in many developing countries, treatment of water to make it fit for human consumption is still a major problem. Expensive and complex treatment plants have been built but many of these do not function satisfactorily because of inappropriate design, irregular power supply, and lack of fuel, chemicals, replacement parts and trained manpower. There is therefore an obvious need for more reliable and simpler water treatment systems, which can be maintained by local technicians without major contributions from external sources. Slow sand filtration has been identified as a method, which can fulfill these requirements. The IRC document however goes on to indicate that though slow sand filtration is a simple economical and reliable treatment method, it is essential to initiate the community education and participation process prior to the introduction of a water supply. Hygiene education is also pointed out as a key element in the community's behavioural change from practices detrimental to the desired impact.

Within our local Ghanaian context, the concepts of decentralisation and community ownership and management are gradually influencing the roles of centrally controlled agencies involved in community water supply. Their current emphasis is rather on empowering the communities and assisting them to access and harness appropriate technologies for their development needs. The stark reality of the high investment costs for production and distribution infrastructure, unavailability of funds for external inputs and other expensive operational requirements for larger water supply schemes tend to place smaller dispersed villages at a great disadvantage with regards to accessing funds for completely new water systems. There is thus need to improve the existing water supply sources to meet nationally acceptable quality standards.

[25] Visscher et al, Slow Sand Filtration for Community Water Supply ,IRC Technical paper no.24 , 1987, pp.1, IRC The Hague.

3.6 Filtration Theory

3.6.1 Objectives of Filtration

The basic objectives of all water treatment unit operations are to prepare the water for effective disinfection[26]. Filtration is the purification process whereby the water to be treated is passed through a porous substance. During this passage water quality is improved by part removal of suspended and colloidal matters, by a reduction in the number of bacteria and other microorganisms and by changes in its chemical constituents in particular a destruction of organic matter by oxidation. In principle, the porous substance may be any stable material, as well as a granular bed of sand, crushed stones, anthracite, glass, porous concrete and stoneware. In the field of drinking water purification, however, sand is almost used exclusively as filtering material because of its availability, relative low cost and the satisfactory experience that it has given[27].

3.6.2 Filtration Processes

The filtration process can be classified according to where the deposits are retained: surface or cake filtration and deep bed filtration. In surface or cake filtration the bed consists of finer grains and the bulk of deposits are within the upper layers of the bed. Majority headloss therefore occurs at the surface of the filter.

In deep bed filters e.g. rapid sand or roughing filters particles are retained along the passage of the raw water through the sand bed. The bigger grain sizes offer opportunities for greater penetration and the headloss is spread over the bed depth depending on grain size and filtration rate.

The filter coefficient (λ) has been defined by Iwasaki (1937) with the following first order kinetic filtration equation with respect to particle concentration C:

$$\angle C / \angle L = -\lambda C$$

[26] Greetham M. IHE lecture notes on basic filtration 1998

where C= concentration of substance to be removed [mg/l]

L= filter depth [m]

λ= filter coefficient [cm^{-1}]

Iwasaki's theory states that the removal of a substance within a filter reduces in depth in relation to the concentration of the substance in the water. The filter coefficient λ is a function of the interstitial flow pattern (depending on filtration rate and pore size distribution), of the grain surface area (depending on size and shape of the filter medium) and on Stokes law parameters of the water and the suspended particles (size, density), (Wegelin, 1996).

It is assumed that the filter coefficient λ remains constant over short periods of time. Over longer time periods λ can be seen to vary with the amount of material due to the blocking of pores and apparent increase in grain size. Wegelin also states that research has shown that filter efficiency is dependent on design variables such as filtration rate, gravel size, filter length, accumulated filter load.

Flow direction, however, is of minor importance for filter performance.

3.6.3 Filtration removal mechanisms

There are three main categories of removal mechanisms in filters i.e. transportation mechanisms, attachment mechanisms, and transformation mechanisms. Normally solid particles have to be transported to a surface, get attached and remain attached for possible transformation by biological and biochemical processes. The interaction of these various processes is of paramount importance and results in the overall removal of impurities from the raw water.

3.6.3.1 Transportation Mechanisms

Screening or straining is the removal of particles that are larger than the pores of the filter bed. This type of activity takes place mainly at the surface of the

[27] Huisman, , IHE Lecture notes on basic filtration 1998

filter where it may lead to clogging and increased resistance to downward movement of water.

Sedimentation separates settleable solids by gravity. The settling velocity is influenced by mass, density, size and shape of the particle, as well as by viscosity and hydraulic conditions of the water (Wegelin, 1996). The particulate suspended matter of size finer than the pore size may settle on the sides of the sand grains. The path of settling of the grains would necessarily cross the flow stream-lines. This mechanism is important in the removal of large dense particles.

Interception occurs when small buoyant particles are brought to the surface of the filter media by following the path of the stream line. The retention of the particulate matter gradually reduces the pore sizes of the media.

Inertial and centrifugal forces also propel particles in the immediate vicinity of filter grains to enable settling and attachment.

3.6.3.2 Attachment Mechanisms

Adsorption can be defined as the process whereby molecules of a substance are taken up and held at the surface of a material (Greetham – lecture notes). Adsorption results from the combination of mass attraction and electrostatic forces that enable charged particles to keep in contact with the solids and filter material. Without any doubt, adsorption is the most important purification process during filtration, retaining finely divided suspended matter next to colloidal and molecular dissolved impurities (Huisman – Lecture notes). Passive adsorption occurs when a suspended particle comes into contact with a sand grain and is retained on the sticky coating formed by previously deposited organic matter. Active adsorption however, is occasioned by the action of van-der-waals forces acting between particles of matter and coulomb forces resulting from electrostatic attraction between opposite electrical charges.

Biological Activity within the filter creates a layer of organic matter around the gravel and in the pores of the filter material. Particles are easily absorbed by this organic material, which greatly maintains particulate matter attached in the filter (Wegelin 1996).

The various mechanisms of removal in a filter have different levels of efficiency dependent mainly on the size of the particles. Straining and sedimentation are effective for large particles. Interception is effective for smaller particles. Adsorption and biological action deal effectively with the minutest particles and essentially "polish" the water.

The figure below depicts the relative efficiencies of the different removal mechanisms with respect to the trend of particle sizes.

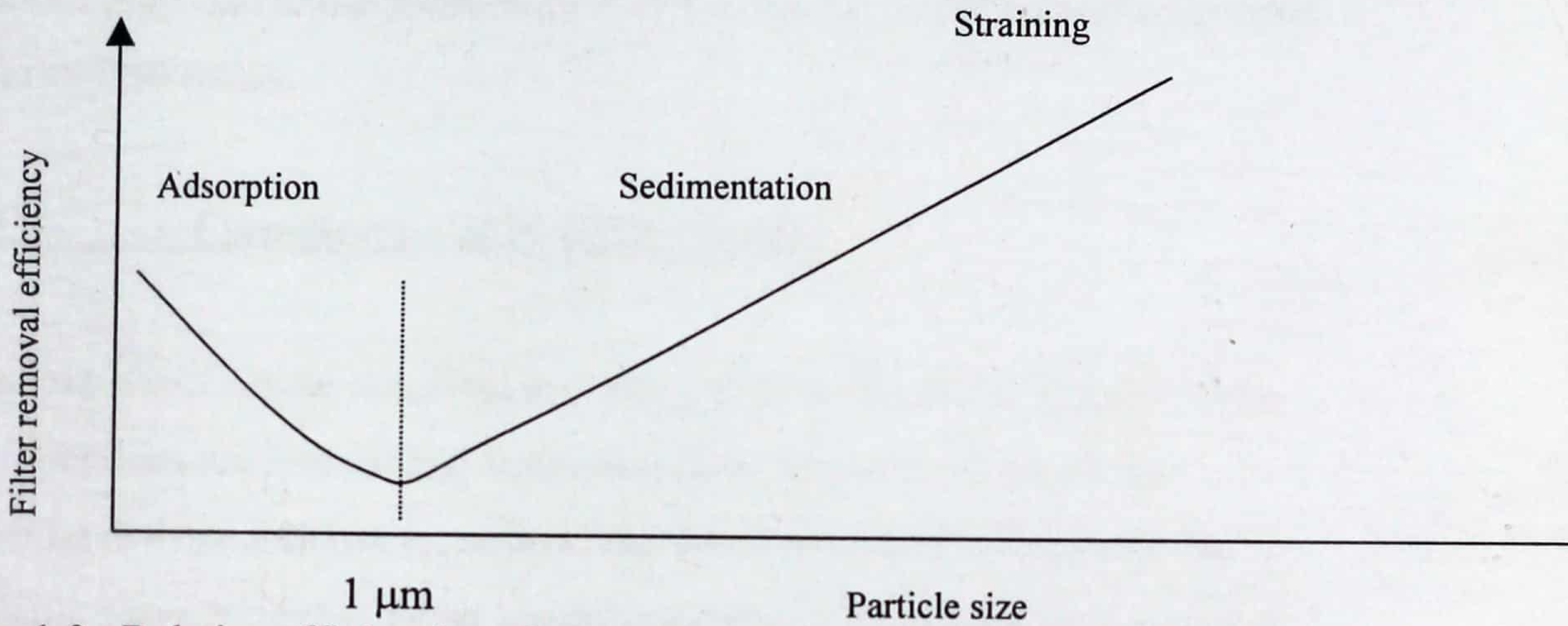

Figure1.0 : Relative efficiencies of removal mechanisms according to suspended particle sizes

(Source: Adapted from Greetham IHE lecture notes Nov. 1997)

3.7 Types Of Filters

Filters that rely on gravity flows are typically classified based on media characteristics and flow rates into four main groups:

Table 5.0: Types of Filters

Filter type	Grain size (mm)	Filtration rate (m/h)
Rock filter	>50	1-5
Roughing filter	20-4	0.3-1.5
Rapid sand filter	4-1	5-15
Slow sand filter	0.35-0.15	0.1-0.2

The following discussion is restricted to only roughing filters and slow sand filters.

3.7.1 Roughing Filters

Removal of suspended solids by roughing filters is a complex process involving settling supported by adsorption and some biological action. The settling is the main transport mechanism, which brings the suspended solids to the surface of the filter bed media for attachment to take place through biological activity and some adsorption. Subsequent biochemical activity by microbes may lead to the conversion of some organic materials and suspended and dissolved solids.

3.7.1.1 Classification of Roughing Filters

Roughing filters can be classified according to flow direction. The two main flow directions are vertical and horizontal flow. The vertical flows may further be divided into two ie, upflow and downflow filters. Normally the roughing filters consist of either separate compartments arranged in series or succeeding layers in the same compartment.

3.7.2 Slow Sand Filters

3.7.2.1 Slow Sand Filtration Process

Visscher et al[28] define slow sand filtration as one the most effective, simplest and least expensive water treatment processes and is therefore particularly suitable for rural areas in developing countries. Essentially, this process differs from rapid sand filtration because of its biological nature, high efficiency, and suitability for village level operation and maintenance. The basic process of slow sand filtration involves the slow movement of water (0.1 $m^3/m^2/h$ -0.3 $m^3/m^2/h$) through a bed of fine sand with the consequent removal

[28] IRC Technical Paper 24,1987).

of turbidity and microorganisms (bacteria, viruses, and cysts). In a slow sand filter impurities in the water are removed by a combination of processes; sedimentation, straining, adsorption, chemical and bacteriological action. Purification begins in the supernatant layer where large particles settle on the filter bed and smaller particles agglomerate to settleable flocs as a result physical, chemical or biochemical interactions. Under the influence of sunlight, algae, which have entered the filter with the raw water, grow and influence the purification process .

The grain sizes of the filter encourage cake filtration involving mainly physical straining at the surface. According to Wegelin, a thin layer on the surface of the sand bed formed by retained organic and inorganic matter and a large variety of biologically active microorganisms are responsible for the physical, chemical and biological improvement of the water (Wegelin, 1996). This thin layer, called the "schmutzdecke", must first develop in a new slow sand filter and may take 2 to 4 weeks. The duration required for development of this layer is referred to as the 'ripening period. Visscher et al[29] state that impurities including bacteria and viruses, are removed from the raw water as it passes through the filter skin and the layer of sand just below. The removal of bacteria from the water is probably due primarily the action of predators such as protozoa. These impurities carried deeper into the filter bed will come into contact with, and become attached to, sand grains so that the sand particles gradually become covered with a thin layer composed mainly of organic material and microorganisms. These in turn adsorb the impurities by various attachment mechanisms. The purification mechanisms extend from the filter skin to approximately 0.3-0.4 m below the surface of the filter bed, gradually decreasing in activity at lower levels as the water becomes purified and contains less organic material and nutrients. More products of the biological processes are removed at even greater depth by physical processes (adsorption) and biochemical action (oxidation). After ripening of the filter it produces high quality effluent free of disease-causing organisms and biodegradable organic matter.

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[29] IRC Technical Paper 24,1987).

3.7.2.2 Quality Improvement in Slow Sand Filters

Slow sand filters act mainly as surface filters. The “Schmutzdecke” which forms on the surface of the sand bed is mainly responsible for the physical, chemical and biological improvement of the water.

Slow sand filters essentially reduce the number of bacteria, viruses, protozoa, eggs and worms present in the water thereby improving the bacteriological water quality. In addition fine organic and inorganic matter is separated and the organic compounds dissolved in the water are oxidised.

An indication of the performance of slow sand filters is summarised on the following table.

Table 6: Performance of slow sand filters

Water quality parameter	Purification effect of slow sand filter
Colour	30-100% reduction
Turbidity	Generally reduced to less than 1NTU
Faecal coliforms	Between 95-100% and often 99-100% reduction in level of faecal coliforms
Cercariae	Virtual removal of cercariae of schistosoma, cysts and ova
Viruses	Virtually complete removal
Organic matter	60-75% reduction in COD
Iron manganese	Largely removed
Heavy metals	30-95% reduction

Source: IRC Technical paper 24

3.7.2.3 Summary Considerations in Slow Sand Filtration

Table 7.0 below presents the main considerations, which influence the choice of slow sand filtration as the preferred treatment option for a community water supply project.

Table 7.0: Summary Considerations in Slow Sand Filtration

Consideration	Comments
Quality of treated water	Best single process to improve the physical, chemical and biological quality of surface water. In many rural areas, slow sand filtration may be the only feasible treatment.
Ease of construction	The relatively simple designs facilitate construction from local materials using local labour. Little or no special pipework or equipment are usually required.
Ease of operation and maintenance	After a short period of training, local caretakers with little formal education can operate the system.
Cost of operations	Operation costs and energy requirements are lower than for other systems. No chemicals are required.
Reliability	The process is reliable and mechanical failures are minimal. Fluctuations in water quality can be accommodated without disrupting the efficiency of the process.
Cleaning	The cleaning process is simple but somehow labour-intensive. Although the cost may be low, in most developing countries, labour may not always be available at the required time.
Large surface area	A fairly large area is required for the filters: about 0.02-0.08m^2 per consumer . Because of the low cost of land in many rural areas, this may represent only1-2 % of total construction costs. However this may be a constraint in areas where land is scarce.
Rapid clogging of the filters when turbidity is high	High turbidity of raw water may cause rapid clogging of the filters. This may often be overcome by simple pre-treatment.

(Source: IRC Technical Paper 24,1987)

3.8 Choice of Treatment Processes

Broadly speaking virtually any desired finished water quality is possible considering the wide range of available treatment options. The limiting constraints are however the economic and operational considerations. The primary factors influencing the actual choice of treatment processes may be enumerated as follows:

1. Treated water specifications
2. Raw water quality and its variations
3. Local constraints
4. Relative costs of different treatment processes

The finished water requirements and raw water quality generally exert the greatest influence on process selection whiles the local constraints govern the implementation of the water supply projects. The local constraints refer to issues like limitations of capital, skilled labour, materials and equipment requirements, and national policies.

3.8.1 Selection of Water Treatment System for Rural Water Supply

The technical considerations involving actual selection of a definite treatment system for rural water supply is dependent on a number of parameters including the following:

- turbidity expressed in nephelometric turbidity units (NTU)
- faecal coliform count
- presence of guineaworm or schistosomiasis (not usually through ingestion)

The following table presents some guidelines for selecting particular treatment systems for rural water supply based on the average values of the turbidity and faecal coliform concentrations and presence of guineaworm and schistosomiasis in the raw water.

Table 8: Guidelines for the selection of a water treatment system for surface water in rural areas

Average water quality	Treatment required
Turbidity: 0-5 NTU Faecal coliform MPN*:o Guineaworm or schistosomiasis not endemic	No treatment
Turbidity: 0-5 NTU Faecal coliform MPN*:o Guineaworm or schistosomiasis endemic	Slow sand filtration
Turbidity: 0-20 NTU Faecal coliform MPN*:1-500	Slow sand filtration Chlorination, if possible
Turbidity: 20-30 NTU (30 NTU for several weeks) Faecal coliform MPN*:1-500	Pretreatment advantageous Slow sand filtration Chlorination, if possible
Turbidity: 30-150 NTU Faecal coliform MPN*:500-5000	Pretreatment Slow sand filtration Chlorination, if possible
Turbidity: 30-150 NTU Faecal coliform MPN*:>5000	Pretreatment Slow sand filtration Chlorination
Turbidity: >150 NTU	Detailed investigation and possible pilot plant study required

* Faecal coliform counts per 100 ml

(Source: IRC Technical Paper no.24)

3.9 History and Application of Slow Sand Filters

"Slow sand filtration was the first water treatment process introduced to improve the quality of surface water in Europe and North America and soon proved to provide protection against cholera and typhoid. It has remained a suitable treatment technology throughout the world and is recognised as particularly appropriate for application in developing countries by reason of the simplicity of design and construction and the ease of operation and maintenance. In areas where land is available, slow sand filtration is a low cost water treatment process which can be operated and maintained by a trained member of the local community. No other available water treatment technology, excluding disinfection, can produce as safe a drinking water and provide as great a protection of public health." This statement by Professor M.B. Prescod[30] of the University of Newcastle-Upon-Tyne, UK summarises the track record of slow sand filters in the western world and points out the applicability of the technology for low cost water treatment in less developed countries.

In the decade after 1976 the International Reference Centre for Community Water Supply and Sanitation (IRC) coordinated an 'Integrated Research and Demonstration Project' involving research institutions Ghana, India, Kenya, Sudan, Thailand, Colombia and Jamaica. The project activities included initially conducting applied research on the engineering aspects and later constructing village demonstration plants in most of these countries.

Generally speaking Africa has been slow in taking advantage of this technology with the exception of the Republic of Cameroon where many slow sand filters have been installed through a cooperative programme with HELVETAS, the Swiss Association for Technical Assistance. After 1984 Tanzania also actively started incorporating slow sand filter technology in village water supply schemes after field testing horizontal roughing filtration and slow sand filters from 1980 to 1984[31].

In Ghana the application of slow sand filtration has been low key with trial plants at Damongo and Salaga in the Northern Region and a full-scale operational plant at Mafi-Kumasi in the Volta Region.

3.9.1 Development Of Slow Sand Filtration Technology In Northern Ghana

3.9.1.1 Small Town Water Supply

In the early nineties the Ghana Water and Sewerage Corporation initiated pilot plant trials in slow sand filtration to determine the feasibility of such technology for water treatment in northern Ghana. The first pilot plant was built at Damongo, the capital town of the West Gonja district. Lessons from

[30] Prescod et al, Slow Sand Filtration, WHO European Regional Office Publication, Executive Summary

[31] Mbwette, T.S.A. Slow Sand Filters- The Tanzanian Experience, Asian Institute Technology, Environmental Sanitation Information Centre,Newsletter,7,2,4 Bangkok ,Thailand, 1985.

this trial were incorporated in the design and construction of the second plant at Salaga the capital of the East Gonja district. The first full-scale plant has subsequently been designed and constructed at Zabzugu in the northern region of Ghana[32]. It is yet to be commissioned.

Damongo pilot plant

The plant consisted of 4 slow sand filters preceded by 2 horizontal roughing filtration units. The summary of findings[33] from these trials indicated the following;

- slow sand filtration is an appropriate process for improving the hygienic quality of surface water
- slow sand filtration is not capable of reducing high iron concentrations to acceptable levels, sufficient aeration and sedimentation is required prior to roughing filtration

Salaga pilot plant

The second plant constructed at Salaga had aeration and sedimentation units incorporated before the roughing filter units. The source of raw water was the river Daka. The main conclusions drawn from the results of those trials included[34];

- alkalinity and hardness were not affected by slow sand filtration
- iron content was significantly reduced by the aeration and precipitation and also by slow sand filtration
- the slow sand filtration could not remove all the colour and turbidity. The maximum reductions were 82%(colour) and 91%(turbidity).
- micro-organisms (eg. coliform bacteria) in the raw water were reasonably reduced by the slow sand filters(30%-100%).
- lower flow rates yielded better filtrate quality
- shading of the filters eliminated algal growth

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[32] Martin Wegelin. Review of Zabzugu water treatment plant design and pilot plant studies at Salaga,report on evaluation mission September 1993

[33] Balaara E.Y. Damongo slow sand filtration pilot plant study, Water quality analysis report, GWSC internal report, August 1994

[34] Dwamena-Boateng, Salaga slow sand filtration pilot plant study, Water quality analysis report, GWSC internal report, August 1994

3.9.2 Village Level Water Supply

An attempt to apply the principles of slow sand filtration to village level water supply was conducted by Keiko Baba[35], a Japan Overseas Cooperation Volunteer in Tamale, and staff of the GWSC laboratory in 1998. The site of the pilot plant was in the village of Gizaa-Gundaa in the Tolon-Kumbungu district of the northern region. The laboratory assessment of the final water quality indicated safe water suitable for human consumption. The structural design of the system however facilitated the intrusion of reptile into the water resulting in the decomposition of their dead bodies in the water. This situation unfortunately prompted the boycott of the resulting water by the village folk.

[35] Keiko Baba, The improvement of dam water for human consumption by sand filtration, prevention of the water flea "cyclops-guineaworm") November 1998, unpublished report

4.O THE USER COMMUNITY

4.1 Community Profile

Introduction

In order to obtain an accurate profile of the community hosting the pilot plant, a specialist community animation team was commissioned to enter the village and produce a detailed report to allow a proper profile of the village to be developed. These animators, the Tamale Archdiocese Animation Team undertook their research on April 15 and 16, 1999 using a combination of PRA and DELES techniques to collect the required data. In addition to a written report, a community map (Drawn by participants) was also produced to provide a pictorial representation of the village layout. The outcome of this exercise, which describes the community served by the pilot plant, is presented below.

Location and description

Gizaa-Gundaa is a Dagomba village in the Tolon-Kumbungu district of the Northern Region of Ghana. It is located 30 kilometres from Tamale off the Tamale Nyankpala road (fig. 1,location map).

Population

The village comprises 35 local compounds and 2 staff quarters. It has a population of 550 people. The detailed breakdown of the different age groupings is presented in Table8.

TABLE 9: POPULATION GROUPS DISTRIBUTION BY AGE AND SEX

AGE / SEX	0-15	16-30	31-45	46+	TOTAL
Males	163	74	13	7	257
Females	18	109	6	10	293
Total	331	183	19	17	550
%	60.18	33.27	3.45	3.09	100

total population of males = 46.7%

total population of females = 53.2%

the range of household population = 4 – 60

the mean population	=	15 persons/household
the median population	=	11 persons/household

Decision making structures

The village is under the traditional authority of the Tolon paramount chief . The local political decision making structure of the village is made up of the village chief and his elders (including women leaders) and opinion leaders. The leaders of women socio-economic groups, organized traditional dance groups, village maintenance team members, Functional Literacy classes and the school P.T.A executive are also recognised as part of the decision making echelon of the community.

Infrastructural development

The main infrastructure developments in the community are one Primary School, one Clinic, two KV.I.P toilets, one church building, one mosque building and an access feeder road. There is also a woodlot in the village.

Main economic activities

The primary economic activities in the community are farming of cotton, rice and groundnuts, processing of shea butter, rice and groundnut cakes and animal rearing (sheep, cattle and fowls).

Other sources of income available in the village include petty trading, butchering, mat, basket and food barn weaving, pomade and soap making.

Maize, guinea corn, yam, millet, beans and pepper are also farmed purposely for feeding the people.

Available technical skills

The only technical skills available in the village are blacksmithing, agro-food processing, soap and pomade making.

Prevalent diseases

The most prevalent diseases in the community are malaria, convulsion and diarrhoea. Malaria is the most prevalent of the three.

4.2 Water supply situation

Water demand

The population of Gizaa was counted to be 550 in April 1999. The average daily water consumption is estimated to be 30 litres/capita/day. The total daily demand would therefore be 16,500 litres. Studies on the water fetching patterns of such communities[36] have indicated that two peak periods exist during the day of approximately 3 hours each. This indicates that half of the total water requirement has to be supplied over a 3-hour period every morning and evening. A maximum storage of 8,250 litres is thus required to meet domestic demand.

Water sources

Gizaa-Gundaa has 25 traditional wells and two surface reservoirs (1 for human consumption and 1 for watering livestock).

The traditional wells yield water only during the rainy season since they are fed from surface infiltration generated immediately after storms. During the dry season there is no production from these sources.

The surface reservoirs were constructed by the Village Water Reservoirs Project (Tamale Catholic Archdiocese) in 1992 to impound storm runoff for use during the long dry season. The community's dependence on reservoir storage is mainly during the dry season when all the local wells dry up. The water is piped from one reservoir into cisterns, in the raw state, for the community's use. The reservoir was sized based on a per capita water consumption of 30 litres per day for a drought period of 7 months in addition to estimated evaporation and seepage losses. The design life was 20 years.

Water treatment practices

The main water treatment practice in the village was at the household level. The water from the dam cisterns was strained through pieces of calico before being put in the drinking pot. The purpose of this straining was to intercept any guineaworm cyclops that may have been present in the water. The scarcity of fuelwood in these local communities precludes the boiling option as a regular treatment option.

Dam maintenance

The village has a four-member (2 men, 2 women) dam maintenance team. These persons have been trained to mobilise and provide the necessary guidance to the community for routine maintenance tasks and the general dam area management.

Project financing

The main mode of financing projects in the community have involved one or more of the following:

(a) Monetary contributions

(b) Unskilled Labour contribution

(c) Feeding and accommodation of project workers

4.3 Response to questionnaire

Twenty respondents (10 men, 10 women) were interviewed. These included the village chief, elders, women leaders, village maintenance team members, farmers teachers, housewives, agro-food processors, traders and traditional birth attendants. The summaries of the various responses are presented in the table that follows.

Table10: Summary of questionnaire results

	QUESTION	YES	No	Can't tell
1	Do you Filter the water you fetch from the dam?	20	0	0
2.	Are you aware of the filter near the dam?	19	1	0
3.	Did you request for the filter?	0	20	0
4.	Where you consulted before the filter was fixed?	14	6	0
5.	Do you know its purpose?	18	2	0
6.	Do you think this is necessary?	20	0	0
7.	Do you use water from the filter?	14	6	0
8.	Do you like it?	7	0	13

[36] Animation Section well-side and water quantity observation report, VWR Project April

The following explanations were offered by the respondents to clarify some of the answers to the questions.

Those who said no to question 7 do not fetch the water because the work on the filtration project is not yet completed. Those who said yes have actually stopped using the filtered water because the wells are so low that frogs and snakes tend to fall inside the filtration chambers and rot in the water. They however indicated that since the well was being raised, they would use the water filtration gallery when the on-going work was completed.

All respondents said the village people took care of the filter surroundings.

The open-ended questions were responded to as follows:

(1) They filter the water fetched from the dam because they want to prevent germs and diseases, eliminate guinea worm, make the drinking water clean and have good health

(2) The purpose for installing the filtration project is to filter their drinking water before they fetch, to make their drinking water clean, to provide them pure and clean water, to eliminate water borne diseases e.g. guinea worm, and to provide them water which we would not have to filter again.

(3) They think the filter project is necessary to improve their health, which will improve their working hours on the farm and increase their farm yields. It is necessary if they are to drink clean water and save them the cost of buying filter cloths.

(4) Those who used the water said it was clean, pure, it tasted good and it was clear. One could actually see through the water in a glass container.

(5) They also said it would enhance their health.

The community paid ¢300,000.00 in cash for the construction of their drinking water dam and for improvement of the dam for watering their animals.

1992.

They continue to pay for routine long-term maintenance of their dam based upon which the Village Water Reservoir Project visits twice a year to assess the dam and advice on maintenance.

They said they would pay for maintenance or repairs if the filter project develops problems. Presently the village takes care of the filter project surroundings. The village maintenance team members are very active in the care of the filter.

4.4 General Observation

The general impression created was that of a communal willingness to ensure the life of the filter project.

5.0 PILOT PLANT STUDIES

5.1 Location and Description

The pilot plant is located at Gizaa-Gundaa, a Dagomba village 30 kilometers from Tamale,in the Tolon-Kumbungu district of the Northern region of Ghana. The source of raw water is a constructed earth reservoir with design storage of 22500 m^3. This reservoir was constructed to supply two adjoining villages with a total design population of 2000. The total storage is to cater for both human consumption and livestock watering.

5.2 Layout of treatment scheme

The water from the reservoir flows through a 75 mm HDPE pipe, under the influence of gravity, into concrete cisterns (wells) from which the community members fetch for use. The filter system was inserted halfway between the source and the fetching point. A valve chamber was built and a valve connected to the main pipeline through a 32mm PVC pipe that served as the feedline to the roughing filter.

5.3 Filter Plant Components

The pilot plant used for the tests was modified from an existing plant used for a similar study previously. The dimensions of the old plant thus fixed the boundaries. The filter surface area of both the roughing filter and slow sand filter was 3 m^2 , thus under steady flow conditions, the filtration rates for both filters would have to be the same. This hydraulic condition was found unacceptable for this research. Some modifications were therefore introduced into the structural components of the roughing filter to ensure a specified range of filtration rates.

Roughing filter

The roughing filter is concrete tank partitioned into three chambers in a series arrangement with sandcrete blocks. The dimensions of each chamber are 1m x 3m x 3m. The filter surface area per chamber was thereby reduced to 3m^2 and the filtration rate consequently increased above that of the slow sand filter, for a steady flow condition through the filter system. The first chamber is a vertical up-flow filter and is separated from the second one by a weir fitted with a 60 V notch for flow measurement and control. The second and third units are vertical down-flow and up-flow roughing filters respectively. The filter media consists of rounded medium quartzitic gravel of sizes ranging from 8mm to 12mm.

The design guidelines are presented below.

d_g (mm)	gravel size = 8mm-12mm
v_f (m/s)	filtration rate=Q/A =Q / (LxW) = 0.3-1.0 m/h
H (m)	filter media depth=0.8m
L (m)	filter length=1.0m (1 chamber)
W (m)	filter width= 3.0m
A (m^2)	filter bed area= 3.0m^2
Q (m^3/h)	flow rate =1.0m^3/h (m/h)

Slow sand filter

The slow sand filter is a single concrete chamber with dimensions 3m x 3m x 3m. It is filled with a 0.8 m thickness of fine to medium sand with a uniformity coefficient of 0.4. A perforated HDPE collector pipe underlies the sand and transports the filtrate to the fetching well. The collector pipe is supported in a bed of gravel that also prevents the movement of the sand media into the pipe. The design guidelines of the slow sand filter are presented below;

d_g (mm)	effective grain size = 0.15-0.3
Uc	uniformity coefficient <2
v_f (m/h)	filtration rate=0.1-0.2
Q (m^3/h)	flow rate=1
H (m)	filter media depth=0.8-1.0

Fetching point

The filtrate is collected in a concrete chamber (well) fitted with a Nira AF 85 handpump. The depth of the well is 3.2m. The wellhead is raised 0.8 m above the existing ground. Only one container may be filled at a time.

Flow measurement and control devices

The system is essentially inlet controlled. The valve in the valve chamber controls the inflow of raw water into the filter system. Measurement of flow through this valve was by means of a stopcock, stopwatch and measuring cylinders. The V notch in the roughing filter weir also allows monitoring of the flow through the system.

The different units of the filter system were connected by PVC pipes.

Cleaning facilities

Manual cleaning is envisaged for both filters. The filter chambers may be drained through 25 mm diameter pipes located at the bottom of the filter chambers.

5.4 Water Quality Analysis

5.4.1 Schedule of Sampling

The newly modified filter was allowed to operate for three days before any sample was taken for analysis. This initial duration was allowed for start-up of the slow sand filter. It was estimated that 3 days was enough for the commencement of biological activity but not enough for significant development of the "schmutzdecke". Serious observations began on day 3 and samples were subsequently taken for analysis to record the progressive improvement across the different filter units.

Samples were taken periodically from four (4) different points for physico-chemical and bacteriological analyses. The samples were taken from the reservoir, first roughing filter chamber, third roughing filter chamber and the discharge from the handpump. The samples taken from the first roughing filter chamber were to help determine whether a smaller filter size would not be adequate for turbidity reduction prior to slow sand filtration. The sampling started on May 4,1999 and continued to June 21,1999.

5.4.2 Laboratory Testing

Laboratory testing was restricted to factors and parameters that contribute to the taste, colour, smell and microbiological quality of the water. The samples were subjected to a series of physico-chemical and microbiological test procedures. Staff of the water quality assurance department of Ghana Water and Sewerage Corporation conducted the tests at the corporation's regional laboratory in Tamale.

The table below summarises the analytical methods used in the determination of the selected quality parameters.

Table 11:Water quality tests

Parameter	Method	Location	Instrument
Conductivity	Electrochemical probe	In-situ	HACH conductimeter
PH	Electrochemical probe	In-situ	HACH pH meter
Temperature	Thermometry	In-situ	Thermometer
Total hardness	Titrimetry	Laboratory	
Total alkalinity	Titrimetry	Laboratory	
Chloride	Titrimetry	Laboratory	
Colour	Visual comparison	Laboratory	Lovibond comparator
Turbidity	Nephelometry	Laboratory	HACH turbidimeter
Total iron	Spectrophotometry	Laboratory	HACH DR/2000
Manganese	Spectrophotometry	Laboratory	HACH DR/2000
Fluoride	Spectrophotometry	Laboratory	HACH DR/2000
Sulphate	Spectrophotometry	Laboratory	HACH DR/2000
Sulphide	Spectrophotometry	Laboratory	HACH DR/2000
Ammonia	Spectrophotometry	Laboratory	HACH DR/2000
Nitrite	Spectrophotometry	Laboratory	HACH DR/2000
Nitrate	Spectrophotometry	Laboratory	HACH DR/2000
Total coliform	Multiple Tube Test	Laboratory	

5.4.2.1 Physico-chemical analyses

Some of the physico-chemical tests were done on site using portable testing kits whiles the rest were conducted under laboratory conditions. A significant advantage of field testing is that tests are carried out on fresh samples whose characteristics have not been contaminated or otherwise changed as a result of storage in a container. Parameters measured in the field included pH, colour, conductivity, and temperature using a Lovibond Comparator and Nessleriser. The other parameters ie, turbidity, chloride, iron, manganese, total hardness and total alkalinity were transported to the laboratory for testing. The physico-chemical water quality analyses was carried out according to the procedures specified under the relevant sections for water quality parameters in the

Standard Methods for the Examination Water and Waste Water, 16th edition, 1985.

5.4.2.2 Bacteriological analyses

This analysis was concentrated on the detection and enumeration of total coliform. Samples were stored in sterilised bottles and transported to the lab for all tests. All samples were analysed within18 hours of sampling. The method used was the Multiple Tube Test (MTT) .Samples for the MTT were incubated at 37 for the estimation of total coliform and 44.5C for faecal coliform estimation

The broth used was McConkey broth.

5.5 Cost of Filter System

The summary of the various items of cost involved in constructing the filter is tabulated below. All items were procured in the region.

Table 12: Summary of Construction Costs

COMPONENT	COST (¢)
BLOCKWORK	
▪ Primary valve chamber	151,200
▪ Secondary valve chamber	110,400
▪ Roughing filter chamber	888,000
▪ Slow sand filter chamber	772,800
▪ Clear-well	360,000
Floor concrete	440,000
Plastering	1,635,000
Roofing	426,000
Filter media	300,000
Handpump	1,200,000
Pipes, valves, stopcocks	400,000
Excavation (manual)	800,000
Skilled labour	1,400,000
	8,883,400

6.0 PRESENTATION AND DISCUSSION OF RESULTS

The results from the laboratory tests have been summarised and presented under two distinct headings namely analysis of water quality parameters and filter performance

6.1 Analyses of water quality parameters

6.1.1 Raw water characteristics

The American Society of Civil Engineers (1969) has characterised water sources for potable supplies according to water quality, using parameters of biochemical oxygen demand, pH, chlorides and fluorides as shown in the following table.

Table 13: Quality of raw water sources

Average parameter Values	Excellent source	Good source	Poor source	Rejectable source
BOD_5 (mg/l)	.75-1.5	1.5-2.5	2.5-4	>4
Coliforms (mpn/100ml)	50-100	100-5,000	5,000-20,000	>20,000
pH	6-8.5	5-6 8.5-9	3.8-5 9-10.3	>10.3
Chlorides (mg/l)	<50	50-250	250-600	>600
Fluorides (mg/l)	<1.5	1.5-3	>3	-

Source: Adapted from ASCE 1969

Some of these selected quality parameters for the reservoir under observation were monitored during the period of the filter trial and the results are presented in the following table .

Table14: Raw water characteristics of selected reservoir.

Filter run	pH	Chloride (mg/l)	Fluoride(mg/l)	Coliform (mpn/100ml)
day 3	7.3	10	0	4100
day 7	7.5	8	0	1200
day 11	7.3	8	0	1500
day 18	7.5	6.6	0	1300
day 27	7.3	10	0	1600
day 38	7.3	13.2	0	2000
day 41	7.1	14.3	0	4000
day 45	7.5	12	0	4000
day 51	7.6	11	0	2000
Average	**7.4**	**10**	**0**	**2411**

With the exception of the high coliform levels the average values of the monitored water quality parameters lie within the specified ranges for an excellent source. The reservoir under observation may thus be described as a good source of surface water for treatment into drinking water.

6.1.2 Characteristics of final water

The results of the laboratory tests after the ripening period (18 days) of the filter indicates water of a quality acceptable for human consumption by the stipulated WHO standards for drinking water. The maximum concentrations of all the measured quality parameters fall below stipulated WHO guideline values. The inference may thus be drawn that the filter system is very capable of producing water safe for human consumption.

Table 15:Final water characteristics

Filter run	Turbidity (NTU)	Fe (mg/l)	NH_3 (mg/l)	Mn (mg/l)	Colour (HU)	Total coliform (mpn/100ml)
day 3	76.9	0.57	0.78	0.076	150	400
day 7	30	0.19	0.78	0.025	70	400
day 11	21.1	0.11	0.1	0.025	35	300
day 18	5.1	0.11	0.11	0.009	5	0
day 27	6.66	0.05	0.33	0.012	5	0
day 38	5.6	0.04	0.06	0.047	5	10
day 41	4.2	0.05	0.11	0.008	10	0
day 45	2.8	0.01	0.05	0.002	4	0
day 51	3	0.11	0.03	0.011	4	0
MAX(after day 18)	**6.66**	**0.11**	**0.33**	**0.047**	**10**	**10**
MIN(after day 18)	**2.8**	**0.01**	**0.03**	**0.002**	**4**	**0**
AVG(after day 18)	**5**	**0**	**0**	**0**	**6**	**3**
WHO	**5**	**0.3**		**0.1**	**15**	**0**

6.2 Filter performance

The removal efficiencies of the different filter units with respect to various water quality parameters studied are presented in the following tables.

Table 16:Roughing filter 1 performance data

Removal efficiency (%)					
	Turbidity	Colour	Nitrate	Ammonia	Total Coliform
Day 3	71	60	63	42	51
Day 7	33	44	-	26	50
Day 11	60	67	20	26	60
Day 18	60	60	0	37	67
Day 38	69	56	63	27	55
Day 41	57	55	25	29	60
Day 45	76	83	0	49	83
Day 51	74	80	0	62	75
Max	**76**	**83**	**63**	**62**	**83**

Table 17:Roughing filter 3 performance data

Removal efficiency (%)					
	Turbidity	Colour	Nitrate	Ammonia	Total Coliform
Day 3	0	0	0	0	50
Day 7	59	0	-100	56	17
Day 11	42	40	88	26	33
Day 18	73	-17	56	3	0
Day 38	69	0	0	0	89
Day 41	57	22	33	9	69
Day 45	76	-20	-13	29	71
Day 51	74	0	-29	-35	40
Max	**76**	**40**	**88**	**56**	**89**

Table 18:Slow sand filter performance data

Removal efficiency (%)					
	Turbidity	Colour	Nitrate	Ammonia	Total Coliform
Day 3	-161	-150	-167	-95	60
Day 7	19	44	-100	0	80
Day 11	11	22	-200	57	75
Day 18	4	93	-25	69	100
day 38	80	91	-100	86	89
day 41	85	71	-25	74	100
day 45	89	87	22	71	100
day 51	86	87	33	87	100
Max	**89**	**91**	**33**	**87**	**100**

Table 19: VARIATION OF pH IN DIFFERENT FILTER UNITS

		RF 1	RF 3	SSF
DAY 3	Influent Value	7.3	9.4	9.4
	Effluent Value	9.4	9.4	9.4
DAY 7	Influent Value	7.5	7.3	9.4
	Effluent Value	7.3	9.4	9.1
DAY 11	Influent Value	7.3	7.3	9.5
	Effluent Value	7.3	9.5	9.4
DAY 18	Influent Value	7.5	6.9	7.1
	Effluent Value	6.9	7.1	9.1
DAY 38	Influent Value	7.1	no value	8.3
	Effluent Value	8.3	no value	8.3
DAY 41	Influent Value	7.5	9.1	9.3
	Effluent Value	9.1	9.3	9.3
DAY 45	Influent Value	7.6	9.2	9.4
	Effluent Value	9.2	9.4	9.4
DAY 51	Influent Value	7.5	7.9	8.3
	Effluent Value	7.9	8.3	8.9

Observations

1) The ripening period of the filters was 18 days since after that length of time the effluent from the slow sand filter assumed uniform conditions and produced rather good results.

2) The roughing filters were installed to primarily reduce the raw water turbidity to levels convenient for loading of the slow sand filter (ie.50NTU). Evaluation of the performance of the first roughing filter indicates clearly that one roughing filter would be enough to perform the required function. The range of effluent turbidities was from 41NTU to 19 NTU. A further look at the results of the third roughing filter does not show any significant improvement of the effluent of the first filter. The range of effluent turbidities was between 29 NTU to 19 NTU. The third roughing filter may thus be considered as unneccesary for this particular circumstance.

3) The removal efficiencies measured for roughing filter 1 for turbidity, colour and total coliform have been summarised as follows;
   - Turbidity (69%-76%)
   - Colour (55%-83%)
   - Total coliform (55%-83%)

4) The pH of the water increased considerably after passage through the roughing filtration. The significance of this pH increase is however not clear since it did not seem to adversely affect the functioning of either of the roughing filter or the slow sand filter. This increase in pH apparently seems to be attributable to the effect of the fresh cement used in constructing the partition walls in the roughing filter chambers. A longer period of observation and more detailed analysis would be required to confirm the actual cause and whether this condition is temporary or permanent.
   The variation in pH across the different filter units is presented in Table 19.

5) The primary function of the slow sand filter was to improve the bacteriological quality of the final water. In addition to this, some improvements in turbidity, colour and the chemical characteristics were also anticipated. The water quality parameters measured for the final

water clearly show the effect of the slow sand filter on the specified parameters. The maximum removal efficiencies range from 89% to 100% for the bacteriological quality parameters and from 71% to 91% for the physical and chemical parameters after the 18-day ripening period. The slow sand filter thus performed its functions very well within the set filtration rate of.0.11m/hr.

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Based on the field observations and analysis of the collected data the following conclusions have been made.

1) Slow sand filtration is an adequate treatment technology for improving surface reservoir waters for drinking purposes in the Northern Region of Ghana. The technology is simply to install operate and maintain. The purification action simply replicates what happens in nature and this is easily observed and understood by the local village folk who are to operate and maintain the system.

2) Vertical roughing filters may be used to pre-treat turbid raw waters prior to the actual treatment. A retention time period between 3 and 6 hours is adequate enough for the necessary removal mechanisms to effectively operate.

3) The filter system may be constructed completely from materials obtainable in the north. Clean river-bed gravel of sizes raging between 12 and 18 mm diameter may be used effectively as the media.

4) Good quality final water from the clear-well can only be assured if access to the final water is restricted through the use of a pump. No buckets or other similar fetching containers should be allowed direct access into the well.

5) Rural communities may economically operate a well designed slow sand filter system if adequate training in hygiene and operation and maintenance techniques is provided in a timely manner.

6) When rural communities are allowed to participate in the planning and development of their community slow sand filtration schemes, their will be a higher probability of them becoming more capable of assuming full responsibility for management of the system.

7.2 Recommendations

To enable such a very simplified filter system perform well under very typical village conditions will require a lot of innovative designing and training in both the technical operations and the environmental health related issued of hygiene and sanitation. The following recommendations seek to provide some guidelines based on the experience gained from this research work.

1) The filter system must comprise at least 2 parallel lines to allow for flexibility of operation and maintenance.
2) The filter system must be designed for individual village units or a small cluster (eg.3 villages) with populations ranging between 200 and 1000 inhabitants. A single reservoir could thus have more than one filter system being fed from it. This arrangement would foster a higher sense of ownership and consequently generate greater responsibility from the individual communities.
3) The minimum retention time in the roughing filter should be 3 hours to allow for adequate pre-treatment.
4) Maximum production capacity of the system must cater for market day populations (peak factor of 1.5 is reasonable).
5) Clear well must be sized to store all water produced in the night.
6) Only simply flow control devices should be incorporated in the design eg. Gate valves, colour-coded V-notch.
7) An effective well must be inserted to control the discharge from the slow sand filter and prevent sucking out of sand grains by pump.
8) All pipe drains used for cleaning purposes must be passed into a sump that can be bailed-out with buckets.
9) The design of the whole system mush ensure that animals cannot enter any of the individual units since the may die inside and contaminate all the water inside the system. The community folk may refuse to use water from facilities that suffer these problems.
10) The filter system must be roofed to discourage algae growth.
11) A comprehensive and properly scheduled training programme covering the technical, and health and hygiene aspects will be necessary to ensure a prolonged usage of the facilities. The training activities will, of necessity, be repetitive in nature.

LIST OF REFERENCES

1. Visscher J.T., Papamasivan R., Raman A.; Heijnen H.A., Slow sand filtration for community water supply, IRC Technical paper no.24, 1987, IRC, the Hague
2. Wegelin Martin, Surface water treatment by roughing filters, A design construction and Operation manual, 1996
3. Cairncross Sandy & Feacham Richard, Environmental health engineering in the tropics: An introductory text, 1991, John Wiley & Sons
4. Droste R.L. & Schiller E.J. Water supply & sanitation in development countries, 1982, Arbor science series
5. Wegelin Martin & Dorcoo Kolly, Potential of slow sand filters in the norhtern region of Ghana, Field report on evaluation mission, 1992
6. Wegelin Martin, Review of Zabzugu water treatment plant design and pilot plant studies at Salaga. Report on the evaluation mission, Sept, 1993
7. Akari Peter, Galaa Sylvester and Mohammed Janet Adama, VWR project monitoring report 1996
8. Greetham Mathew, IHE lecture notes on filtration, 1998
9. Huisman, IHE lecture notes on filtration, 1998
10. Visscher, J.T. & Veenstra S. Slow sand filtration manual for caretakers – 1985
11. Balaara E.Y. Damongo SSF pilot plant study, water quality analysis report, internal GWSC report, 1994
12. Dwamena-Boateng P., Damongo SSF pilot plant study, water quality analysis report internal GWSC report, 1994
13. Ahsan Tanver, Process analysis and optimization of direct horizontal-flow roughing filtration, doctoral dissertation IHE-Delft, 1995, AA Balkema, Rotterdam
14. Chapman Deborah, (editor) Water Quality Assessments, a guide to the use of biota, sediments, water in environmental monitoring, Chapman & Hall, 1992

LIST OF REFERENCES

1. Visscher J.T., Papamasivan R., Raman A., Heijnen H.A., Slow sand filtration for community water supply, IRC Technical paper no.24, 1987, IRC, the Hague
2. Wegelin Martin, Surface water treatment by roughing filters, A design construction and Operation manual, 1996
3. Cairncross Sandy & Feacham Richard, Environmental health engineering in the tropics: An introductory text, 1991, John Wiley & Sons
4. Droste R.L. & Schiller E.J. Water supply & sanitation in development countries, 1982, Arbor science series
5. Wegelin Martin & Dorcoo Kolly, Potential of slow sand filters in the norhtern region of Ghana, Field report on evaluation mission, 1992
6. Wegelin Martin, Review of Zabzugu water treatment plant design and pilot plant studies at Salaga. Report on the evaluation mission, Sept, 1993
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8. Greetham Mathew, IHE lecture notes on filtration, 1998
9. Huisman, IHE lecture notes on filtration, 1998
10. Visscher, J.T. & Veenstra S. Slow sand filtration manual for caretakers – 1985
11. Balaara E.Y. Damongo SSF pilot plant study, water quality analysis report, internal GWSC report, 1994
12. Dwamena-Boateng P., Damongo SSF pilot plant study, water quality analysis report internal GWSC report, 1994
13. Ahsan Tanver, Process analysis and optimization of direct horizontal-flow roughing filtration, doctoral dissertation IHE-Delft, 1995, AA Balkema, Rotterdam
14. Chapman Deborah, (editor) Water Quality Assessments, a guide to the use of biota, sediments, water in environmental monitoring, Chapman & Hall, 1992

15. Handbook on water treatment, Kemira Kemi AB, Water treatment, 1990

16. Ubels Jan, Frits van den Steen van Ommeren, Rural water supply in the Archdiocese of Tamale: Evaluation and project proposals, 1985, SAWA, Utrecht, the Netherlands

17. Village Water Reservoirs Project quarterly report 1994, 1995

18. GWSC-Tamale, Laboratory test records

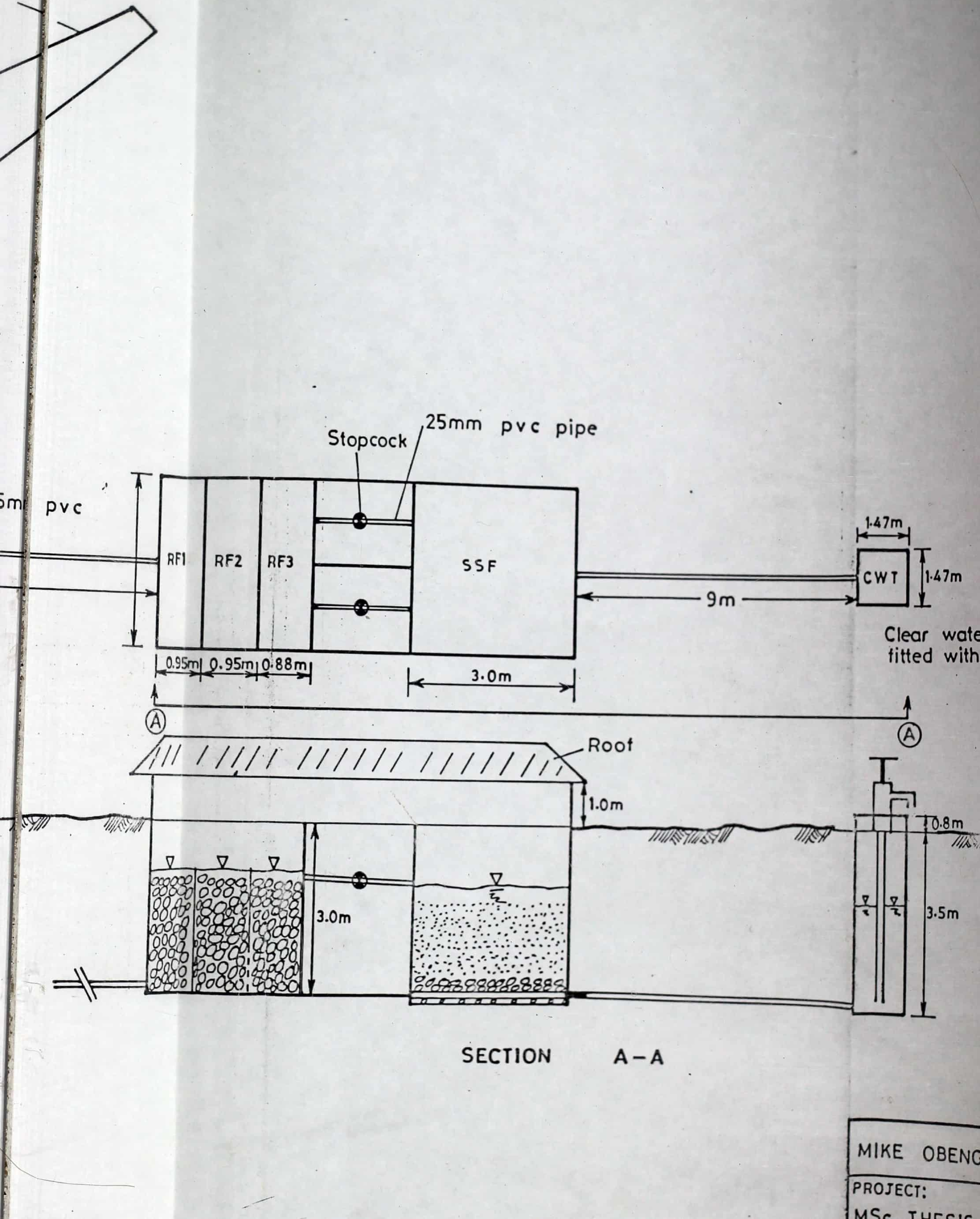
19. WHO Guidelines for drinking water quality. Vol.1 Recommendations, Geneva, 1984 (reprinted 1988)

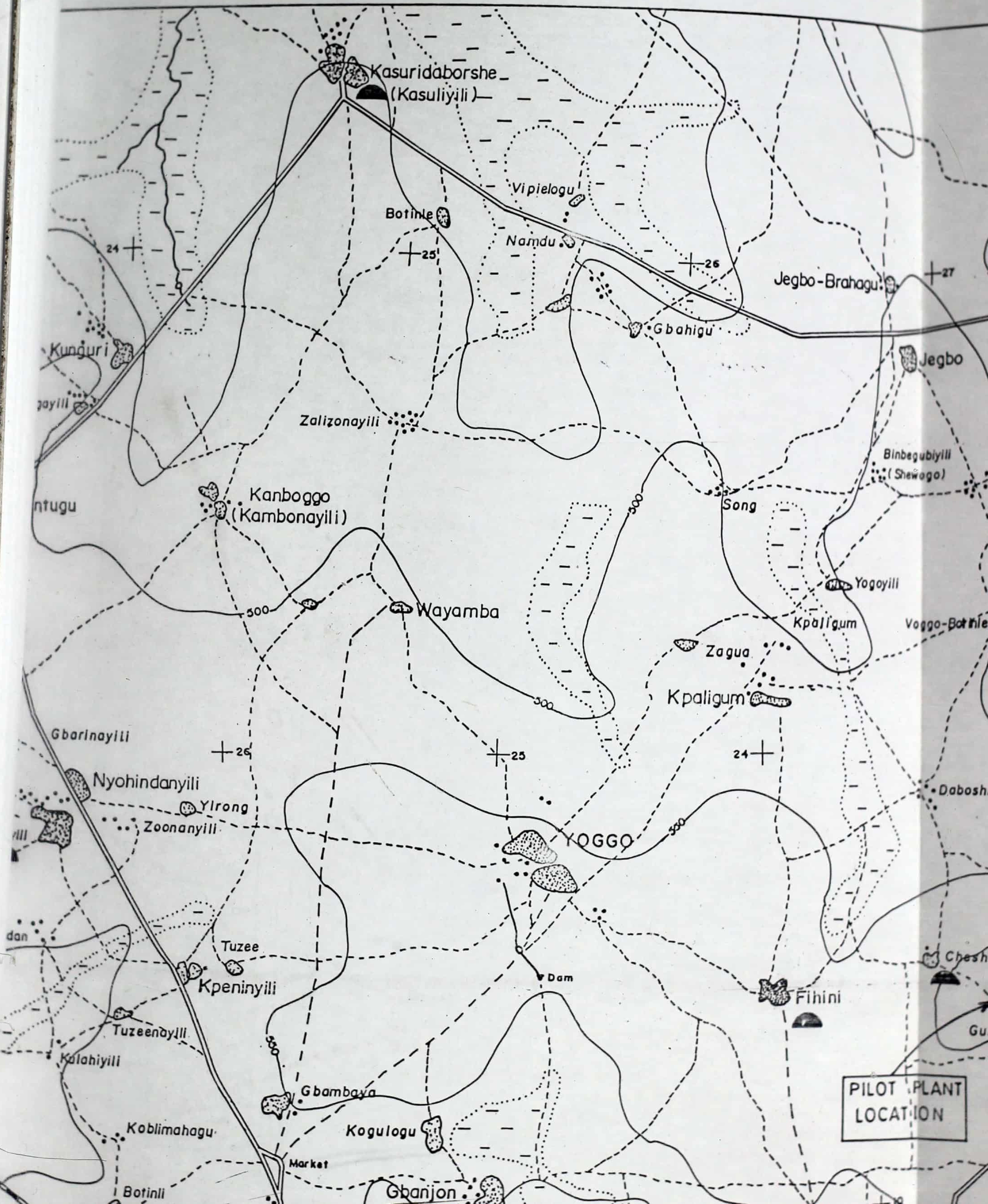
20. WHO Guidelines for drinking water quality, Vol.3: drinking water quality control in small community supplies, Geneva, 1985

21. Pescod M.B. et al, Slow Sand Filtration: A low cost treatment for water supplies in developing countries. Published by WRC(UK) & IRC for WHO European Regional Office pp 4-5.

LIST OF APPENDICES

Reservoir
Floating Intake
Earth Dam
75mm Feed line to Community
37.5mm pvc
Valve chamber
25m
RF1
0.95m
A
Communal fetching point
To GIZAA-GUNDAA Community


Stopcock
25mm pvc pipe
pvc
RF1
RF2
RF3
SSF
CWT
1.47m
1.47m
9m
0.95m
0.95m
0.88m
3.0m
A
A
Roof
1.0m
3.0m
0.8m
3.5m
SECTION A–A
PROJECT:


Kasuridaborshe
(Kasuliyili)
Vipielogu
Botinle
Namdu
24
25
26
Jegbo-Brahagu
27
Gbahigu
Kunguri
Jegbo
Zalizonayili
Binbegubiyili
(Shewago)
Kanboggo
(Kambonayili)
Song
Yogoyili
500
Wayamba
Kpaligum
Voggo-Botinle
Zagua
Kpaligum
Gbarinayili
26
25
24
Nyohindanyili
Ylrong
Zoonanyili
YOGGO
500
Daboshi
Tuzee
Kpeninyili
Dam
Fihini
Tuzeenayili
Kulahiyili
Gbambaya
PILOT PLANT LOCATION
Koblimahagu
Kogulogu
Market
Botinli
Gbanjon

Kasuridaborshe
(Kasuliyili)
Vipielogu
Botinle
Namdu
Gbahigu
Jegbo-Brahagu
Jegbo
Zalizonayili
Binbegubiyili
(Shewogo)
Kanboggo
(Kambonayili)
Song
Yogoyili
Wayamba
Kpaligum
Voggo-Botinle
Zagua
Kpaligum
Nyohindanyili
Yirong
Zoonanyili
Daboshie
YOGGO
Tuzee
Kpeninyili
Dam
Cheshegu
Fihini
Tuzeenayili
Kulahiyili
Gundaa
Gbambaya
PILOT PLANT
LOCATION
Koblimahagu
Kogulogu
Market
Botinli
Gbanjon
Zolbyili
Yobizeri
Tali
Sabegu
MP 20
MP 19
Vowageri
MP 18
Kanshegu
(Deserted)
Reservoir
MP 17
Reservoir
Dam
TOLON
RH
MP 16
Kurugu-Vahiyayili
Nambulegu

Dam
28
Voggo
Jego-Brahagu
27
26
Gbahigu
Jegbo
500
Binbegubiyili
(Shewogo)
Bonayili
Song
Yogoyili
Nyeris
Kpaligum
Voggo-Botinle
Zagua
Kpaligum
Bihinayili
Yrong
22
24
23
500
Daboshie
GGO
550
Kunkulun
550
Cheshegu
Fihini
Gundaa
Gizaa
PILOT PLANT
LOCATION
Jakpahi
11
550
10
09
Yobizeri
550
Sabegu
Vowageri
500
Reservoir
600
TOLON
RH
MP17
Dam
MP16
450
MP15
Woreboggo
RH
MP14
Bilisi
Reservoir
MP13
Nayili
D A M B I
Dingoni
Reservoir
06
05
07

TABLE A1: WHO GUIDELINE VALUES FOR DRINKING WATER QUALITY

PARAMETER	UNITS	GUIDELINE VALUE
Colour	TCU	15
Turbidity	NTU	5
pH		6.5-8.5
Hardness	mg/lCaCO3	500
Alkalinity	mg/lCaCO3	400
Sodium	mg/l	200
Chloride	mg/l	250
Sulphate	mg/l	400
Fluoride	mg/l	1.5
Iron	mg/l	0.3
Manganese	mg/l	0.1
Total coliforms	No./100ml	0
Faecal coliforms	No./100ml	0

Source: Water Quality Assessments, Deborah Chapman,1992, pp72-74, Chapman & Hall

Table A2 :Overview of functioning water supply facilities in Northern Region (November,1998)

DISTRICT	POP.1998	STANDPIPES/TAPS			BOREHOLES		DUG WELLS		TOTAL POP. SERVED	% of POP. SERVED
		PCI / CT	MECH.B-HOLES	POP. SERVED	NO.	POP. SERVED	NO.	POP. SERVED		
TAMALE	298,002	100		28,572	1	300	5	732	29,604	10
YENDI	118,154	2		528	99	25,383	4	279	26,190	22
BOLE	164,461		23	6,900	229	59,647	6	331	66,878	41
WEST GONJA	129,673	1		300	25	6,825	16	2,316	9,441	7
TOLON KUMBUNGU	212,127	60		15,296	-		7	1,050	16,346	8
EAST MAMPRUSI	190,766				10	2,789	47	6,724	9,513	5
WEST MAMPRUSI	244,612		1	300	190	51,111			51,411	21
SAB-CHERIPONI	95,017	86		7,991	55	10,509	52	4,695	23,195	24
GUSH.KARAGA	146,430	-			83	21,423	11	850	22,273	15
SAV.NANTON	101,442	5		1,500	34	9,386	10	835	11,721	12
ZAB.TATALE	74,085		1	300	92	21,659			21,959	30
NANUMBA	193,800	13		3,666	109	28,899			32,565	17
EAST GONJA	200,161	4		1,160	40	10,842	11	150	12,152	6
	2,168,730	**271**	**25**	**66,513**	**967**	**248,773**	**169**	**17,962**	**333,248**	**15**

SOURCE: Extracted from Community Water and Sanitation Agency (N/R) records

FIG.B1: TURBIDITY CHARACTERISTICS OF 4 RESERVOIRS IN PROJECT AREA

Monitoring period (months)

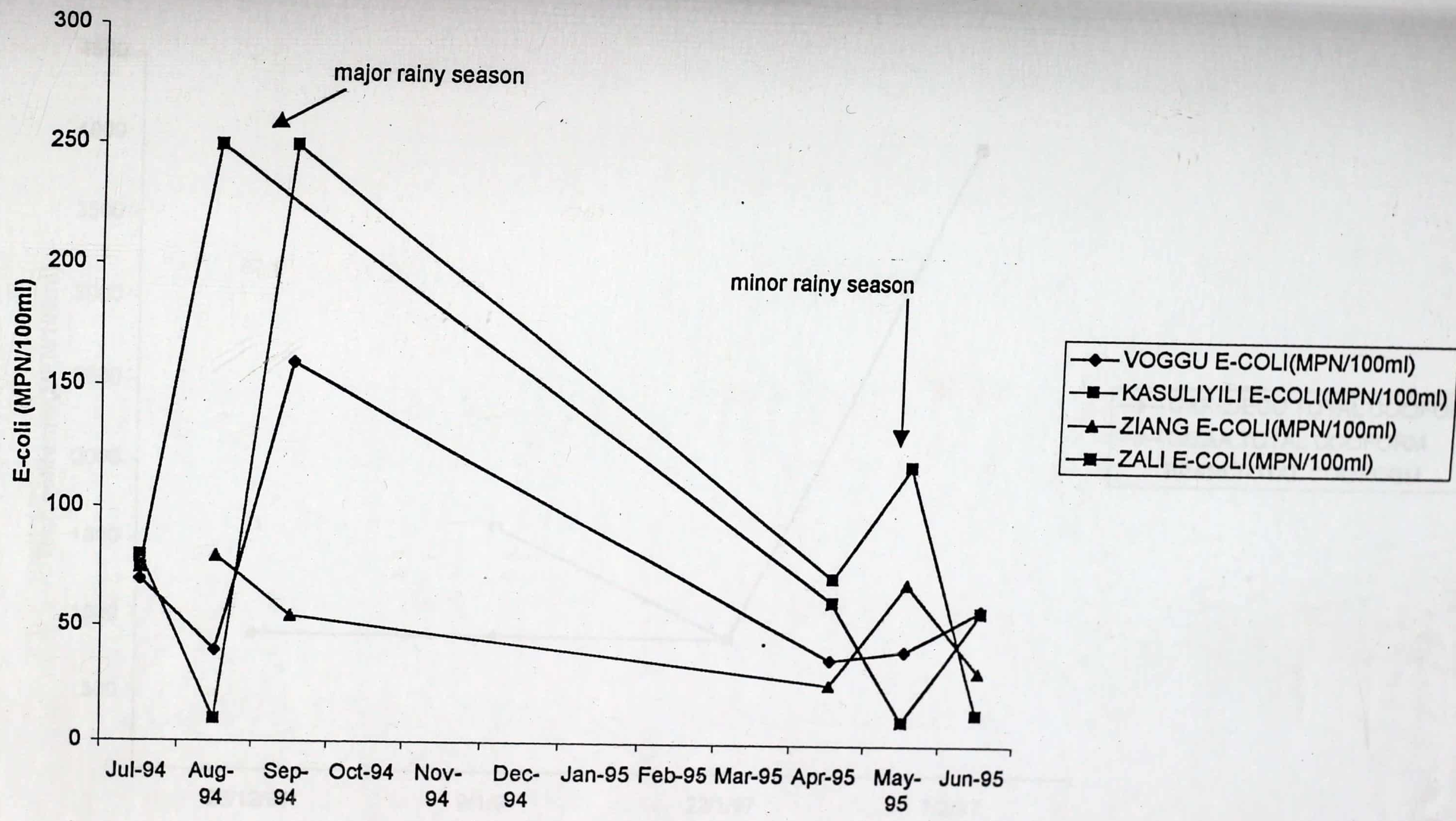
Source:Village Water Reservoirs quarterly reports

FIG.B2: TURBIDITY CHARACTERISTICS OF 3 RESERVOIRS IN PROJECT AREA

Source:GWSC Laboratory,Tamale

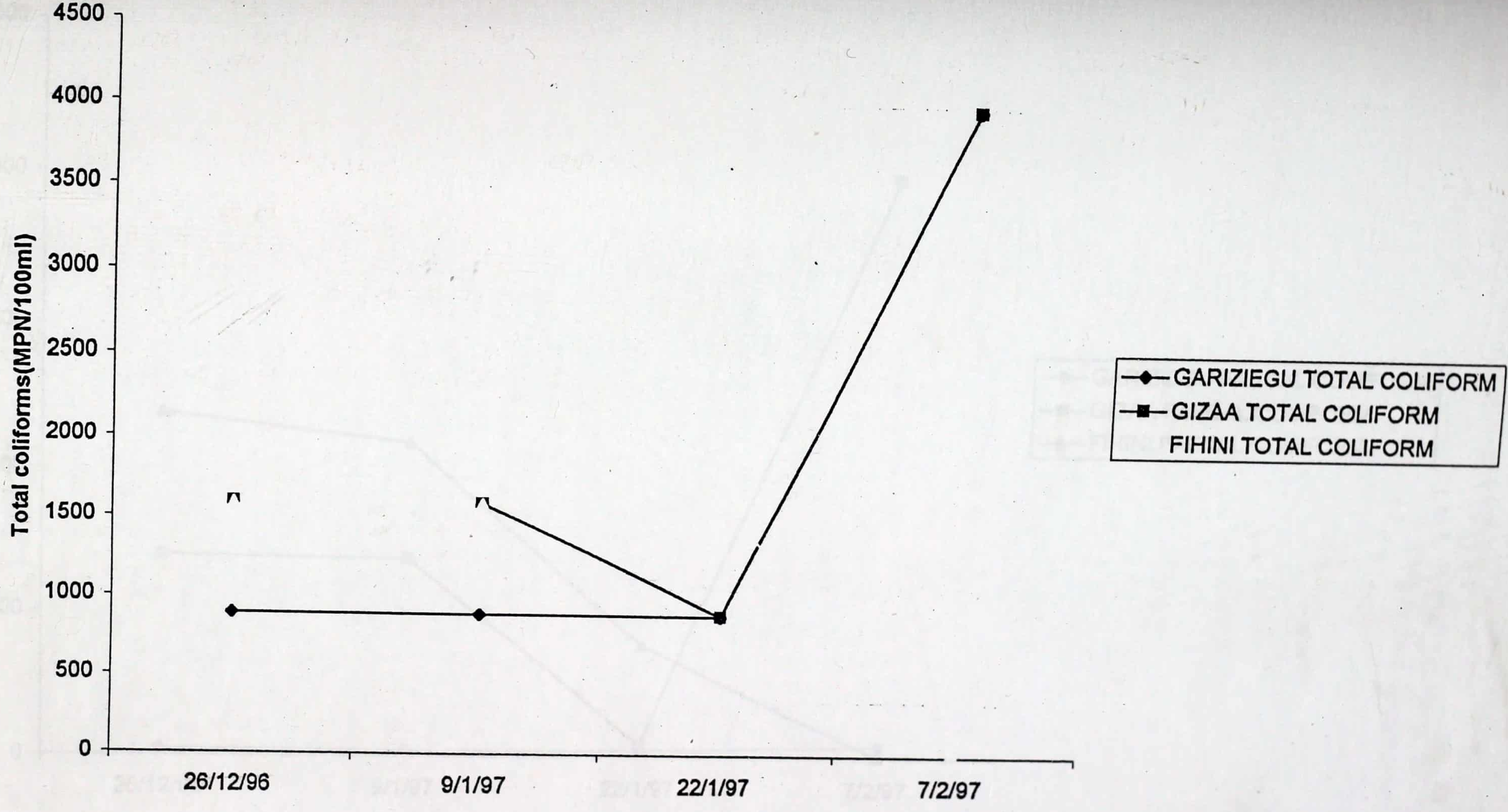
FIG.B3: CONDUCTIVITY CHARACTERISTICS OF 3 SELECTED RESERVOIRS IN THE PROJECT AREA

Source:GWSC Laboratory,Tamale



Source:Village Water Reservoirs quarterly reports

FIG.B5: TOTAL COLIFORM CHARACTERISTICS OF 3 SELECTED RESERVOIRS IN PROJECT AREA



Source:GWSC Laboratory,Tamale

FIG.B6: FAECAL COLIFORM CHARACTERISTICS OF 3 SELECTED RESERVOIRS IN PROJECT AREA

Source:GWSC Laboratory,Tamale

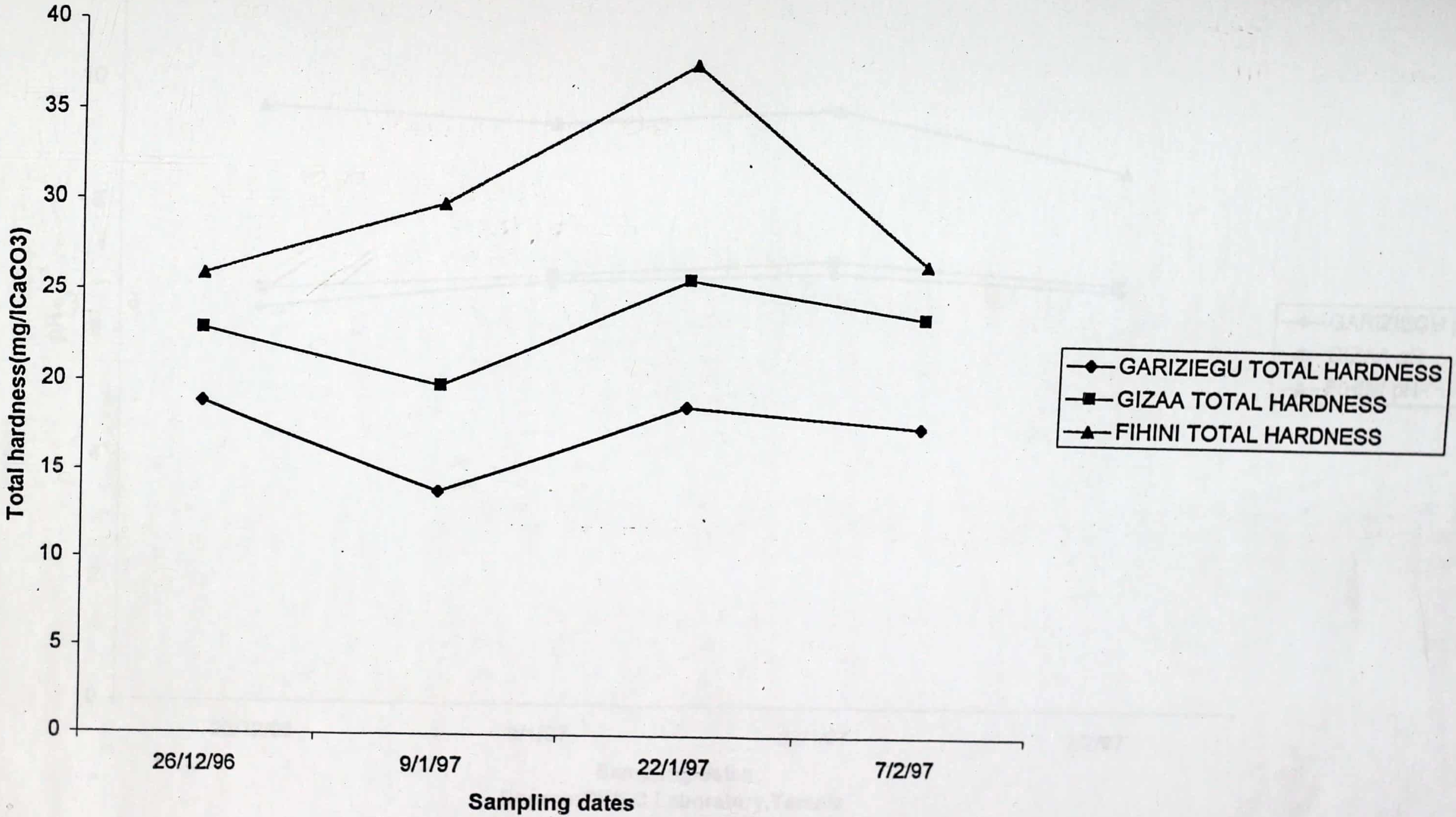
FIG.B7: TOTAL IRON CHARACTERISTICS OF 3 SELECTED RESERVOIRS IN THE PROJECT AREA

Source:GWSC Laboratory,Tamale

FIG.B8: AMMONIA CHARACTERISTICS OF 3 SELECTED RESERVOIRS IN THE PROJECT AREA

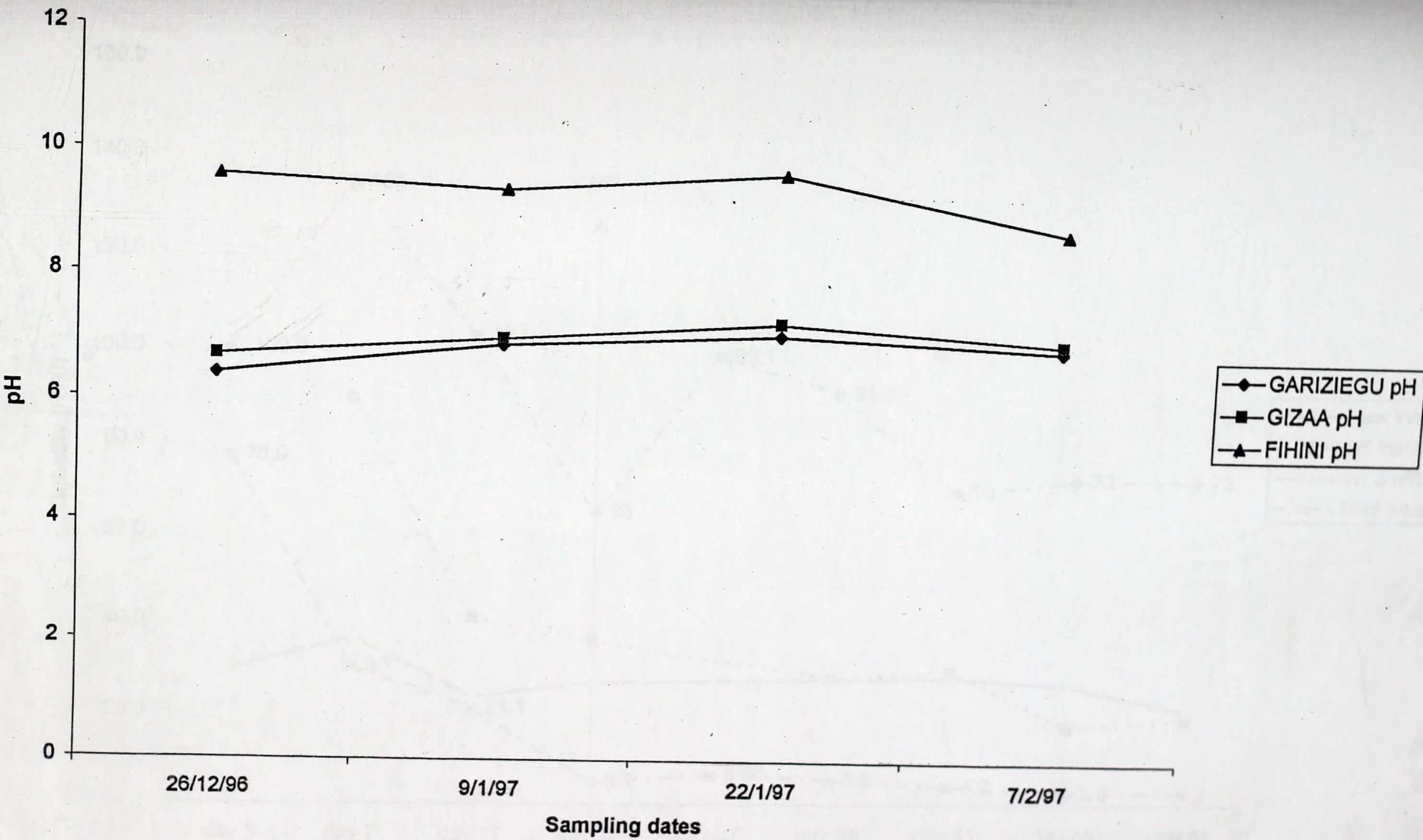
Source:GWSC Laboratory,Tamale

FIG.B9: TOTAL HARDNESS CHARACTERISTICS OF 3 SELECTED RESERVOIRS IN THE PROJECT AREA



Source:GWSCLaboratory,Tamale

FIG.B10: pH CHARACTERISTICS OF 3 SELECTED RESERVOIRS IN THE PROJECT AREA



Source:GWSC Laboratory,Tamale

FIG.C1: TURBIDITY VARIATION OVER FILTER RUN

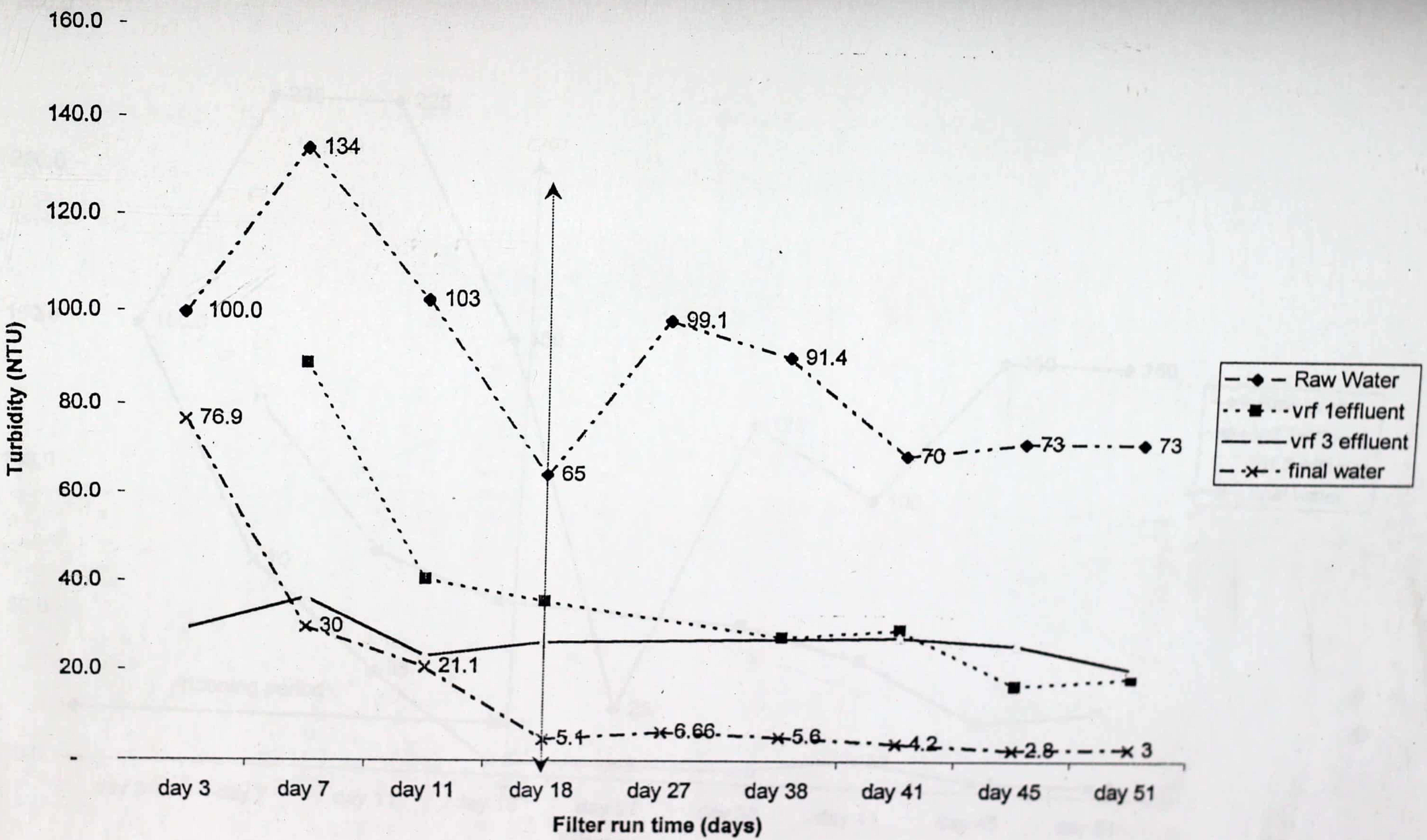


FIG.C2: VARIATION OF COLOUR OVER FILTER RUN

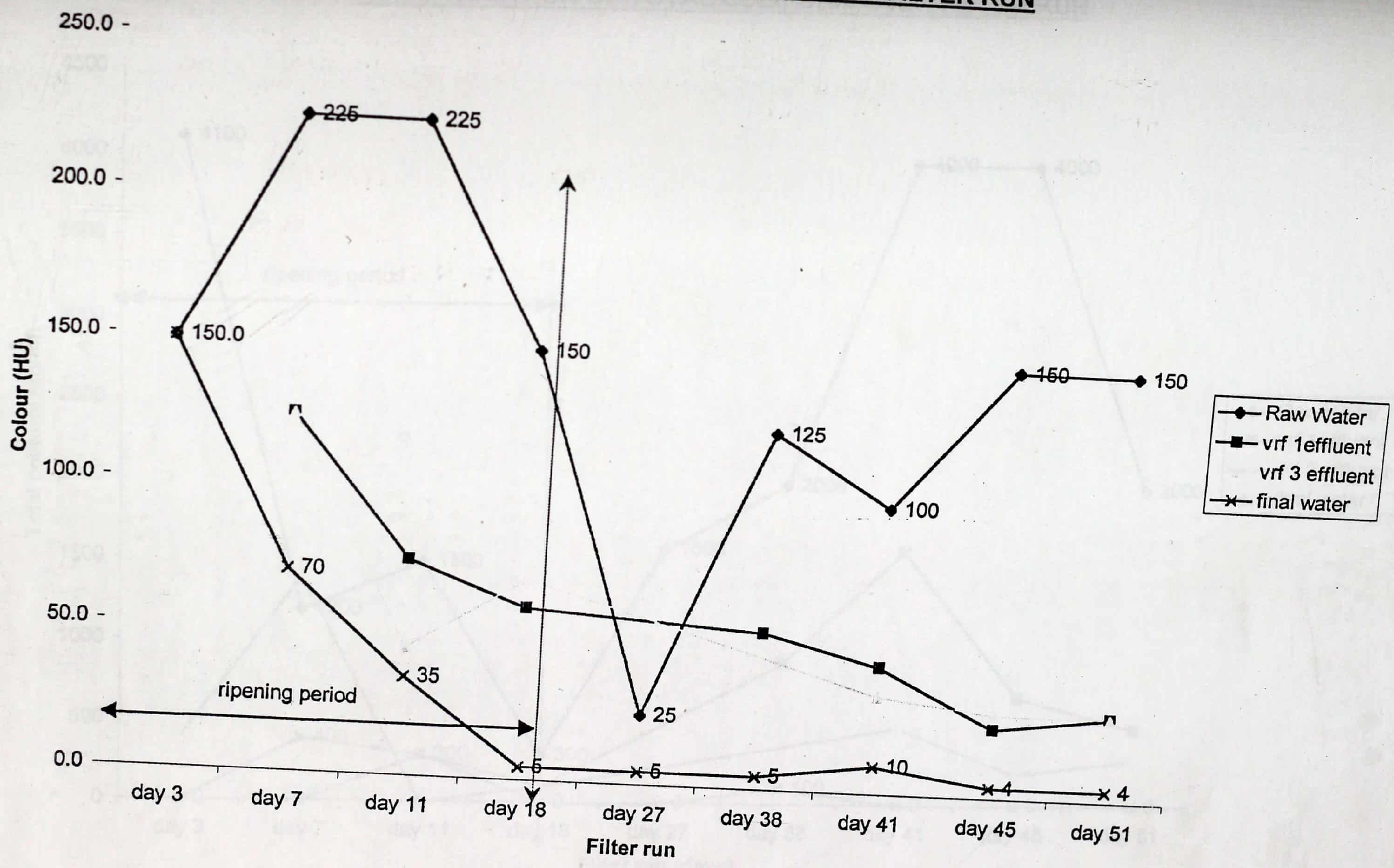


FIG.C3 VARIATION OF TOTAL COLIFORM OVER FILTER RUN

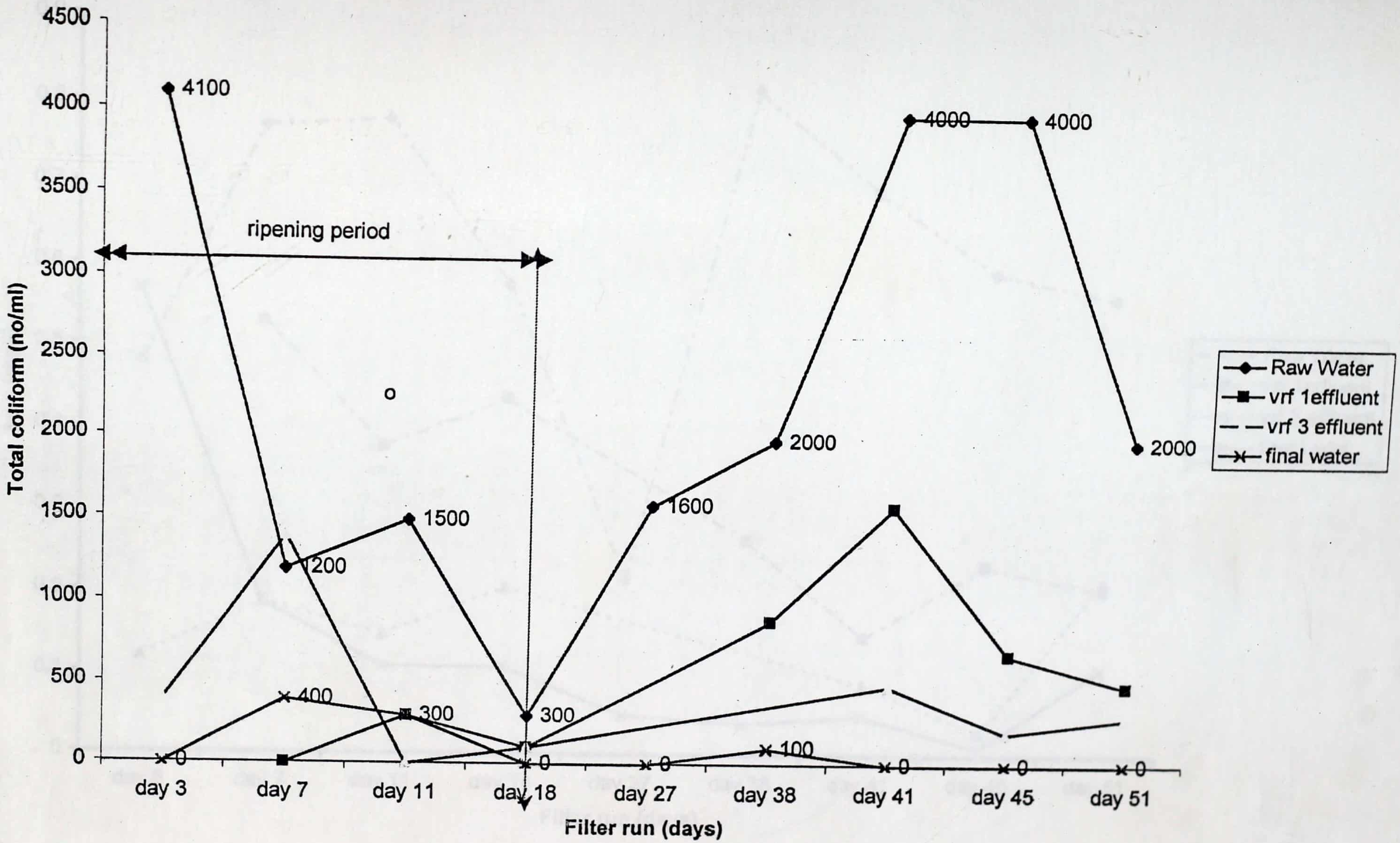


FIG.C4: VARIATION OF IRON CONTENT OVER FILTER RUN

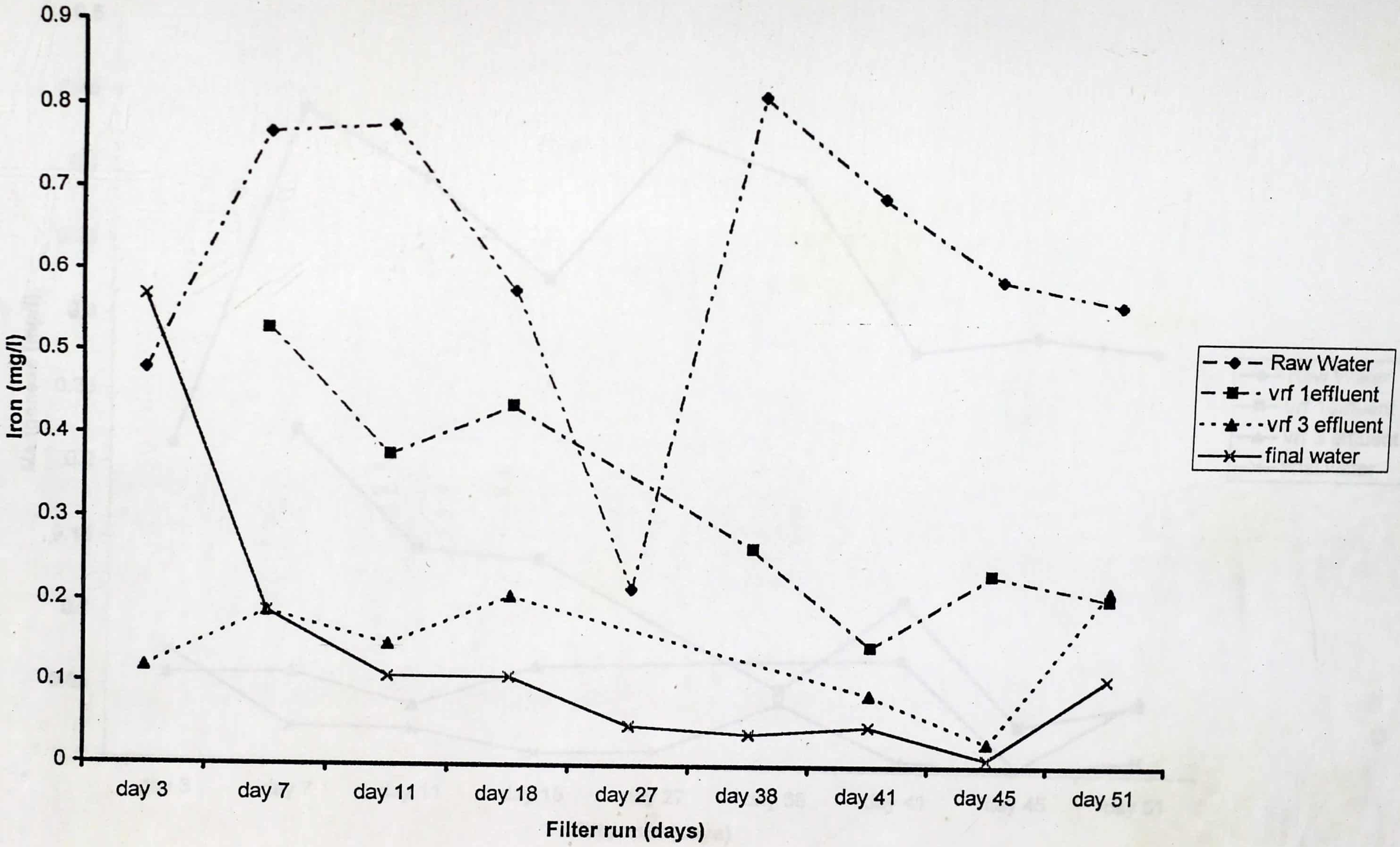


FIG.C5: VARIATION OF MANGANESE OVER FILTER RUN

FIG.C6: VARIATION OF AMMONIA OVER FILTER RUN

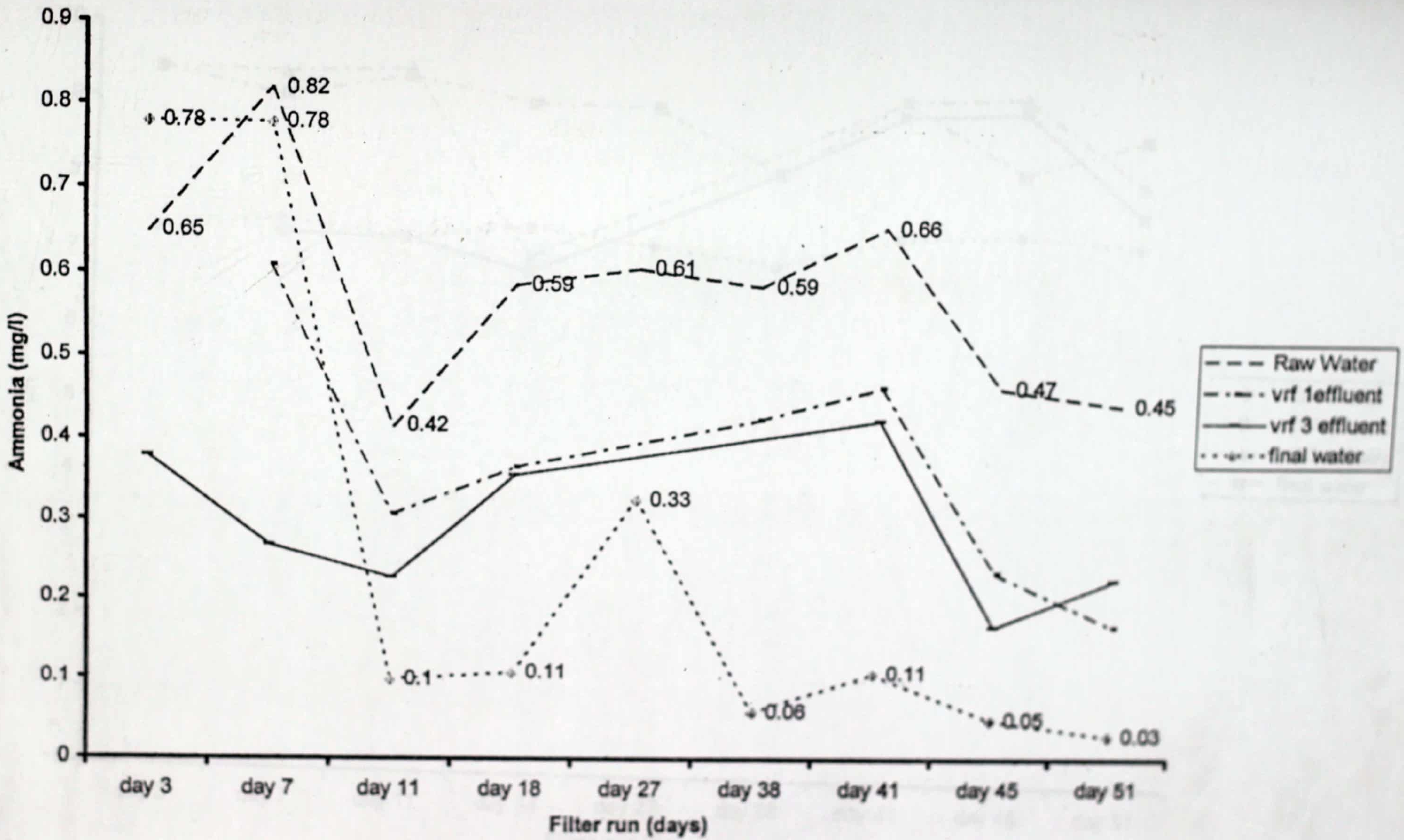


FIG.C7: pH VARIATION OVER FILTER RUN

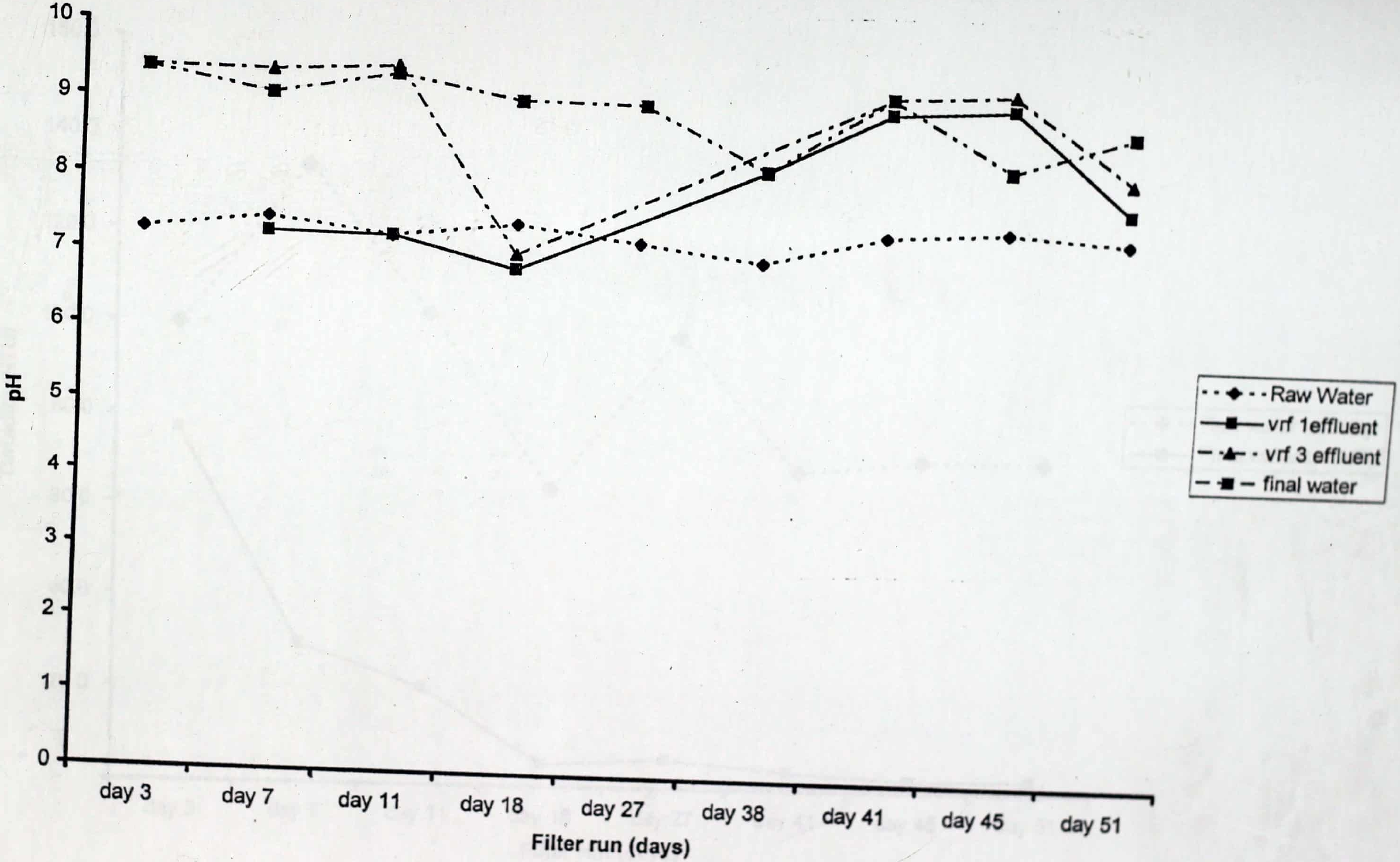
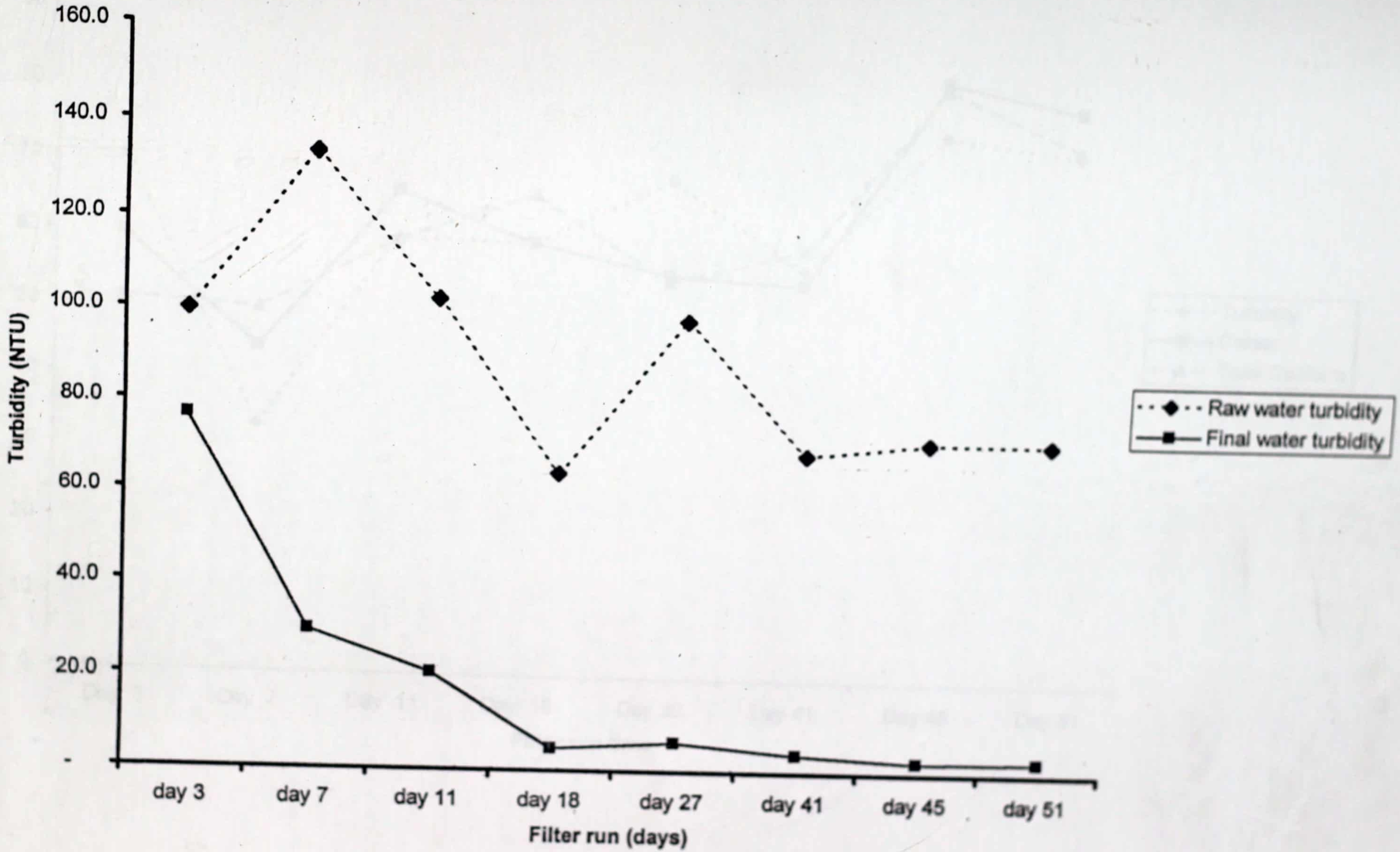


FIG.C8: TURBIDITY VARIATIONS OVER FILTER RUN




Removal efficiency (%)
0
10
20
30
40
50
60
70
80
90
Day 3
Day 7
Day 11
Day 18
Day 38
Day 41
Day 45
Day 51
Filter run time
Turbidity
Colour
Total Coliform

FIG.D2: REDUCTION OF TURBIDITY,COLOUR & TOTAL COLIFORM IN VRF 3

FIG. D3: REDUCTION OF TURBIDITY, COLOUR & COLIFORM IN SSF

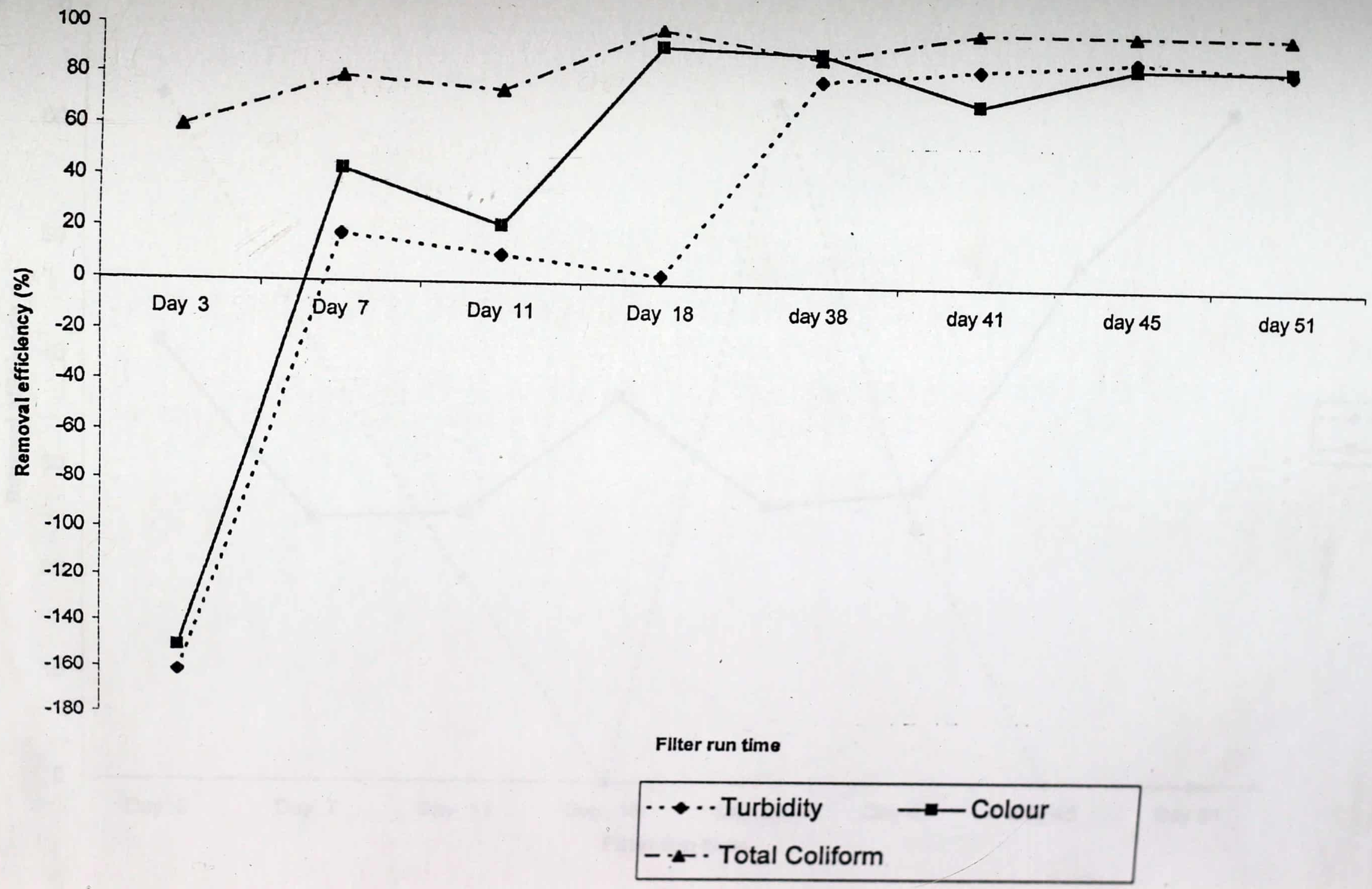


FIG.D4: AMMONIA & NITRATE REMOVAL IN VRF1

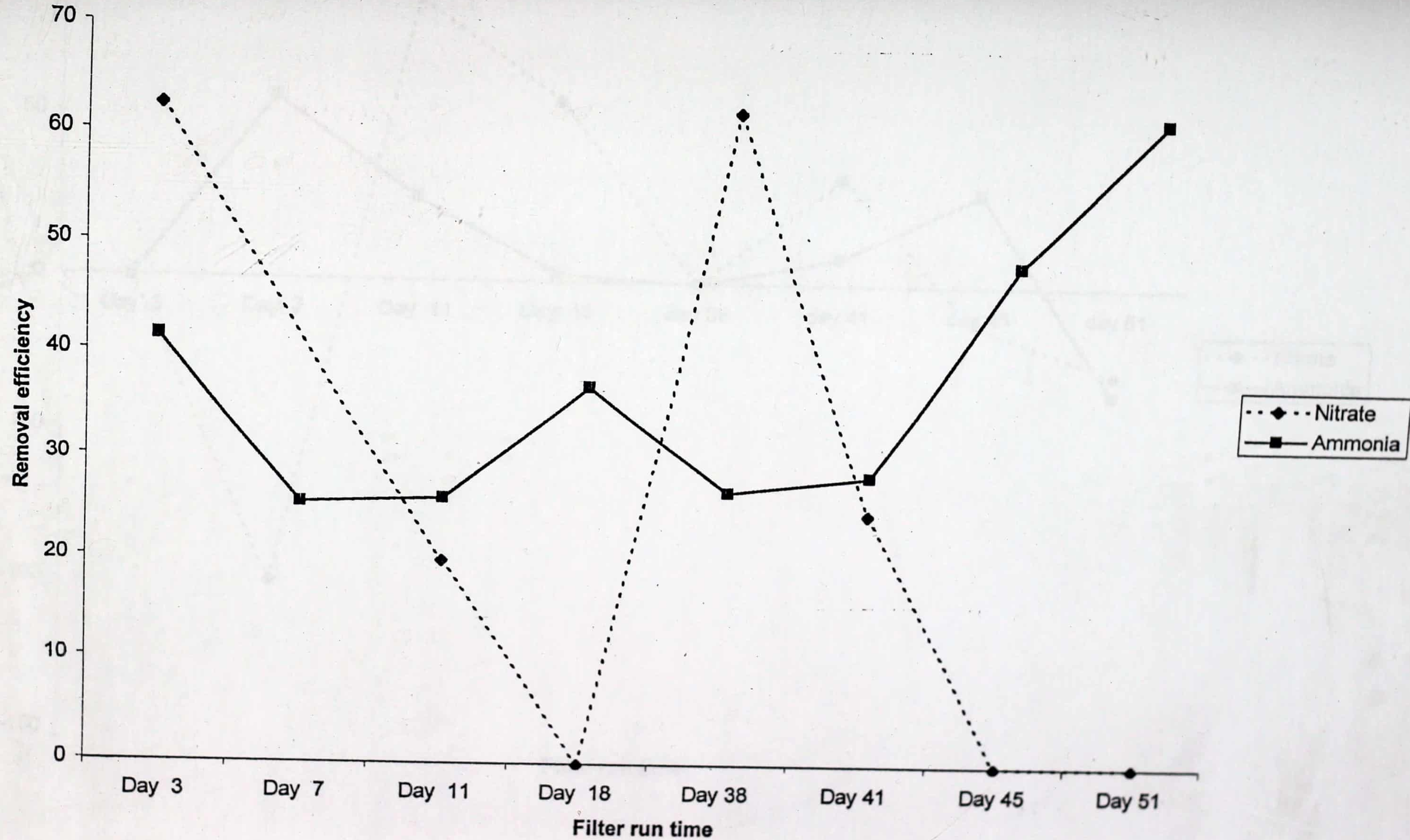


FIG.D5: AMMONIA & NITRATE REMOVAL IN VRF3

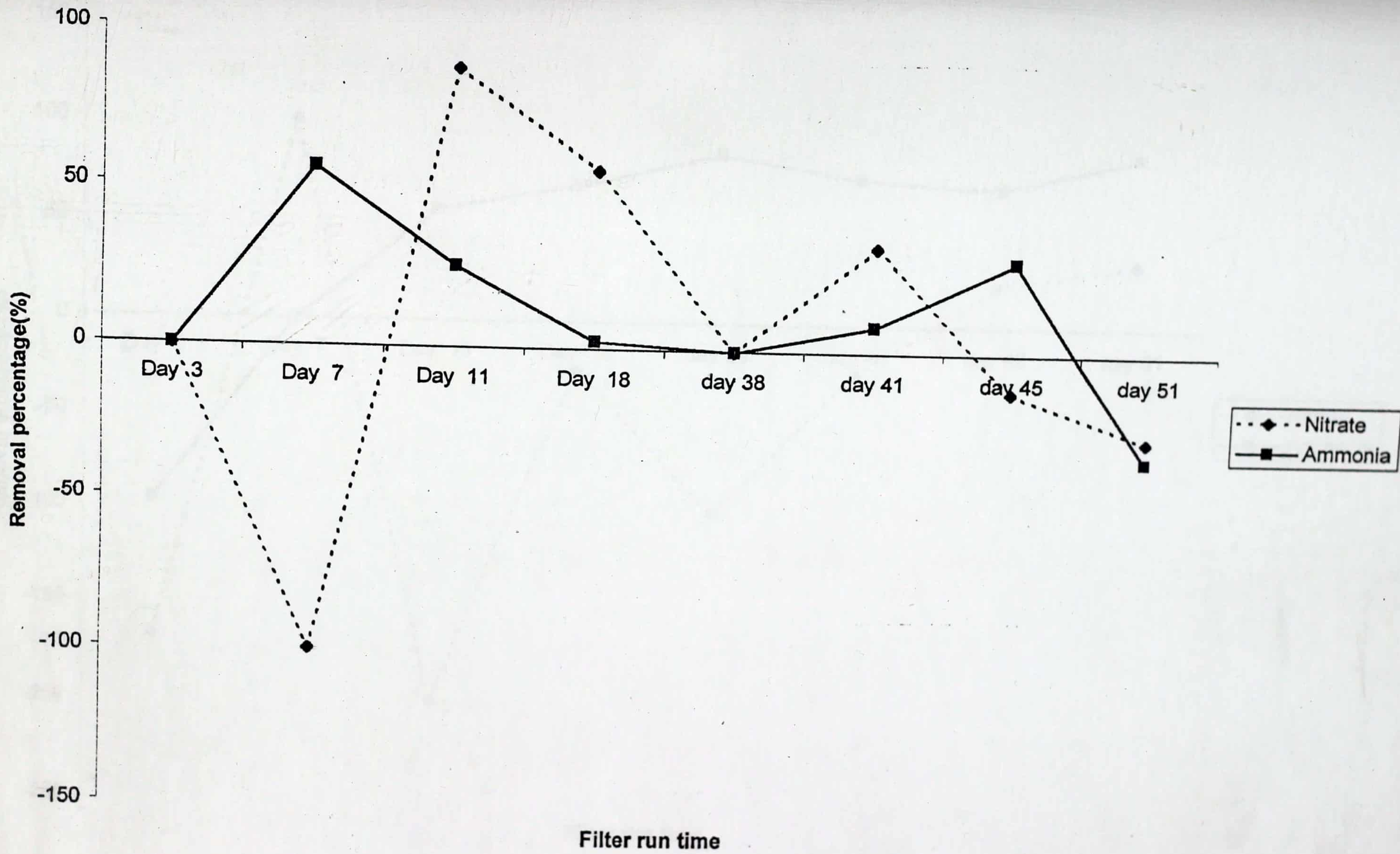


FIG.D6: REDUCTION OFAMMONIA & NITRATE SSF

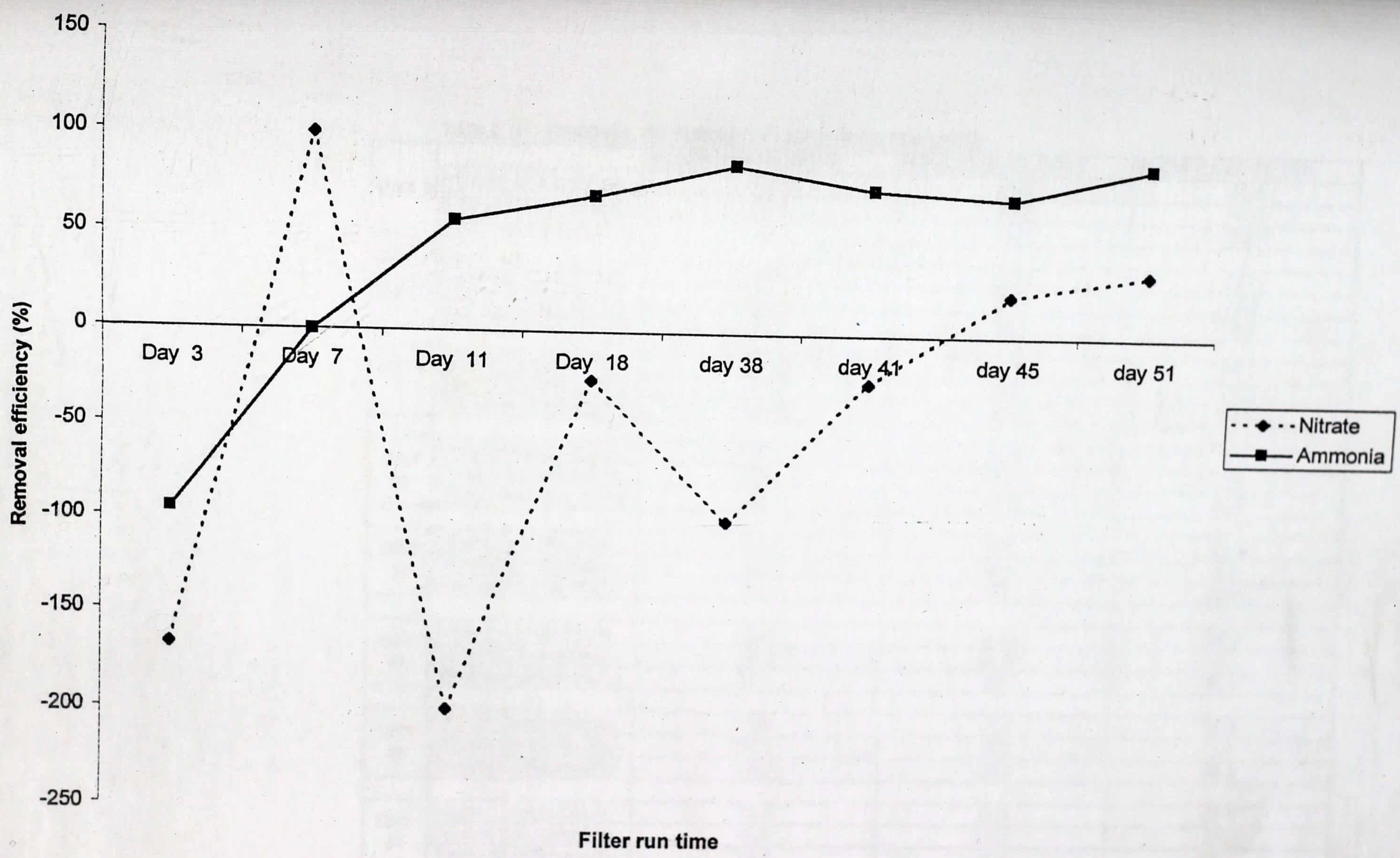


TABLE D1: REMOVAL OF TURBIDITY (NTU) IN FILTER UNITS

		ROUGHING FILTER 1	ROUGHING FILTER 3	SLOW SAND FILTER
DAY 3	Influent Concentration	100.0	29.5	29.5
	Effluent Concentration	29.5	29.5	76.9
	Removal Efficiency(%)	70.5	0.0	-160.7
DAY7	Influent Concentration	134.0	89.3	36.8
	Effluent Concentration	89.3	36.8	30.0
	Removal Efficiency(%)	33.4	58.8	18.5
DAY1 1	Influent Concentration	103.0	41.0	23.7
	Effluent Concentration	41.0	23.7	21.1
	Removal Efficiency(%)	60.2	42.2	11.0
DAY 18	Influent Concentration	75.1	30.0	8.1
	Effluent Concentration	30.0	8.1	7.8
	Removal Efficiency(%)	60.0	73.0	4.0
DAY 38	Influent Concentration	91.4	N/A	28.2
	Effluent Concentration	28.2	N/A	5.6
	Removal Efficiency(%)	69.1	N/A	80.1
DAY 41	Influent Concentration	70.0	30.0	28.3
	Effluent Concentration	30.0	28.3	4.2
	Removal Efficiency(%)	57.1	5.7	85.2
DAY 45	Influent Concentration	73.0	17.3	26.5
	Effluent Concentration	17.3	26.5	2.8
	Removal Efficiency(%)	76.3	-53.2	89.4
DAY 51	Influent Concentration	73.0	19.0	21.0
	Effluent Concentration	19.0	21.0	3.0
	Removal Efficiency(%)	74.0	-10.5	85.7

TABLE D2: REMOVAL OFCOLOUR (HU) IN FILTER UNITS

		ROUGHING FILTER 1	ROUGHING FILTER 3	SLOW SAND FILTER
DAY 3	Influent Concentration	150.0	60.0	60.0
	Effluent Concentration	60.0	60.0	150.0
	Removal Efficiency(%)	60.0	0.0	-150.0
DAY 7	Influent Concentration	225.0	125.0	125.0
	Effluent Concentration	125.0	125.0	70.0
	Removal Efficiency(%)	44.4	0.0	44.0
DAY 11	Influent Concentration	225.0	75.0	45.0
	Effluent Concentration	75.0	45.0	35.0
	Removal Efficiency(%)	66.7	40.0	22.2
DAY 18	Influent Concentration	150.0	60.0	70.0
	Effluent Concentration	60.0	70.0	5.0
	Removal Efficiency(%)	60.0	-16.7	92.9
DAY 38	Influent Concentration	125.0	0.0	55.0
	Effluent Concentration	55.0	0.0	5.0
	Removal Efficiency(%)	56.0	0.0	90.9
DAY 41	Influent Concentration	100.0	45.0	35.0
	Effluent Concentration	45.0	35.0	10.0
	Removal Efficiency(%)	55.0	22.2	71.4
DAY 45	Influent Concentration	150.0	25.0	30.0
	Effluent Concentration	25.0	30.0	4.0
	Removal Efficiency(%)	83.3	-20.0	86.7
DAY 51	Influent Concentration	150.0	30.0	30.0
	Effluent Concentration	30.0	30.0	4.0
	Removal Efficiency(%)	80.0	0.0	86.7

TABLE D3: REMOVAL OF NITRATE (mg/l) IN FILTER UNITS

		ROUGHING FILTER 1	ROUGHING FILTER 3	SLOW SAND FILTER
DAY 3	Influent Concentration	0.8	0.3	0.3
	Effluent Concentration	0.3	0.3	0.8
	Removal Efficiency(%)	62.5	0.0	-166.7
DAY 7	Influent Concentration	0.0	0.0	0.0
	Effluent Concentration	0.0	0.0	0.0
	Removal Efficiency(%)	0.0	0.0	-100.0
DAY 11	Influent Concentration	1.0	0.8	0.1
	Effluent Concentration	0.8	0.1	0.3
	Removal Efficiency(%)	20.0	87.5	-200.0
DAY 18	Influent Concentration	0.8	0.8	0.4
	Effluent Concentration	0.8	0.4	0.4
	Removal Efficiency(%)	0.0	56.0	-25.0
DAY 38	Influent Concentration	0.8	0.3	0.3
	Effluent Concentration	0.3	0.3	0.6
	Removal Efficiency(%)	62.5	0.0	-100.0
DAY 41	Influent Concentration	0.8	0.6	0.4
	Effluent Concentration	0.6	0.4	0.5
	Removal Efficiency(%)	25.0	33.3	-25.0
DAY 45	Influent Concentration	0.8	0.8	0.9
	Effluent Concentration	0.8	0.9	0.7
	Removal Efficiency(%)	0.0	-12.5	22.2
DAY 51	Influent Concentration	0.7	0.7	0.9
	Effluent Concentration	0.700	0.90	0.6
	Removal Efficiency(%)	0	-28.57	33.3

TABLE D4: REMOVAL OF AMMONIA (mg/l) IN FILTER UNITS

		ROUGHING FILTER 1	ROUGHING FILTER 3	SLOW SAND FILTER
DAY 3	Influent Concentration	0.7	0.4	0.4
	Effluent Concentration	0.4	0.4	0.8
	Removal Efficiency(%)	41.4	0.0	-90.2
DAY 7	Influent Concentration	0.8	0.6	0.3
	Effluent Concentration	0.6	0.3	0.3
	Removal Efficiency(%)	25.6	55.7	0.0
DAY 11	Influent Concentration	0.4	0.3	0.2
	Effluent Concentration	0.3	0.2	0.1
	Removal Efficiency(%)	26.2	25.8	56.5
DAY 18	Influent Concentration	0.6	0.4	0.4
	Effluent Concentration	0.4	0.4	0.1
	Removal Efficiency(%)	37.3	2.7	69.4
DAY 38	Influent Concentration	0.6	0.0	0.4
	Effluent Concentration	0.4	0.0	0.1
	Removal Efficiency(%)	27.1	0.0	86.0
DAY 41	Influent Concentration	0.7	0.5	0.4
	Effluent Concentration	0.5	0.4	0.1
	Removal Efficiency(%)	28.8	8.5	74.4
DAY 45	Influent Concentration	0.5	0.2	0.2
	Effluent Concentration	0.2	0.2	0.1
	Removal Efficiency(%)	48.9	29.2	70.6
DAY 51	Influent Concentration	0.45	0.17	0.23
	Effluent Concentration	0.17	0.23	0.03
	Removal Efficiency(%)	62.22	-35.29	86.96

TABLE D5: REMOVAL OF TOTAL COLIFORM (no./ml) IN FILTER UNITS

		ROUGHING FILTER 1	ROUGHING FILTER 3	SLOW SAND FILTER
DAY 3	Influent Concentration	41.0	20.0	10.0
	Effluent Concentration	20.0	10.0	4.0
	Removal Efficiency(%)	51.2	50.0	60.0
DAY 7	Influent Concentration	12.0	6.0	5.0
	Effluent Concentration	6.0	5.0	1.0
	Removal Efficiency(%)	50.0	16.7	80.0
DAY 11	Influent Concentration	15.0	6.0	4.0
	Effluent Concentration	6.0	4.0	1.0
	Removal Efficiency(%)	60.0	33.3	75.0
DAY 18	Influent Concentration	3.0	1.0	1.0
	Effluent Concentration	1.0	1.0	0.0
	Removal Efficiency(%)	66.7	0.0	100.0
		MPN/100ML	**MPN/100ML**	**MPN/100ML**
DAY 38	Influent Concentration	2000.0	55.0	900.0
	Effluent Concentration	900.0	6.1	100.0
	Removal Efficiency(%)	55.0	89.0	88.9
DAY 41	Influent Concentration	4000.0	1600.0	500.0
	Effluent Concentration	1600.0	500.0	0.0
	Removal Efficiency(%)	60.0	68.8	100.0
DAY 45	Influent Concentration	4000.0	700.0	200.0
	Effluent Concentration	700.0	200.0	0.0
	Removal Efficiency(%)	82.5	71.4	100.0
DAY 51	Influent Concentration	2000.00	500.00	300.00
	Effluent Concentration	500.00	300.00	0.00
	Removal Efficiency(%)	75.00	40.00	100.00

TABLE E1: Sample of Questionnaire for Community Members

Name :
Occupant:
Age:
• Do you filter water you fetch from the dam Yes---- No----
• Are you aware of the filter near the dam? Yes---- No----
• Did you request for the filter ---- Yes No----
• Were you consulted before the filter was fixed Yes---- No----
• Do youknow its purpose Yes---- No----
• What is it..
• Do you think it is necessary Yes---- No----
• Why..
• Do you use water from the filter Yes---- No----
• What is the water like..
• Do you like it Yes---- No----
• Who takes care of the filter surroundings..................................
• Did youpay money towards construction of the dam Yes---- No----
• How much..
• Do you pay money towards maintenance of the dam Yes---- No----
• How much..
• If the filter develops a problem would you be prepared to pay money for repairs Yes--- -No----
• Why..

TABLE E2: Name of Respondents

NAME OF RESPONDENT	OCCUPATION	AGE (years)
1. Azara	Cooked rice seller	40
2. Barichisu Danaa	Paddy rice processor	30
3. Memunatu Adam	Housewife	32
4. Lansah	Paddy rice processor	40
5. Adamu Haruna	Housewife	32
6. Martha Issah	Petty trader/Birth attendant	
7. Labi Alhassan	Trader	
8. Mamunatu Musah	Housewife	25
9. Mariamah Imoro	Housewife	
10. Belimsa Dokurugu	Housewife	
11. Haruna Dawudu	Farmer	35
12. Shero Issah	Farmer	46
13. Sheini Dahamri	Farmer	40
14. Yakubu Naporo	Farmer	40
15. Sirazu Dachea	Teacher/Assemblyman	33
16.Damba Suyiri	Farmer	65
17.Sayibu Abukari	Farmer	25
18. Abdulai Dahamini	Farmer	60
19. Barnabas Salifu	Farmer	30
20. Abdulai Tia	Farmer	36