THE QUALITY OF WATER OF THE WEIJA DAM AND THE DENSU RIVER

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DECLARATION

I declare that this document embodies results of my own work as presented under the supervision of Professor G.S. Ayernor of the Department of Nutrition and Food Science, University of Ghana, Legon.

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DEDICATION

This work is dedicated to my family, Hon. Joshua and Borley Alabi. I am so blessed to share my life with you. Thank you for the care, support and encouragement.

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ABSTRACT

In recent years there has been an immense public outcry over the concern of the quality of water from the Densu River and the Weija reservoir.

In an attempt to study the quality of water from the Densu River and the Weija reservoir, a 2 x 5 factorial experiment with two seasons (rainy and dry) and five sources of water (Akwadum, Asuboi, Nsawam, Manhia and the Weija Dam) as variables was performed. These water samples were analysed for various physical, chemical, nutritive and microbiological indices of water quality using the American Public Health Association (APHA) Standard Methods. As well, the quality of water from the surface and bottom levels of the Weija Dam were analysed and compared with that of treated water from the Weija Dam. The results of the quality of water from this current studies were compared to the quality of water from the Densu River Basin at the pre-impoundment era.

The quality status of water from the Densu River and the Weija reservoir revealed that generally the water can be classified as an acceptable source of water supply even though it is quite polluted. This is because the present quality is comparable to that of the pre-impoundment era, which was classified as a good source of water supply using Todd's classification of water quality on the Densu River. Contrary to this classification, phosphate level of the Densu River at that time was as high as that of the highly eutrophic Lake Barekese in the Ashanti Region, which ranged from 0.01-1.2 mg/L. However, predictions from earlier studies stated that if the phosphate levels observed at that time was maintained, the Weija Lake would suffer from eutrophication and its attendants problems, which includes poor quality and high cost of treatment. With a range of 0.08-0.64 mg/L, this study reveals that the current quality status of water in Densu River Basin confirms the prediction.

Nutritively, the high phosphate level coupled with the dramatic increase in BOD levels that have no guideline values, and ranged from 0.77–9.9 mg/L during the period under consideration is indicative of the level of organic matter pollution. In addition, the low Dissolved Oxygen (DO) levels, which range from 1.6-9.4 mg/L indicates poor nutritive quality.

Physically, the quality of water in the Densu River basin can be said to be poor as suggested by the high colour value (30-90 TCU against a guideline value of 15 TCU), turbidity (6-54 NTU against a guideline value of 5 NTU), pH (7.5-8.4) and conductivity (162-681 µg/cm as against a guideline value of 400 µg/cm). Biologically, the chlorophyll A levels ranging from 16.5 – 83.0 µg/cm, which even though were not excessive, indicates a degree of algal biomass. Total coliform (TC) and faecal coliform (FC) counts, which ranged from 100–1940 count/100ml are indicative of high microbial contamination, reflecting poor sanitary conditions in the Basin.

Chemically, the quality of water in the basin can be said to be acceptable except for Iron which had values ranging between 0.2-1.59 mg/L, which was above the guideline value 0.3 mg/L, and chloride that had values within 9.2 and 112.0 mg/L, is indicative of some level of pollution. The comparative studies between the quality of water in the rainy and dry seasons revealed that generally the quality of water in the Densu River Basin is better in the rainy season than the dry season. Trends in the water quality were also observed to decrease down across the Densu River Basin. However, water from the Weija dam was relatively better in quality compared to the quality of water in the Densu River Basin.

In conclusion, the quality of water from both the Densu river and the Weija Dam were regarded acceptable and within the guideline values given for their

physical, chemical and microbiological quality limits, even though a few chemical indices showed values that were slightly above their guideline limits. This signifies water from both the Weija Dam and the Densu River Basin are polluted. However, the level of pollution observed in the two water bodies though quite high, is not high enough to conclude that they are bad sources of water for human activities and treatment for consumption.

The study therefore recommends among others, the improvement of the quality in the management process of water in the Densu River Basin. These may involve the enforcement of regulations regarding fishing and farming in the Densu River Basin, improvement of sanitary conditions, education as well as follow-up research studies to be conducted on the quality of water from the basin.

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1.0 INTRODUCTION

1.1 Importance of water

Water is one of the most important natural resources without which life cannot exist. It is the most abundant and the most widely distributed and used chemical compound, which is very important to life and its related activities. Man has put water into several uses in order to sustain animal and plant life. Water is of fundamental importance to all social and economic activities and thus integral to the process of every development. We live in a world of water, but only 1% of the world's total water reserves is available for human use (World Book Encyclopaedia, 1994). However, the total quantity of fresh water on earth could satisfy all the needs of human population if it were evenly distributed and accessible. This is because 97% of the earth's water is saline ocean water, 2% is frozen in polar icecaps and glaciers, and of the remaining 1% of the earth's water more than half (0.6% of the total supply) is contained in ground water and the remaining in rivers, streams and lakes (Shiklomanov, 1993). As a matter of fact barely 0.3% of the earth's water is available for human use (Engleman and Le Roy, 1993).

Besides this, as world's population increases, the need for water also increases and the resultant effect on the resource also escalates. The consequence is that the availability and quality of the resource also keep declining. Indeed the stresses produced by water resource inadequacies are not only limited in use but rather the frustrations over water scarcity and over-dependence keep becoming more pronounced leading to disputes within and between countries. The result is that, some one billion people mostly in developing countries do not have access to clean water and about two to three million children die annually because of diseases associated with lack of water and its associated sanitation problems (EPA, 1997). Eighty percent of common diseases in developing nations are caused either by unwholesome water or lack of sanitation and about twenty-five thousand lives most of them being children are destroyed daily through water borne diseases (Dando, 1995).

In addition to this, trace amounts of some potentially toxic chemicals or excessive amounts of some minerals can also be harmful. These could pose hazards to human health when present in drinking water. The problem associated with these chemical constituents arises from their ability to cause adverse health effects after prolonged periods of exposure. For instance, acute exposure of humans to high concentrations of benzene primarily affects the central nervous systems and at lower concentrations, is toxic to the haematopoietic system causing a continuum of haematological changes, including leukemia (WHO, 1993). Many of the possible contaminants are organic compounds. These are from chemicals used as insecticides, detergents, lubricants, and from other industrial productions. Toxicological effects of water-borne organics have been observed principally in connection with the chlorinated hydrocarbon and organic phosphorus compounds used as pesticides (Clarke, 1977).

The role of water in the environment is important to the proper functioning of various ecosystems, the survival of species including man and for socio-economic development. The peculiar point about water is that while it is vital to the survival of ecosystems, it can also be impacted upon adversely by human development. The threats to ecosystem functioning arising from the degrading quality of water and its diminishing quantity are issues that countries, both developed and developing have become acutely aware of and are putting strategies in place to contain them. Water therefore is a social, economic as well as a political resource which if not well handled could create a serious social and political upheaval.

This calls for an effective management of all water resources. However, the management of water in a drainage basin can only be successful if goal-oriented workable decisions are made on sound diagnosis and data and, of course, executed (Colerangle, 1994).

1.2 The need for water quality management in Ghana

In Ghana the need for an intensive and integrated water resources management is even more critical and calls for an urgent attention to the quality of our water bodies. This situation has arisen due to the increasing population within Ghana and in upstream nations that share the Volta River with Ghana. This has led to the acute water shortage problems currently affecting many sectors of the economy. Pollution and land degradation are also undermining the already stressed resource base. It has been reported that 44% of the country's water need is for domestic consumption, 54% for agriculture and 3% for industry (Boateng, 1995).

All types of pollutants affect the water bodies in Ghana since most manufacturing industries discharge untreated waste directly into them. Moreover, untreated household water is also discharged directly into these water bodies. The introduction of these wastes coupled with the dumping of waste from some economic and environmental activities have led to the death of water bodies like the Korle Lagoon in Accra, Sakumono Lagoon in Tema and Fosu Lagoon at Cape Coast.

Currently the Densu River basin is the next in the series since the mass media reveal news items often on the rapid deteriorative nature of the Densu River and it's reservoir, the Weija Dam besides the numerous consumer complains about the taste and odour characteristics of water from this source. Apart from this deteriorative nature of our water bodies, it is being speculated that the nation may face an additional problem of insufficient water supply by the turn of the century. The need to curtail the over-dependence on the Volta River is indeed most timely. The Densu River which forms part of the coastal river systems of Ghana and serves a significant number of people in Accra West, Nsawam, and Koforidua is said to be in a deplorable situation due to pollution. This plays a key role in Ghana's water management problems due to its strategic location though relative to other river basins, the Densu Basin is small (Warm, 1998).

The issue of water quality and sustainable development cannot be said to be given full focus without considering the problem of pollution and quality of the Densu River as well as the Weija lake, if the goal of good drinking water for every Ghanaian by the year 2020 is to be realized (Warm 1998). This is because a country's development depends on the health of the people, which also depends to a large extent on the quality of water available. This calls for an investigation into the important water bodies in Ghana in relation to their water quality and management. An insight into the quality status of water from the Densu River Basin will not only help enhance the strategies of quality management in the basin but will also help to improve the taste and odour qualities of treated water from the Weija Dam since the quality of any finished product depends to a very large extent on the quality of the raw materials used for its production.

1.3 Aims and objectives

This study therefore sought to investigate the quality status of water from the Densu River Basin and the Weija Dam and to make recommendations on sustainable water quality management in the Densu River Basin.

1.3.1 Specific objectives

The specific objectives of the study were:

i. to evaluate the physical, chemical, biological and microbiological qualities of raw water from the Densu River Basin and the Weija Dam,

ii. to compare the quality of raw water in the Weija Dam with that of the Densu River Basin as collected from designated points in the Densu River Basin and to study the trends of water quality along the Densu River basin,

iii. to compare the quality of raw and treated water from the Weija Dam and

iv. to compare the changes that have occurred in the quality of water between the pre-impoundment era and current studies.

2.0 LITERATURE REVIEW

2.1 Water Quality in Ghana - An Overview:

The huge Akosombo Dam occupying 4% of the area of Ghana and the erratic but regular rainfall pattern have created a myth of abundance and secure water supplies in the country (Warm, 1998). However, the emerging water crisis that is affecting every segment of the economy is creating a very different picture. It is evident that in the past, water scarcity was not very common, though fewer people had access to potable water and most people especially those in the rural areas had to travel long distances to draw water.

Today, the situation is different and water scarcity is becoming pervasive and persistent. Drought has exacerbated and underscored the weaknesses of the existing water supply problems being experienced throughout the length and breath of the country (Warm, 1998). Increasing population within Ghana and in upstream nations which share the Volta River with Ghana have increased the demand for water for human consumption, industrial production, crop production, and generation of electricity as well as for recreation. This has resulted in acute water shortages, which is affecting every segment of the Ghanaian economy (Warm, 1998).

In Ghana, however, the non-availability of water in adequate quantities (including acute shortages) is not the only problem but the quality of that which is available as well. More than half of the diseases affecting Ghanaians would be eliminated if people had potable water for their domestic needs (Bugri, 1998). Bugri explained that the department of Public Health still had a problem of eradicating guinea-worm disease because places which have been cleared have been re-infected by people from areas where there is no potable water (Bugri, 1998).

The common water-borne and water-related diseases including typhoid, dysentery, schistosomiasis and onchocerciasis which have been the major causes of death due to ingestion of contaminated water common in rural areas have become a point of interest that require attention (EPA, 1997). From an environment standpoint, the primary principle states that water should be made available in a potable form for the entire population with minimal effort, and that its availability on a sustainable basis should be guaranteed (EPA, 1997). The World Health Organisation (WHO) guideline for drinking water quality also indicates that, a supply of drinking water should be sufficient in quantity, wholesome and not injurious to health (WHO, 1996) but this is not the case in Ghana. Only 30% of the population of Ghana can be said to have ready access to potable water (EPA, 1997). It is also indicated that although water is fairly abundant in Ghana there are seasonal shortages. These shortages are attributed primarily to poor management and inadequate use of available technologies (EPA, 1997). Colerangle (1994) attributed the decline in water quality in the country to population pressure.

However, according to the Warm study report (Warm, 1998), the key issues and challenges underlining the limited quantity and quality of Ghana's water resources are the myth of abundance, water pollution, catchment degradation, effects of transboundary water, the very weak financial positions of water agencies which are self-financing, inadequate data and information, absence of a policy framework and public awareness. Among these factors, pollution and land degradation are direct offsprings of population pressure and inadequate data and information on the quality of water from our water bodies can be said to be the main factors responsible for the poor water quality in Ghana.

2.2 The Problem of Pollution

The problem of pollution arises from the indiscriminate disposal of inadequately treated or untreated human wastes which are disposed off on-land, in-shallow pits and in some cases directly into streams. However, in the industrial sector the main polluters are the breweries, textile mills, food and beverage and petroleum refining companies. Most of these are in the Accra-Tema Metropolis (Warm, 1998). The mines also pollute the waters with their liquid and solid waste from gold, bauxite and diamond ore processing plants, which are discharged, untreated into nearby water bodies. The Pra and Ankobra rivers suffer the most from these mining activities (Warm, 1998).

Agricultural practices also contribute a great deal to the pollution problem. These include pollution from agro-chemicals such as fertilizers, pesticides, and insecticides. Leaching of soil nutrients also takes place where lands are deforested through bush fires, lumbering, and fuel-wood harvesting. The nutrients find their way into water bodies to impact on their quality. The Densu River is presently said to be the most polluted river from human, industrial and agricultural waste. Because of this cost of treatment to make the Densu water suitable for domestic use in the Accra-Tema Metropolis is one of the highest in the country (Warm, 1998).

Indeed, pollution can be said to be the number one threat to water quality management system in the country. Neglect and poor management can be said to be degrading the already stressed resource base. Warm (1998) emphasized that the problem of water quality management in Ghana includes the perception that water is a cheap public good, which can be handled anyhow. However the poor stewardship, which is a result of this perception and lack of knowledge of the consequence of this misuse on the quality of our water resources, can be said to compound the problem.

The Environmental Protection Agency (EPA) of Ghana, which has the responsibility to control pollution, emphasizes the lack of data and information as the factors hindering the proper management of pollution. This is because without having adequate knowledge of the nature of our water resources, appropriate steps cannot be taken to conserve, preserve or improve upon the quality status of our water resources (EPA, 1997).

An evaluation carried out in 1995 by the Water Resources Institute (WRI), showed that, there were weaknesses and gaps in the collection of water cycle data. In particular, surface water quality was not monitored on a regular basis and data on ground water, sediment discharge and soil moisture were hardly collected. According to the report, present evaluation of water quality is based on limited parameters. In particular organic micro-pollutant, pesticides and other toxic substances were not normally evaluated. This is because the specialised equipment to do so are not available (Larmie, 1995).

2.3 Reforms in the Water Resources Sector

The Warm Study Report (Warm, 1998) revealed that Ghana does not have an overall water policy in the form of strategies and national water monitoring plans and mechanisms for inter sectorial co-ordination and conflict resolution, and until recently, policies regarding tariffs setting, were all non-existent. Ghana has assigned responsibility for each category of water use to a different agency, which makes water resources development policy decisions without co-ordination of its actions with others. On the other hand, regulation of water use such as abstraction and pollution control is fragmented among a number of agencies. This sectorial and fragmented approach is at the core of the problem of water resources management (Warm, 1998).

The government has therefore in recent years, introduced a number of reforms that will help move the country away from the integrated management of water resources to a holistic approach. The Economic Recovery Programme, decentralization of administration, the national development framework (Vision 2020) and environmental protection have dictated these. These are accompanied by direct reforms in the water sector (Warm, 1998).

The reforms in the water resources sector have become necessary owing to increased competition among users, that is domestic consumption, mining, agriculture, industry, power supply, livestock, wildlife resources, and recreation which have become more intense contributing to conflicts at local, national, and regional levels and requiring mechanisms for coordination and conflict prevention and resolution.

The water resources sector strategy for water management employs several instruments. These include economic instruments (pricing, pollution penalties, taxes, subsides, etc.), regulation (water rights, effluent discharge standards, land use requirements, etc.) and participatory process (through public awareness, consensus building etc.) (Warm, 1998). These new reforms in the water sector seem to be the ray of hope for an effective water quality management. Water quality management is multifaceted in nature and therefore needs to be handled from a multidisciplinary perspective. Unfortunately these water sector reforms are not well co-ordinated at the moment. However with the establishment of the Water Resources Commission under the auspices of the Ministry for Works and Housing, much is hoped to be achieved (Warm, 1998).

Evidently, Ghana faces numerous challenges in managing its water resources and particularly the quality management of water bodies. Water quality management is indeed becoming one of the largest problems facing Ghana. The task of supplying enough water of the required quality to the growing population and the safe disposal of wastes is straining the agencies responsible to the limit and challenging their effectiveness.

There is therefore the need for a more comprehensive water policy based on sound water resources assessment for an effective regulatory framework and a capacity to enforce approved law and regulations if improved water quality is to be achieved. Indeed, the establishment of the Water Resources Commission seems to be a good beginning to face the challenge.

2.4 Water Quality Standards in Ghana

2.4.1 Definition of Water quality

Quality water can be said to be water whose characteristics make it suitable to the needs of the consumer. However, the quality of most waters has been so degraded through various human activities that these waters cannot be used in their natural state without some risks (Osei and Marfo, 1995). Quality water can therefore be said to be water, which is suitable in its existing state for an intended use. This definition allows for the fact that water has different uses, which do not necessarily require the same standards. There is therefore the need to establish water quality standards for the various uses to which water is principally put, in order to ensure that the quality of water delivered to the consumer for an intended use satisfies the requirements of that need. As a result, water quality standards have been established for drinking water, water used for irrigation, water for industrial use and recreation (Osei and Marfo, 1995).

Of prime importance are the drinking water standards, which are established to ensure that potable water is chemically and bacteriologically safe for human consumption, as well as being aesthetically pleasant to the consumer. A standard is however, a definite rule of measure, or limit for a particular water quality parameter established by a legal authority (Osei and Marfo, 1995).

Apart from the standards, there is also the criterion, which is a yardstick for the assessment of the suitability of a measured quality. Clarke (1977) stated that a criterion is a standard of judgment used to test the suitability of a water supply for a particular purpose or a goal to be achieved.

2.4.2 Quality Standards of water

The Ghana Standards Board has the statutory obligation to establish and promulgate water standards with the objective of ensuring good quality water, among other goods produced in Ghana whether for local consumption or for export (Osei and Marfo, 1995). As part of its efforts in pursuance of these objectives, the Ghana Standards Board has a committee responsible for elaborating standards for the following:

(i) Drinking Water
(ii) Water for Irrigation
(iii) Water for industry
(iv) Water for livestock

However, Ghana has not yet finalised standards of its own at the moment and there are presently no national planning standards or guidelines to ensure national welfare by ensuring public safety, economy in the use of the resources, or ensuring adequate water quality for all beneficial users. Consultants therefore use standards from other countries or organisations such as the United Nations (UN), World Health Organisation (WHO), or the European community (Warm 1998).

For drinking water, WHO guidelines as enshrined in the WHO 1993 edition of the Guidelines for drinking water quality have been adopted with considerations to cultural, social, economic and environmental issues. As already stated, of prime importance is the quality standards for drinking water. Standards have therefore been formulated not only for treated water entering a distribution system for domestic supplies but also for ground and bottled water. However, this does not cover mineral water (Osei and Marfo, 1995).

2.4.3 Requirements for drinking water:

The main objective of establishing water quality standards is to ensure a constant supply of drinking water which is aesthetically pleasing and devoid of toxic pollutants to consumers. Various requirements have therefore been laid down in the standards for drinking water quality, and these cover the microbiological, biological, chemical, physical and radiological qualities of water.

2.4.3.1 Microbiological Requirements:

Water has the potential to spread massive epidemics by bacteria and other microorganisms. To protect the consumer from water-borne diseases, it is required that water intended for household purposes shall not contain any water-borne pathogens (Osei and Marfo, 1995). It is therefore imperative to use certain indicators to assess whether water, intended for drinking or domestic use satisfies this requirement.

Although several pathogens of diverse origin can be present in water, the use of normal intestinal organisms as indicators of faecal pollution rather than the pathogens themselves is universally accepted for the monitoring and assessing microbial safety of water supplies (WHO, 1996). Because the bacterium *Escherichia coli* satisfies most of the criteria though not all those needed by an ideal indicator and also happens to be the most numerous and most specific bacterium indicator of faecal pollution from humans and animals, it is the bacterium of choice (Marfo and Osei, 1995). Marfo and Osei (1995) explained the criterion to be that thermotolerant coliform organisms must not be present in a 100ml sample of any water intended for domestic use.

It must be emphasized that *E. coli* is the organism of choice when resources for supplementary microbial examinations are limited. However, thermotolerant coliform organisms can also be used, as supplementary indicators of faecal pollution in certain instances though these satisfy the criteria required by an ideal indicator to a lesser extent (WHO, 1996). Because enteroviruses of the cysts of some parasites are known to be more resistant than *E. coli* and coliform organisms to disinfection, the absence of these organisms in surface water that has been disinfected will not necessarily indicate freedom from enteric viruses and the resting stages of *Crystosporidium giardia*, amoebae and other parasites (WHO, 1996). This makes the criterion stated by Osei and Marfo (1995) as the absence of thermotolerant coliform to leave a little more to be desired. Even though Osei and Marfo (1995) admitted that the requirement for drinking water is that, it must be free from human enteroviruses to ensure negligible possibility of transmitting viral infection, they added that this cannot be achieved because of the length of time involved in such examination as well as the cost involved. However it must be noted that this is a very important aspect of the requirement which the committee responsible for the setting of the criterion must reconsider.

Besides, though *E. coli* or in some cases thermotolerant bacteria are the organisms of choice, owing to their abundance in faecally polluted water, certain anaerobic bacteria such as bifidobacteria and the *Bacteriocides fragilis* group are more abundant than coliform organisms in faeces, but they decay rapidly in water and accepted standard methods for their detection and enumeration are not available and therefore do not fulfill the requirement as indicators. However, some total coliform that have non-faecal sources in the environment for example, in soil or decaying vegetation or even in aquatic environment and therefore cannot be used as indicators of faecal contamination can have useful properties that enable them to be used for particular purposes. For example, faecal *streptococci* and *enterococi* and the spores of sulfite - reducing *clostridia,* typified by *Clostridium perfringens* are less numerous than coliform in faecally polluted water. However they have greater power of survival and so can be used to confirm the presence of faecal contamination when *E. Coli* is not found, or to assess the efficiency of treatment processes (WHO, 1996). It is widely assumed however, that the presence of faecal coliform, is an indication that water presents risks to consumers.

2.4.3.2 Biological Requirement:

The maximum contaminant levels for pathogenic protozoa, helminthes and free-living organisms have not been set. However these agents should not be present in drinking water because one or very few of these organisms can produce infections in humans. Analytical methods for monitoring their presence in water are not only expensive but also time-consuming and therefore cannot be used for routine purposes. It is however highly recommended that remedial measures be taken to ensure that drinking water is not contaminated by these organisms (Osei and Marfo, 1995).

2.4.3.3 Chemical Requirement

When chemical compounds both organic and inorganic are present in water above certain limits of concentration, they pose certain health hazards after a certain period of exposure. Normally, the effect is over a long period of exposure, unlike the biological or microbial effect, which could be immediate. However the effect could be either acute or chronic. It is mostly chronic with the inorganic compounds but acute with the organics, though this depends on the level of concentration and the type of compound (WHO, 1984).

Although some chemical compounds may not necessarily pose health hazards they may affect the aesthetic and organoleptic quality of the water. Aluminum present in water for example, contributes only small proportion of the estimated daily human intake (Zook and Lehmann, 1965) and therefore its presence in water does not pose any serious health hazard. However the incidence of discoloration in drinking water in distribution systems increases if aluminum levels exceed 0.1 mg/L in the final water whereas a total consumption of 88 mg per person per day has been estimated (Gabovich, 1966).

For this reason a guideline value of 0.2 mg/L in drinking water is recommended based on aesthetic considerations (WHO, 1984). Others in this category include iron, manganese and chloride. However, the WHO report indicates that the level of chloride for example in unpolluted water is often less than 10 mg/L and may often be less than 1mg/L (WHO, 1984). The danger here is that the aesthetic effects may lead consumers to opt for possible unsafe sources.

The chemical requirement therefore, has to do with the maximum contaminant levels for both organic and inorganic compounds above which they may pose a health hazard (Osei and Marfo, 1995) and in addition to this, mar the aesthetic quality of the water. Below are three tables showing the different categories of compounds and their adopted guideline values as used in Ghana.

Table 2.1: Inorganic Constituents of Health Significance.

Constituents	Maximum Contaminant Level (mg/L)
1. Antimony	0.05
2. Arsenic	0.01
3. Barium	0.7
4. Boron	0.3
5. Cadmium	0.003
6. Chromium	0.06
7. Cyanide	0.07
8. Fluoride	1.5
9. Lead	0.01
10. Mercury	0.001
11. Molybdenum	0.07
12. Nickle	0.02
13. Nitrate (NO_4)	The sum of the ratio of the concentration of each to its respective level should not exceed 1.
14. Nitrite (NO_3)	3
15. Selenium	0.01

Source: Osei and Marfo, (1995)

Table 2.2: Parameters of Drinking Water that may affect Aesthetic Quality

Constituents	Maximum Contaminant Levels (mg/L)
1. Aluminum	0.2
2. Ammonia	1.5
3. Chloride	2.50
4. Iron	0.3
5. Manganese	0.1
6. Sodium	200
7. Sulfate	250
8. Zinc	3
9. Total dissolved solids	1000
10. Toluene	24-170
11. Xylene	20-18000
12. Ethyl Benzene	2-200
13. Copper	1

Source: Osei and Marfo, (1995)

Table 2.3: Organic Constituents of Health Significance in water

Constituents	Maximum Contaminant Levels (mg/L)
A. Pesticides	
(i) Methoxychlor	20
(ii) Chlordane	0.20
(iii) Lindane	2
(ix) 2,4 – Dichloropheno	
Xyacetic acid (2,4-D)	30
(v) Heptachlor and heptachlorepoxide	0.03
B. Disinfectant	
(i) Monochloroamine	3
C. Chlorinated Alkanes	
(i) Dichloromethane	20
D. Chlorinated Benzene	
(i) Monochlorobenzene	300

Source: Osei and Marfo, (1995)

2.4.3.4 Physical Requirement

This has to do with limits of turbidity, colour, temperature, odour and taste that will not make drinking water acceptable to consumers. Colour and turbidity are the first parameters that dictate the aesthetic acceptability or otherwise of drinking water by consumers. From the philosophy of ''see before taste'' point of view, taste and odour follow colour and turbidity in determining consumer acceptability of drinking water. However, whereas objectionable levels of colour in drinking water may not necessarily render it unfit for consumption despite its aesthetic effects, turbidity on the other hand always has serious health as well as aesthetic implications. This is because the particulate matter, which causes turbidity normally, forms a good platform for microorganisms to grow and thrive (WHO, 1984). However according to the WHO (1984), taste and odour problems in drinking water account for the largest single class of consumer complaints.

The relationship between high turbidity in both raw and filtered water, and taste and odour has also long been recognized and suspended particulate matter in a potable water supply renders the water unattractive to consumers (Atkins and Tomeinson, 1963). It has also been reported that algal blooms can cause changes in the source of water turbidity, pH, taste and odour. The danger is that water with such unattractive physical attributes may cause consumers to seek other possible sources of water that may be unsafe for consumption.

i. Colour:

Colour in drinking water may be due to the presence of coloured organic substances, usually humics, metals such as iron and manganese, or highly coloured industrial waste. The primary importance of colour in drinking water is aesthetic but the sensory aspect may be regarded as a health effect (WHO, 1984).

There are two types of colour in water, which include apparent colour and true colour. Apparent colour is defined as colour measured in water that contains suspended matter and true colour is defined as colour measured in a water sample from which particulate matter has been removed or as the colour of water from which turbidity has been removed. True colour has been reported to be due to dissolved substances (APHA, 1976). About 50% of colour in water is said to be due to colloidal fraction of humic substances (Pemmanen, 1975).

The recommended guideline value for colour in drinking water is less 15 True Colour Units (T C U). This is obtained by removing colour due to humic substances in a true solution through centrifugation or filtration (Sawyer and McCarty, 1967).

ii) Turbidity:

Turbidity in water is caused by the presence of suspended matter such as clay, silts, colloidal organic particles, plankton and other microscopic organisms (WHO, 1984). The presence of turbidity can have a significant effect on the microbial quality of drinking water. This is because it complicates the detection of bacteria and viruses in drinking water (Brock, 1966). Besides, it also gives protection to bacteria and viruses from the action of disinfectants (WHO, 1984).

It has been reported that the presence of coliform organisms in water with turbidity ranging between 3.8 and 8.4 Nephelometer Turbidity Units (NTU) is high, even after treatment with chlorine (Clarke, 1964). According to Downing and Crowley (1979), lowland waters are often more turbid than upland streams because they normally contain dispersive clays which often make them more turbid than upland waters which passes over rocks. The recommended guideline for turbidity by WHO is 5 NTU and preferably less than 1 for disinfection efficiency (AWWA, 1990).

iii. Taste:

The taste of water is said to be the sensation that results from the interaction between the saliva and substances that have dissolved in the water as perceived by receptors located in the taste buds. Problems associated with the taste of water can be due to natural causes or the result of industrial activities. They may be associated primarily with the raw water, the treatment method, the distribution system, or with a combination of all the three (WHO, 1984). Ground water is reported to have only few taste problems whereas surface water supplies are subjected to seasonal taste and odour problems. This suggests that such problems may be of biological origin (Bruvold, 1975). High concentrations of colour and turbidity are always associated with nonspecific taste and odour problems (Riddick, 1966). The acuity of taste is reported to depend on temperature and the degree to which taste is influenced by temperature is a function of the specific taste causing substances (Pangborn and Bertolero, 1972). The WHO guideline for the taste of drinking water, is that it must not be offensive to consumers (AWWA, 1990).

It has been reported that residual chlorine can also have an effect on the taste and odour of drinking water. So far work done on organoleptic properties of residual chlorine has not been able to indicate the threshold value of residual chlorine that will ensure microbial safety of water as well as being sufficiently low enough to avoid objectionable taste and odour problems (WHO, 1984). Recent studies have shown that, the average taste threshold concentration has increased from 0.075 mg/L to 0.450 mg/L as the pH increased from 5.0 to 9.0 (Bryan, 1973). The average threshold is 0.156 mg/L to 0.290 mg/L at pH 7.0. The nature of the raw water supply is one major factor, which influences the detectable taste threshold of concentration for residual chlorine (WHO, 1984). Inorganic substances also exert unpleasant taste at much lower concentrations than that required for acute toxic effect. These limits have already been indicated in Table 2, as used in Ghana.

iv. Odour:

The WHO guideline for drinking water defined odour as that sensation due to the presence of substances having appreciable vapour pressure and that which stimulates the human sensory organs in the nasal and sinus cavities (WHO, 1984). Water odour is predominantly caused by the presence of organic substances in water and many of such substances have been reported (Van Germert, 1977). Objectionable odours in drinking water may normally be of either biological origin or industrial. Some of the natural origins may be due to indirect human activities, for example dumping of raw sewage, refuse, etc, into aquatic environment. This enhances biological growth, which may produce odorous products (WHO, 1984).

Natural odours may be described as earthy, musty or sour on one hand or fishy, grassy or cucumber-like on the other hand involving compounds such as geosmin and decanal (Zoeteman and Piet, 1972). Some odours also smell like petroleum or creosote or have medicinal odours and these are normally of industrial origin. Typical examples here are naphthalene, the chlorinated compounds and phenols (Zoeteman and Piet, 1974).

Water purification processes also do have effect on the intensity of odour in water. Some purification processes may convert substances with weak odours into very intense odours such as chloroamines and chlorophenols (Burttschell, 1959).

The proliferation of nuisance organism such as iron and sulfur bacteria in distribution systems may also be a source of odour (WHO, 1984). The non-specific fishy, grassy and musty odours are normally associated with biological growth and tend to occur most frequently in warm surface water in the warmer months of the year (WHO, 1984). Research has shown that about fifty nuisance organisms are responsible for odours in drinking water. The very intense odours in public waters are produced by *actinomycetes.*

Odour in potable water is almost invariably indicative of some form of pollution of a water source or of malfunctioning during water treatment or distribution. Odours of biological origin are indicative of increased biological activity and this may be associated with increased content of dangerous pathogens on the system. Those of industrial origin are indicative of pollution from consumer wastes products some of which may be toxic (WHO, 1984). The requirement as adopted, is that, drinking water should be free from any observable odour by a majority of at least 90% of consumers. The odour intensity is usually measured in terms of the Threshold Odour Number (TON), which is defined as the geometric mean of dilution ratios with odour-free water which is just detectable by a panel of judges under carefully controlled conditions (WHO, 1984).

v. Temperature:

The rate of every chemical reaction is dependent on temperature and this makes temperature an important factor in the treatment and delivery of potable water. Temperature also affects the physical attributes of water. For instance, cool drinking water is preferred to warm and the taste is best at room temperature. This is because when temperature increases, the vapour pressure of trace volatile compounds in drinking water also increases and this may lead to increased odour. It also affects the viscosity of water, which increases with increasing temperature and subsequently decreases the rate of sedimentation and filtration (WHO, 1984). It has also been reported that high temperature is said to favour algal blooms when carbornates and nutrient supplies are conducive (Amuzu, 1975). This affects the microbial characteristics of water, since it affects growth of microorganisms and the subsequent treatment processes (WHO, 1984).

vi. Total Dissolved Solids (TDS):

Total Dissolved Solids in water comprise inorganic salts and small amounts of organic matter. The ions here include carbonates, bicarbonates, chloride, sulfate, nitrate, sodium, potassium and magnesium (EPA, 1976). These have influences on taste, hardness, corrosion properties and tendency to incrustation (WHO, 1984). The guideline value of 1000 mg/L is recommended. Even though levels above this value have not been found to be deleterious, levels above it may have aesthetic implications (Garrison

Investigative Board, 1977). Certain epidemiological studies have shown that TDS in drinking water could have beneficial health effects (Ongerth, 1964). However, the main effect of dissolved mineral salts is claimed to be on the taste and colour of the water (Bruvold and Pangborn, 1966). The grading of TDS is as shown in Table 2.4 below.

Table 2.4: Grading of TDS content of water.

Grading	TDS Level (mg/L)
Excellent	Less than 300
Good	Between 300 and 600
Fair	Between 600 and 900
Poor	Between 900 and 1200
Unacceptable	Greater than 1200

Source: WHO, (1984)

v. Water Hardness

Hard water is literally water that would not react with soap. The extent of hardness therefore is the capacity of water to react with soap (WHO, 1984). Water hardness is caused by dissolved polyvalent metallic ions. These include calcium and magnesium. Strontium, iron, barium and manganese also sometimes do contribute (EPA, 1976). The principal natural sources of hardness in water are sedimentary rocks, seepage and runoff from soils. Hard water therefore, normally originates from topsoil and limestone (Sawyer and McCarthy, 1967). Generally, ground water is said to be harder than surface water (Defulvio and Olari, 1975).

Industrially, hardness can be said to originate from inorganic chemicals and mining residues from the sugar and petroleum refineries, paper production, water treatment, waste water treatment as well as the textile industries.

The main result of water hardness is its effect on domestic use and taste (Zoeteman, 1980). The degree of hardness of drinking water has been classified by the WHO guideline for drinking water quality and this is adopted in Ghana as shown on Table 2.5 below.

Table 2.5: Requirement for hardness of water

Grading	**Calcium Level (mg/L)**
Soft	0 60
Medium Hardness	60 120
Hard	120 180
Very Hard	180 and above

Source: WHO, (1984).

Taste threshold for calcium varies from 100-300 mg/L depending on the anions present and that for magnesium is less than that for calcium (Zoeteman, 1980).

vi. Alkalinity:

Alkalinity of water is an index of the buffering capacity of water (Thomas, 1953). Even though alkalinity closely resembles hardness, it is caused by anions whereas hardness is by cations (WHO, 1984). The ions include hydroxides, bicarbonates, carbonates and other species such as borates, phosphates and silicates.

Alkalinity is normally measured in terms of the quantity of calcium carbonate present. In surface water, high levels of alkalinity is due to the presence of carbonate and bicarbonate ions.

The European Economic Community (EEC) standards for the minimum requirement of softened water intended for human consumption is 30 mg/L as HCO_3^- for alkalinity and 60 mg/L for total hardness as salts (AWWA, 1990).

vii. pH:

pH is a measure of the degree of acidity or alkalinity of a solution. It is defined as the concentration of hydrogen ions present in a solution. Generally, it is required that the pH of any water be it raw or treated should be between the range of 6-7. According to Downing and Crowley (1979), upland waters that originate or pass through rock formations of limestone or dolomite are usually non-acidic.

viii. Dissolved Oxygen (DO):

This is the oxygen content of water. Ideally, water must always have saturated amounts of dissolved oxygen. Frequently, depletion of oxygen below about 80% leads to increased incidence of consumer complaints, especially regarding taste, odour and discoloured water (Ridgeway, 1979). The primary effects of DO is on oxidation reduction reactions, involving iron, manganese, copper and compounds that contain nitrogen and sulfur (WHO, 1984).

In some distribution systems the level of DO falls with residence time and this normally is indicative of corrosion processes or microbial respiration of organic materials, especially in sediments and deposits in pipes (WHO, 1984). However DO can decrease without a marked increase in the concentration of iron in water (Ridgeway, 1979). Conversely water containing marked increase in iron concentration may have little depletion of oxygen (WHO, 1984). The reactions involved, are as shown below.

In corrosion of iron, proportionately little iron is required.

$$2Fe = 2Fe^{2+} + 4e$$

$$4e + 2H_2O + O_2 = 4OH^-$$

Here 1 mg of oxygen per litre will require 3.5 mg of ferrous iron per litre. Therefore a large amount of iron corrosion may occur with little perceptible change in DO. The other reactions involve sulfate-reducing bacteria, reducing sulfate to sulfide and the reduction of nitrate to nitrite.

$$8H^+ + 8e + SO_4^{2-} = S^{2-} + 4H_2O$$

However, increasing the oxygen concentration of water through the dissolution of atmospheric oxygen in water may result in discoloration of water by depositing ferric iron, which may be remote from the source of the problem (Hall and Smith, 1974). Besides, the solubility of oxygen in water is generally said to decrease with increasing temperature (Amuzu, 1975).

DO can also affect the ability of a river to maintain its ecology in a good balance. Amuzu (1995) mentioned that a minimum of at least 5.0 mg/L is required for a temperate river to maintain a varied fish fauna in good condition. Again a concentration of 3.0 mg/L is regarded as hazardous or lethal (Ellis, 1937)

ix. Suspended Solids (SS):

Ideally, drinking water is supposed to be free from suspended solids. The WHO guideline adopted in Ghana states that water intended for drinking must contain no suspended solids (AWWA, 1990; Osei and Marfo, 1995).

x. Conductivity:

Water conductivity is the ability of that water to conduct electricity due to the presence of ions in it (AWWA, 1990). Pure water has relatively few ions, because it is free from mineral salts and therefore has very little capacity to conduct electric current and subsequently low conductivity. When the dissolved salts content of water is high, its conductivity also increases. The guideline level adopted in Ghana is 400 µg/cm at 20°C because salt dissolution increases with temperature. The European Economic Community guideline is adopted here.

xi. Biological Oxygen Demand (BOD):

The BOD is the relative oxygen requirement of water for the biochemical degradation of organic matter present in that water (carbonaceous demand) as well as that used to oxidize inorganic materials such as sulfides and ferrous iron and the reduced form of nitrogen (nitrogenous demand) (Ridgeway, 1979). There is no guideline value at the moment in Ghana.

xii. Chemical Oxygen Demand (COD):

This is a measure of the oxygen equivalent of organic matter content of a sample that is susceptible to oxidation by a strong oxidant (Ridgeway,1979). There is no guideline value presently in Ghana.

2.4.3.5 Radiological Requirement

The effect of radiological radiation is harmful to humans and intake of radioactive material via the consumption of water should be avoided (Osei and Marfo, 1995). Naturally there are a number of radionuclides present in water supplies but these may be increased by human activities. The naturally-occurring radioactive elements include uranium, thorium and radium. These are known to emit alpha and gamma radiations (WHO, 1993).

Artificially-produced radioactive isotopes sometimes find their way into environmental water systems (Osei and Marfo, 1995). The maximum levels as stated in the standards were based on the assumption that two litres of water is taken daily, and the doses resulting from a given intake of radioactive material have been calculated on the basis of the metabolism of an adult (WHO, 1993). Osei and Marfo (1995) also assumed that the most toxic radionuclides likely to be present in appreciable amounts are ^{89}Sr and ^{226}Ra, which contribute to gross radioactivity of drinking water. The maximum values given in the standard are as follows:

1. Gross alpha activity: 0.1 mg/L
2. Gross beta activity: 1 mg/L

These limits are said to give indication that water is potable without any further radiological examination. It should be noted however that if these activity levels are exceeded, it does not imply that the water is unsafe for consumption; rather a more detailed examination of the water would be necessary to assess the hazard (WHO, 1993).

2.5 History of the Densu River Basin and the Weija Dam

2.5.1 The Background of the Densu River Basin:

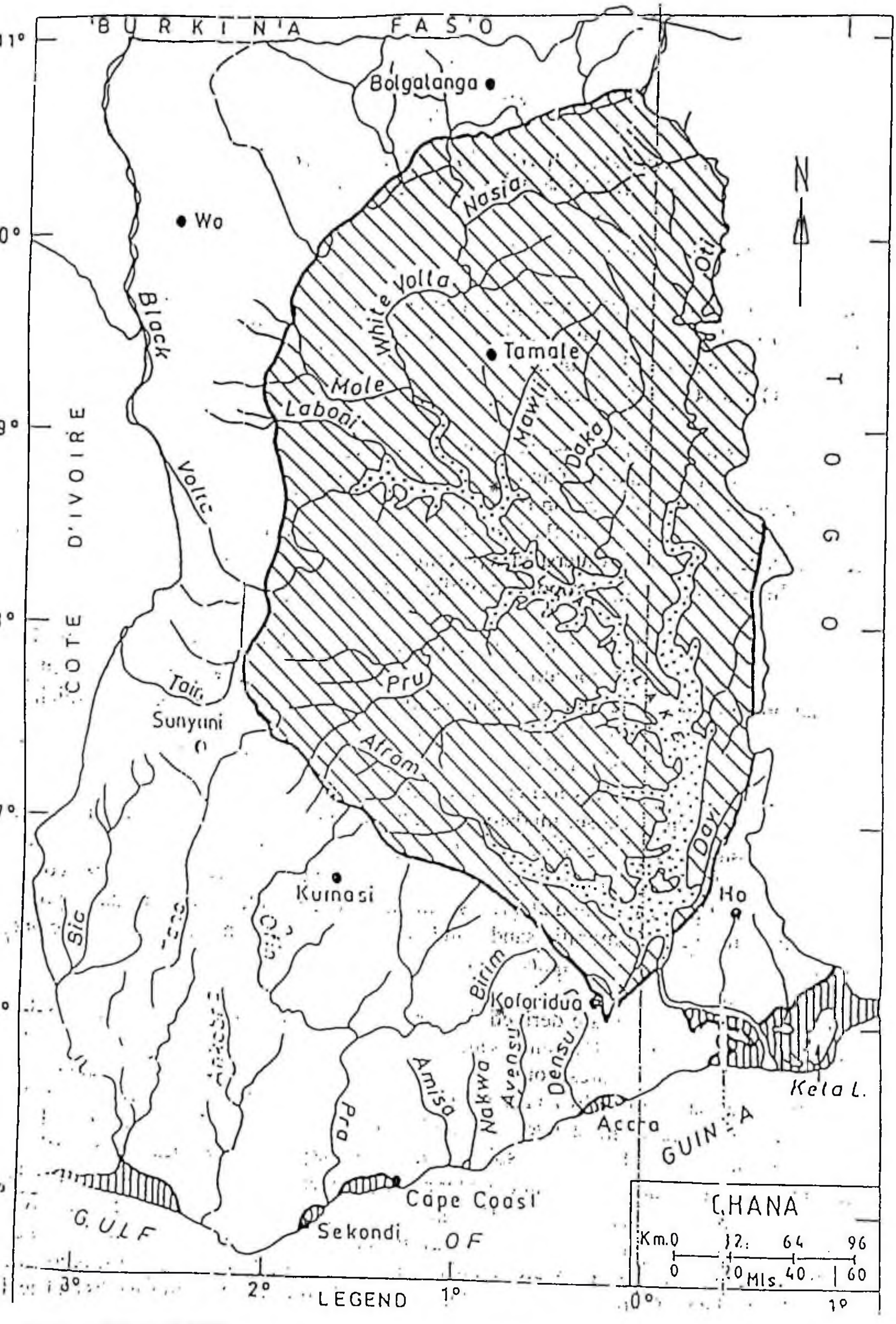
The Densu River Basin forms a minor part of the coastal river systems in Ghana and it is the smallest of the three river systems across the country (Warm, 1998). However, owing to it's strategic topographical location it plays a very significant role in the history of the socio-economic development of the country. Colerangle (1994) stated that though a relatively small river compared to others, the Densu could be claimed to be one of the most important rivers in the country with respect to its economic importance to packed communities. With an annual discharge of only 285 million m^3 the Densu has to meet all the demands of the ever-growing population within its catchment area (Larmie, 1995).

Presently the river serves an estimated 1.5 million in Accra West alone (GWCL Records, 1999) and over two million people living within the Basin or close to it (Larmie, 1995). The river is said to provide water for domestic, agricultural and industrial activities and serves as a disposal facility for both domestic and industrial waste. This has brought untold stress on the river to an extent that it is known to be over-stressed environmentally since various signs of water quality deterioration have been observed in it (Larmie, 1995). The Warm Study Report indicates categorically that the Densu River is presently the most polluted river from human, industrial and agricultural waste (Warm, 1998). This according to the report is made manifest among others, in the cost of treatment to make the Densu River water suitable for domestic and industrial use in the Accra-Tema area the highest in the country (Warm, 1998; Larmie, 1995).

The Densu River is a typical forest zone river, which takes it's source from the Atewa Atwiredu mountain range near Kibi in the Eastern Region of Ghana (Colerangle, 1994). It is said to flow for 115.8 km (72 miles) southwards and discharges into the Sakumo Lagoon which subsequently enters into the Gulf of Guinea near Bortianor in south west Accra (Amuzu, 1975). It drains through eight administrative districts in the Eastern Region of the country. Its tributaries include the Suhien, Mame, Kuia, Adeiso, Nsaki, Dobro, and Jei, with the important ones being Kuia, Adaiso, Nsaki and Dobro. Together with its tributaries, the Densu drains a total area of 2564 km^2 (990 square miles) (Colerangle, 1994; Amuzu, 1975).

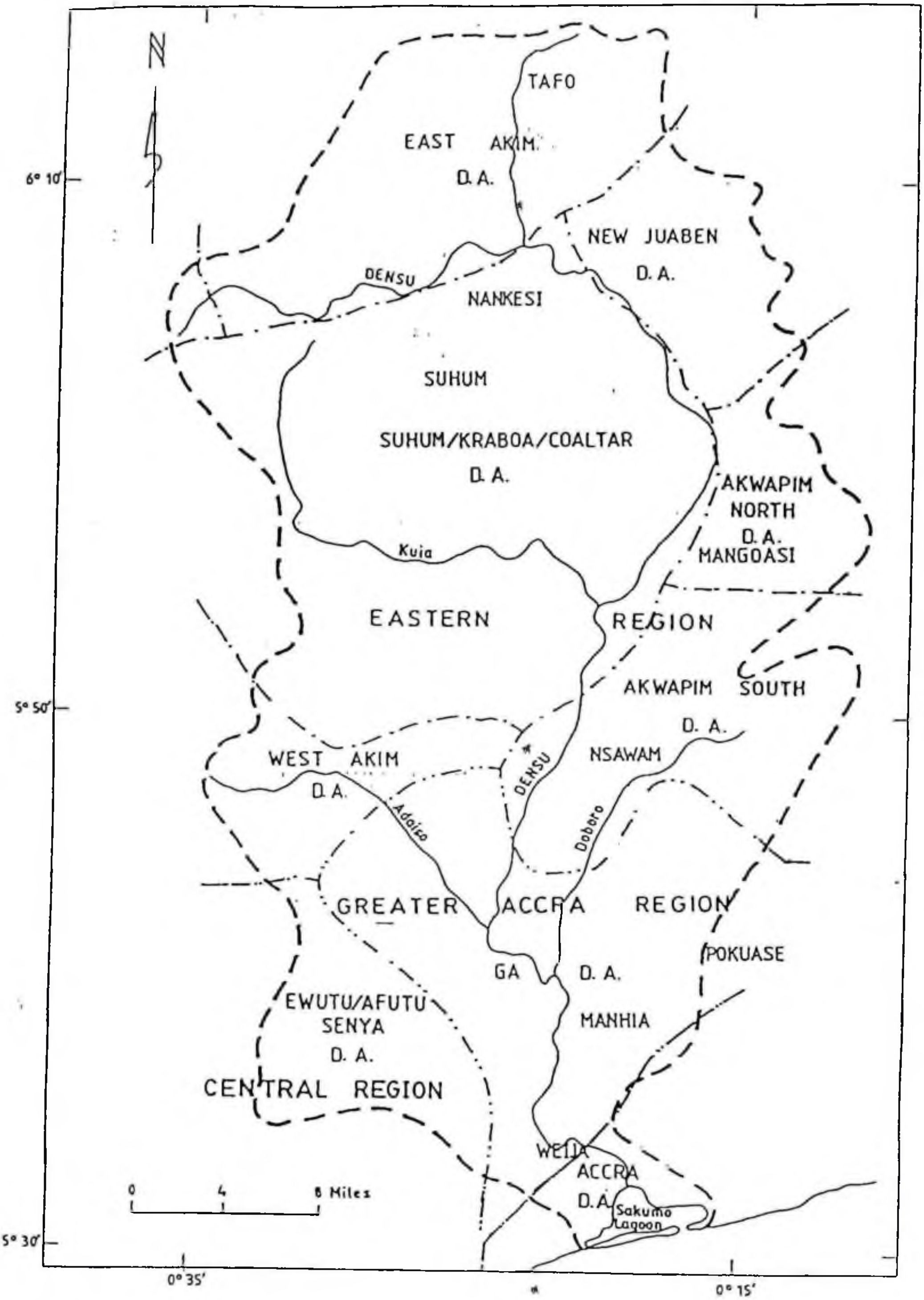
Its upper reaches of length flow through small farming communities whose activities appear to have little impact on the river. However for the rest of its journey through derived and coastal savannas, the story of the Densu is different (Colerangle, 1994). It has been dammed at Weija to create the Weija reservoir with a holding capacity of 116000-acre feet (310000 x 10^6 gallons) of water at a maximum height of 50 feet above sea level (Colerangle, 1994). Figure 2.1 shows the position of the Densu among other rivers in Ghana and Figure 2.2 shows the District Areas within the Densu River Basin.

Fig. 2.1. : Geohydrological Provinces and River System of Ghana



Source: Warm (1998)

Fig. 2.2 : Regional and District Areas within the Densu River Basin



Source: Otui(1998)

2.5.2 The Weija Dam

The history of the Weija dam dates from 1973 when it was constructed with a length of 394.9m and a maximum height of 17m (Amuzu, 1975). The need to augment the water supply source of Greater Accra Metropolitan Area made it necessary for work to start on the impoundment of the river Densu at Weija in 1975 (Amuzu, 1975). Water quality studies started before the impoundment of the Densu reservoir and have continued ever since. Colerangle (1994) stated that before and after the impoundment of the reservoir in 1978, water quality monitoring programmes were put in place and followed.

Larmie (1995) also reported that the history of the Densu River at Weija dates from 1973 when the present lake began forming till 1975. In his report, Larmie indicated that one of the first reported investigations on the quality of the Densu River was by Amuzu in 1974/75. However, Amuzu (1975) argued that, using Todds classification standards, which uses several parameters including pH, chloride, iron, manganese, BOD, DO and colour to classify raw water as excellent, good or poor, the Densu water can be generally classified as a good source for domestic water supply.

Larmie further reported that during the early stages of the lake formation, between 1976 and 1978, Ridgeway (1979) carried a study on the chemical quality of the surface water in relation to the fishery potential of the new lake. According to Larmie, Ridgeway collected samples from five stations in the Basin, which includes the Densu Bridge at Nsawam, Ashalaja, Machigeni, Domiabra and Weija Dam and reported considerable deterioration of oxygenation in the lake water that resulted in only 0.65 to 47.4% across the basin. This is contrary to what was observed during the impoundment stages, where about 50 to 100% saturation and dissolved oxygen were observed by Amuzu (1975). The report by Ridgeway (1979) is said to have compared this to similar development in the

Volta Lake when nuisance growth of algae gave rise to the depletion of oxygen sources (Otui, 1998).

Larmie (1995) concluded that in the late seventies, there was not much difference between the pre-impoundment quality and the quality of the newly formed lake (Otui, 1998). He also explained that the temperature ranged from 26-30°C and the pH from 6.9-7.7, which by WHO guideline are excellently normal. However, phosphate phosphorus was lower in the river (0.0 to 1.2 mg/L) than in the newly formed lake (0.25 to 1.45 mg/L). Nitrate nitrogen was also less than 1.0 mg/L and the conductivity of the lake was between 360 and 2300 mg/L. It was however felt at the time that the Densu was rich in nutrients and had high salt content and therefore could easily undergo eutrophication (Otui, 1998).

Although it was reported that the Densu River had algae, the algae recorded were said to be nuisance diatoms and blue-green algae associated with water pollution, taste, odour and filter clogging (Otui, 1998). With the formation of the reservoir, the algal community structure reportedly changed, with green algae being the most preferred algae for herbivorous fishes, becoming the main component of the community with a reduction in the number of nuisance algae (Otui, 1998).

Colerangle (1994) on the other hand noted that soon after the impoundment, there was deterioration in the quality of water in the reservoir and along the stretch of the river. This was noticed by the steady increase in chloride levels from an average of 24 mg/L in the reservoir in 1978 to the present average of 60 mg/L . pH levels also increased from 6.9 to an average of 7.9 with a maximum of 8.3 over the same period of time. Total phosphate is said to have escalated in the open water from 0.01 mg/L in some parts of the river stretch to a maximum value of 1.45 mg/L. Dissolved oxygen averaged 5 mg/L in the open water on top of the reservoir, though zero values have been recorded in some parts of the river at Nsawam during the dry season (Colerangle, 1994).

Larmie (1995) also stated that for a period of 16 years (1974 – 1990), the mean water temperature was observed to have increased by 4%, mean DO to have reduced by almost 40% in the early 90's and chloride, also reduced by about 3% to 36.4 mg/L. In 1991, however nutrient levels suggested by nitrate appeared to be comparable with the period under discussion. The story of the Weija Lake however, was different, with mean temperature and chloride concentrations increasing to 5% and 27.5% respectively (Otui, 1998). Colerangle (1994) concluded that water in the basin has become polluted to an extent that it has become highly eutrophic and characterised by algogenic taste and odour.

2.5.3 The Problem of Pollution in the Densu Basin

Activities within and around the basin are said to have polluted the Densu and Weija waters so much that, algogenic taste and odour are the characteristics of the reservoir water (Colerangle, 1994). However this taste and odour problem is not only characteristic of the reservoir water but treated water from the reservoir as well. This has attracted a lot of complaints from the public, lately. The magnitude of this problem lies in the fact that this can compel consumers to seek alternative sources, which could probably be unsafe. The inability of the water quality monitoring agencies responsible for the Weija Dam, to identify the root causes of this problem, in order to salvage it and cut down cost, even compounds the situation the more.

It is believed that the problem is mainly due to inappropriate land use in the basin (Otui, 1998) as well as poor waste disposal practices, unorthodox fishing methods and to a little extent mining. Colerangle (1994) stated that the basin has been diagnosed to be predominantly agrarian. Therefore there is the influx of nutrients and also silt-laden stormy waters from agricultural lands, and sewage from the urban centres into the reservoir. Activities of fishermen and shoreline squatter communities have also contributed to the problem.

In addition to the common water-borne diseases mentioned earlier on as those prevalent in the country, Buruli ulcer, a deleterious disease that affects poor rural dwellers in river dependant areas is a major health problem in the Ga District where half of the land lies in the Densu River Basin. A research conducted in May 1999, revealed that there are over 1200 cases of Buruli Ulcer in the Ga district alone, of which more than 500, are active. This makes the district one of the most endemic areas for Buruli Ulcer in the country (Ga District Health Records, unpublished).

3.0 MATERIALS AND METHODS

3.1 MATERIALS

To accomplish the aim of the study, raw water samples were collected from designated points, along the stretch of the Densu river and the Weija dam for quality analysis using American Public Health Association (APHA) Standard Methods. This was to help ascertain the changes in quality as the water travels on its course to the dam, as well as changes that might have occurred over the year through comparison with existing data. Raw and freshly treated water samples were also collected from the Weija dam for analysis using the same standard methods.

3.1.1 Samples and Sampling:

The samples were collected from five points in the Densu Basin namely, Akwadum, Asuboi, Nsawan, Manhia and the Weija Dam during the pseudo-rainy and dry seasons. Figure 3.1 shows the position of these sites within the basin. At each point ten different samples were taken and thoroughly mixed to form a true replica.

Each sample was taken from a central point in the water body in an angular or diagonal manner from an in-depth level. Sometimes it was taken from the bottom parts (for shallow waters) to the surface. This was carefully done in order to get a true replication of the water in question. These samples were put into sterile containers labelled and stored in borosilicate flasks and were then transported to the laboratory for analysis.

At the laboratory, all the analyses were replicated five times, unless otherwise specified and the average taken as a representative of the quality parameter being measured.

Experimental Design:

A 2 x 5 factorial experimental design was used for the study. The principal factors investigated were:

i. Season : Rainy and dry

ii. Source of water : Akwadum, Asuboi, Nsawam, Manhia and Weija.

The samples collected were evaluated for the following:

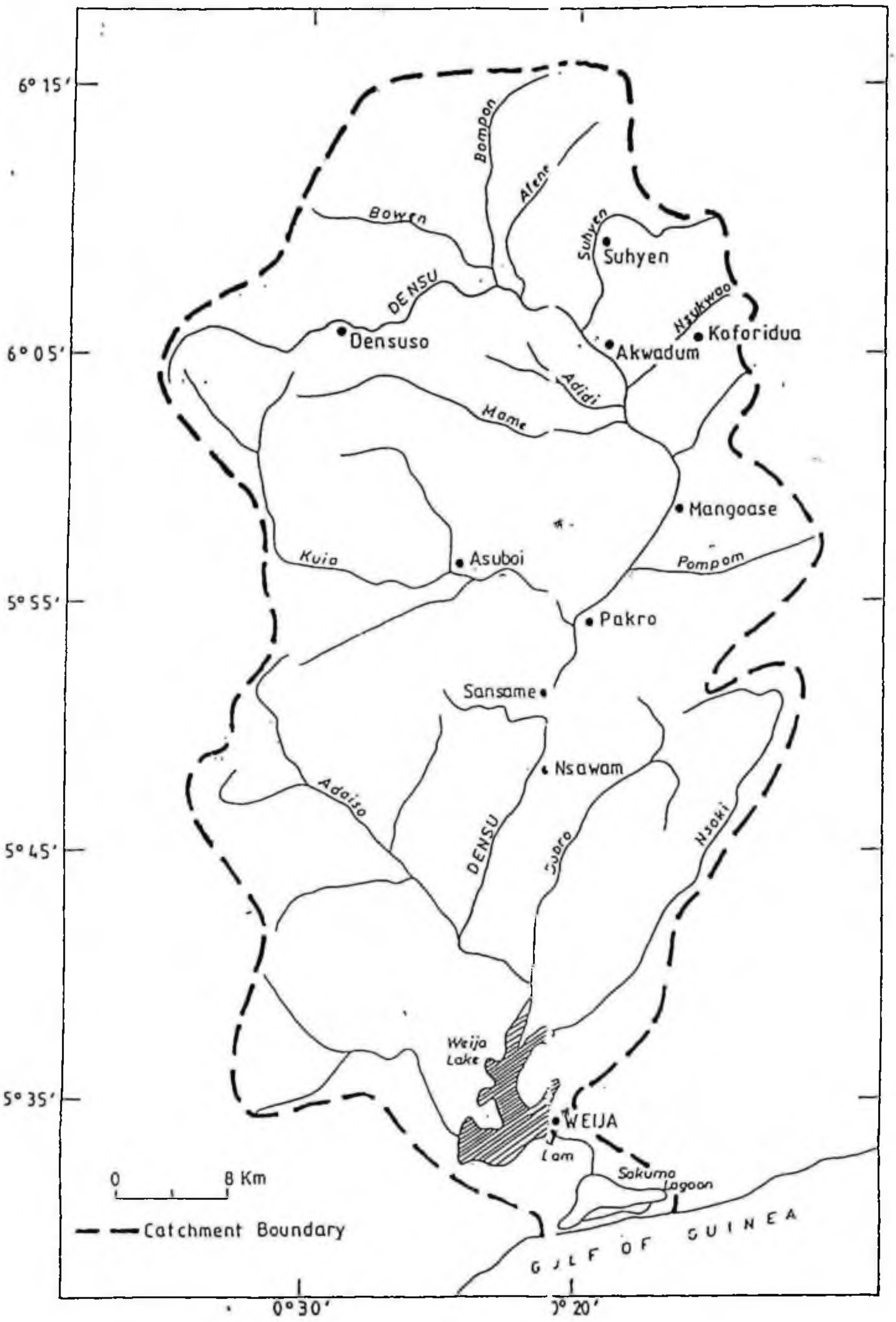
i. Physical qualities (temperature, pH, conductivity, turbidity, colour, suspended solids, and total dissolved solids).

ii. Chemical qualities (sodium, potassium, calcium, magnesium, total hardness, chloride, alkalinity, bicarbonate, sulphate, ammonia, fluoride, nitrate, nitrite, phosphate, chemical oxygen demand and biological oxygen demand).

iii. Biological quality (Chlorophyll a)

iv. Microbiological qualities (total coliforms and faecal coliforms).

Fig. 3.1 : The Densu River Basin Showing Sampling Stations



Source : Otui (1998)

3.2 ANALYTICAL METHODS

3.2.1 Physical Analyses

i. Temperature

Temperature was measured using a mercury-in-glass Thermometer at the sample spot.

ii. pH

pH was measured using the American Public Health Association Standard Method 4500-H (APHA, 1998), with a pH Meter Gallenkamp Model 640 (WPA Linton Ltd., Cambridge, UK).

iii. Conductivity

Conductivity was measured using the American Public Health Association Standard Method 2510B (APHA, 1998), with a Conductivity Meter Jenway Model 4020 (Jenway Co. Ltd., Essex, UK).

iv. Turbidity

Turbidity was measured using the American Public Health Association Standard Method 2130B (APHA, 1998), with a Turbidimeter Model DRT 100B (Partech Electronics Ltd., Charlestown, UK).

v. Colour

Colour was measured using the American Public Health Association Standard Method 2120A (APHA, 1998), with a Lovibond Nessleriser Colour Disc Model BDH MK3 (BDH Laboratory Supplies Ltd., Dorset, UK).

vi. Suspended Solids (SS)

Suspended Solids was measured using the American Public Health Association Standard Gravimetric Method 2540D (APHA, 1998). Fifty millilitres of sample was filtered through a weighed glass fibre filter (9 GF/C) and the residue retained on the filter dried in an oven to constant weight at 105°C. The increase in weight of the filter expressed in mg/L represented the total Suspended Solids.

vii. Total Dissolved Solids (TDS)

TDS was measured using the American Public Health Association Standard Gravimetric Method 2540C (APHA, 1998). Forty millilitres of the filtered sample from the Suspended Solids determination described above was placed in a weighed evaporating dish and the sample evaporated to dryness on a water bath. The dish was then transferred into an oven and dried to constant weight at 105°C. The increase in weight of the dish expressed in mg/L represented the TDS.

3.2.2 Chemical Analyses

i. Sodium (Na) and Potassium (K)

The American Public Health Association Methods 3500B and 3500KB (APHA, 1998) were used for the determination of sodium and potassium respectively, using an Atomic Absorption Spectrophotometer Model FGA 350-L (Gallenkamp Co. Ltd., London, England).

ii Calcium (Ca) and Magnesium (Mg)

The American Public Health Association Methods 3500-Ca B and 3500-Mg B (APHA, 1998) were used for the determination of calcium and magnesium respectively.

iv. Total Hardness and Total Alkalinity

Total hardness and total alkalinity were determined using the American Public Health Association Standard Methods 2340C and 2320A respectively (APHA, 1998).

v. Chloride (Cl^-) and Bicarbonate (HCO_3^-)

Chloride and bicarbonate were determined using the American Public Health Association Standard Methods 4500-Cl and 2320B respectively (APHA, 1998).

vii. Sulphate (SO_4^{2-}) and Phosphate (PO_4^{3-})

Sulphate and phosphate were determined using the Barium Chloride and Stannous Chloride Calorimetric Methods described by the American Public Health Association Standard Methods 4500-SO_4 E and 4500-PD respectively (APHA, 1998), with a

UV/Visible Spectrophotometer Ultrospec II Model PG 25 (LKB Biochron Ltd., Cambridge, England).

viii. Ammonia (NH_3) and Silica (SiO_2)

The direct Nesslerization Methods described by the American Public Health Association Standard Methods 4500-NH_3 C and 4500-SiO_2 B respectively (APHA, 1989) were used, with a UV/Visible Spectrophotometer Ultrospec II Model PG 25 (LKB Biochron Ltd., Cambridge, England).

ix Fluoride (F^-)

Flouride was determined using the SPANDS Calorimetric Method described by the American Public Health Association Standard Method 4500-F^- (APHA, 1998), with a UV/Visible Spectrophotometer Ultrospec II Model PG 25 (LKB Biochron Ltd., Cambridge, England).

x. Nitrate (NO_3^-) and Nitrite (NO_2^-)

The determination of Nitrate and Nitrite was done using the Hydrazine Reduction Methods described by the American Public Health Association Standard Methods 4500-NO_3^- H and 4500-NO_2^- B respectively (APHA, 1989), with a UV/Visible Spectrophotometer Ultrospec II Model PG 25 (LKB Biochron Ltd., Cambridge, England).

xiii. Chemical Oxygen Demand (COD)

For the determination of COD, the Closed Reflux Titrimetric Method described by the American Public Health Association Method 5220C (APHA, 1998) was employed. Samples were refluxed in concentrated sulphuric acid and silver sulphate reagent with standard potassium dichromate ($K_2Cr_2O_7$) solution for 2 hours. The remaining unreduced $K_2Cr_2O_7$ was treated with ferrous ammonium sulphate to determine the amount of $K_2Cr_2O_7$ consumed. The COD was calculated in terms of oxygen equivalent.

xiv. Biological Oxygen Demand (BOD) - 5-day Dilution and Dissolved Oxygen Determination

The determination of BOD was done using the American Public Health Association Standard Method 5210B (APHA, 1998). The samples were incubated in BOD bottles at 20°C for 5 days. Dissolved Oxygen (DO) was measured initially and after incubation, and the BOD was computed from the difference between initial and final DO values.

3.2.3 Biological Measurement:

i. Chlorophyll a - Acetone Extraction and Spectrophotometric Determination

The American Public Health Association Standard Method 10200H (APHA, 1989) was used for the determination of Chlorophyll a. Samples were filtered using glass fibre filter (GF/C) and the filters with residue were then placed in conical flasks containing 90% acetone, to extract the Chlorophyll a. The optical density (OD) of the

Chlorophyll extract was measured on a Spectrophotometer at 645 nm and the Chlorophyll a determined from the OD readings.

3.2.4 Microbiological Analyses - Bacteriological Examination of Water Samples.

Determinations of Total Coliform and Faecal Coliform were done using the Membrane Filtration Method. 100ml of a well-mixed sample or diluted sample was filtered under aseptic conditions, using 0.45 nm pore size filter Two filtrations were done for each sample. The filters were transferred into membrane pads impregnated with lauryl sulphate broth, in petri dishes. The dishes were then incubated for 16 hour at 37°C for total coliforms and 44°C for faecal coliforms.

3.3 DATA ANALYSIS

All statistical analysis were done using Statgraphics (Graphics Software System, STCC, Inc. USA). Descriptive statistics and ANOVA were the major applications used.

4.0 RESULTS AND DISCUSSION

4.1 PHYSICAL AND CHEMICAL QUALITIES OF WATER FROM THE DENSU RIVER DURING THE RAINY SEASON

The results of the physical and chemical quality indices of water from the Densu River during the rainy season are as shown in Tables 4.1 and 4.2. These tables give an overview of the different results obtained from the samples collected from the five different points selected along the Densu River basin during the rainy season.

Table 4.1 : Physical qualities of water from the Densu River Basin during the rainy season

Parameter	Sampling Stations				
	Akwadum	Asuboi	Nsawam	Manhia	Weija
Temperature (°C)	26.0 ± 1.5	25.5 ± 2.0	27.5 ± 1.0	26.0 ± 1.0	27.0 ± 2.0
pH	7.96 ± 0.46	8.04 ± 0.28	7.80 ± 0.31	7.87 ± 0.44	8.64 ± 0.24
Conductivity (µg/cm)	162.0 ± 9.0	248 ± 10.0	246 ± 8.0	298 ± 4.0	303 ± 14.0
Turbidity (NTU)	20.0 ± 1.6	10.0 ± 1.2	54.0 ± 1.2	30.0 ± 1.8	6.8 ± 1.4
Colour (TCU)	70.0 ± 2.0	90 ± 2.0	75 ± 1.0	90 ± 3.0	50 ± 1.0
Total Dissolved Solids (TDS)*	150.0 ± 6.0	216 ± 8.0	212 ± 4.0	222 ± 12.0	266 ± 8.0
Suspended Solids (SS)*	13.0 ± 0.4	7.0 ± 0.2	17.0 ± 0.2	26.0 ± 0.3	14.0 ± 0.2

Mean values of replicates ± standard deviation

* Data in mg/L

Table 4.2 : Chemical qualities of water from the Densu River Basin during the rainy season

Parameter	Sampling Stations				
	Akwadum	**Asuboi**	**Nsawam**	**Manhia**	**Weija**
Sodium (Na)	19.56 ± 2.1	12.20 ± 1.2	17.46 ± 1.4	5.42 ± 0.6	20.56 ± 1.8
Calcium (Ca)	15.79 ± 0.40	21.00 ± 0.25	20.84 ± 0.80	19.96 ± 0.60	14.67 ± 1.20
Magnesium (Mg)	5.6 ± 0.2	7.9 ± 0.4	7.2 ± 0.2	8.4 ± 0.4	10.0 ± 0.3
Iron (Fe)	0.53 ± 0.04	0.52 ± 0.02	0.52 ± 0.02	0.81 ± 0.04	0.37 ± 0.01
Chloride (Cl)	9.2 ± 0.6	15.6 ± 0.2	24.0 ± 0.4	36.4 ± 0.3	40.4 ± 0.6
Sulphate SO_4)	17.86 ± 0.24	17.25 ± 0.18	19.47 ± 0.12	28.33 ± 0.26	14.23 ± 0.18
Bicarbonate (HCO_3)	95.2 ± 1.4	146.0 ± 1.2	129.3 ± 2.4	122.0 ± 1.8	114.7 ± 2.2
Nitrite (NO_3)	<0.03	<0.03	<0.03	<0.03	<0.03
Nitrate (NO_4)	0.14 ± 0.02	0.10 ± 0.02	0.52 ± 0.04	0.18 ± 0.06	<0.01
Ammonia (NH_3)	0.34 ± 0.06	0.35 ± 0.02	0.41 ± 0.05	0.41 ± 0.03	0.28 ± 0.04
Phosphate (PO_4)	0.33 ± 0.02	0.54 ± 0.04	0.64 ± 0.08	0.45 ± 0.05	0.08 ± 0.01
Flouride (F)	0.04 ± 0.001	0.02 ± 0.006	0.06 ± 0.002	0.02 ± 0.004	0.03 ± 0.003
Total Alkalinity (as $CaCO_3$)	78.0 ± 2.0	120.0 ± 3.8	106.0 ± 2.0	100.0 ± 3.0	98.0 ± 1.6
Total Hardness (as $CaCO_3$)	62.8 ± 2.2	85.2 ± 3.0	81.8 ± 2.4	84.4 ± 3.4	78.0 ± 2.8
Calcium Hardness (as $CaCO_3$)	39.5 ± 0.5	52.5 ± 2.6	52.1 ± 0.4	49.9 ± 4.8	36.7 ± 2.5
Magnesium Hardness (as $CaCO_3$)	23.3 ± 2.0	32.7 ± 2.6	29.7 ± 1.8	34.5 ± 1.6	41.3 ± 3.2
Carbonate Hardness (as $CaCO_3$)	62.8 ± 2.5	85.2 ± 1.8	81.8 ± 3.2	84.4 ± 2.6	78.0 ± 4.1
Dissolved Oxygen (DO)	7.4 ± 1.2	7.5 ± 0.8	6.9 ± 0.6	6.1 ± 0.8	9.4 ± 0.4
Biological Oxygen Demand (BOD)	4.4 ± 0.2	4.3 ± 0.1	4.7 ± 0.3	4.3 ± 0.4	5.4 ± 0.2
Chemical Oxgygen Demand (COD)	23.4 ± 2.4	15.6 ± 4.0	32.0 ± 3.2	23.4 ± 4.8	23.4 ± 2.1
Chlorophyl a (mg/m^3)	43.7 ± 4.2	20.8 ± 2.8	47.2 ± 4.8	24.2 ± 3.2	22.8± 1.8

Mean values (mg/L) of replicates ± standard deviation

4.2 MICROBIOLOGICAL QUALITIES OF WATER FROM THE DENSU RIVER DURING THE RAINY SEASON

The results of the microbiological quality indices of water from the Densu River during the second rainy season are as shown on Table 4.3 below. These results, obtained from the samples collected from the five different points selected along the Densu River basin during the second rainy season, are indicative of the microbiological qualities of the water studied.

Table 4.3 : Microbiological qualities of water from the Densu River Basin during the rainy season

Sample	**Total Coliforms (TC) (Counts/100m1)**	**Faecal Coliforms (FC) (Counts/100ml)**
Akwadum	1860 ± 24	420 ± 12
Asuboi	710 ± 14	198 ± 8
Nsawam	1940 ± 18	590 ± 16
Manhia	540 ± 12	250 ± 6
Weija	240 ± 16	47 ± 4

Mean values of replicates ± standard deviation

From Table 4.3, the data presented suggest that the microbiological quality of the water in the Densu River Basin is generally poor. The presence of faecal coliform indicate faecal contaminations which may result from various human activities around the basin. Other environmental sources of contamination other than that from human and animal waste products might have contributed to the high difference between the total and faecal coliforms. The level of faecal contamination was highest for Nsawam and Akwadum, which indicates high human activities such as the siting of refuse dumps close to the river banks, washing and bathing at the river sites, within and around these areas.

4.3 PHYSICAL AND CHEMICAL QUALITIES OF WATER FROM THE DENSU RIVER DURING THE DRY SEASON

The results of the physical and chemical quality indices of water from the Densu River during the dry season are as shown in Tables 4.4 and 4.5 below.

Table 4.4: Physical qualities of water from the Densu River Basin during the dry season

Parameter	**Sampling Stations**				
	Akwadum	**Asuboi**	**Nsawam**	**Manhia**	**Weija**
Temperature (°C)	29.0 ± 2.0	33.0 ± 2.0	30.0 ± 3.0	29.5 ± 1.0	30.0 ± 1.5
pH	7.6 ± 0.12	8.1 ± 0.41	7.6 ± 0.20	7.5 ± 0.80	8.2 ± 0.50
Conductivity (µg/cm)	284 ± 12.0	369 ± 14.0	599 ± 21.0	681 ± 18.2	364 ± 10.0
Turbidity (NTU)	20 ± 0.6	10 ± 0.4	8.9 ± 0.6	7.1 ± 0.8	6 ± 0.4
Colour (TCU)	50 ± 2.0	75 ± 3.0	80 ± 2.0	85 ± 2.0	30 ± 4.0
Total Dissolved Solids (TDS)*	234 ± 6.0	270 ± 4.0	344 ± 4.0	388 ± 8.0	384 ± 6.0
Suspended Solids (SS)*	14.0 ± 2.0	11 ± 2.5	16.0 ± 4.0	38.0 ± 6.0	14.0 ± 2.4

Mean values of replicates ± standard deviation *Data in mg/L

Table 4.5: Chemical qualities of water from the Densu River Basin during the dry season

Parameter	Sampling Stations				
	Akwadum	Asuboi	Nsawam	Manhia	Weija
Sodium (Na)	28.5 ± 2.2	64.0 ± 4.1	13.0 ± 1.1	71.0 ± 5.1	32.0 ± 2.6
Potassium (K)	8.6 ± 0.4	14.2 ± 0.6	10.6 ± 0.2	10.9 ± 0.4	6.9 ± 0.2
Calcium (Ca)	16.0 ± 1.0	33.7 ± 1.4	22.5 ± 0.8	28.9 ± 0.6	24.8 ± 1.6
Magnesium (Mg)	13.1 ± 0.6	15.9 ± 0.2	14.6 ± 0.4	19.9 ± 0.5	24.8 ± 1.2
Chloride (Cl)	67.2 ± 0.8	74.8 ± 1.2	95.4 ± 1.6	112 ± 1.8	74.8 ± 0.8
Sulphate (SO_4)	26.2 ± 0.4	29.8 ± 0.6	41.2 ± 0.6	52.6 ± 0.8	29.0 ± 0.4
Bicarbonate (HCO_3)	205 ± 4.0	239 ± 6.0	202 ± 4.0	212 ± 2.0	225 ± 4.0
Nitrate (NO_4)	0.08 ± 0.01	0.07 ± 0.01	0.20 ± 0.04	0.09 ± 0.01	0.01
Silica (SiO_2)	35.5 ± 2.5	23.7 ± 1.6	24.5 ± 1.2	23.4 ± 1.5	4.5 ± 0.6
Total Alkalinity (as $CaCO_3$)	168 ± 4.0	196 ± 6.2	166 ± 4.3	174 ± 3.8	184 ± 6.8
Total Hardness (as $CaCO_3$)	122 ± 2.8	154 ± 4.2	100 ± 2.6	150 ± 3.4	94.0 ± 2.2
Iron (Fe)	0.30 ± 0.02	1.59 ± 0.04	0.51 ± 0.03	0.51 ± 0.04	0.20 ± 0.01
Zinc (Zn)	0.02	<0.02	0.04	<0.02	0.01
Nickle (Ni)	0.03	0.05	0.08	<0.02	0.03
Cadmium (Cd)	<0.02	<0.02	<0.02	<0.02	<0.02
Lead (Pb)	<0.02	<0.02	<0.02	0.03	<0.02
Manganese (Mn)	<0.02	0.03	0.02	<0.02	0.03
Biological Oxygen Demand (BOD)	6.9 ± 0.3	9.3 ± 0.2	9.9 ± 0.4	6.3 ± 0.3	6.8 ± 0.2
Chemical Oxygen Demand (COD)	27.9 ± 1.3	37.9 ± 1.4	38.9 ± 2.6	28.3 ± 2.2	20.5 ± 3.0
Dissolved Oxygen (DO)	3.6 ± 0.2	6.2 ± 0.4	1.9 ± 0.2	1.6 ± 0.4	7.2 ± 0.3
Chlorophyll a	0.026	0.021	0.001	0.042	0.264

Mean values (mg/L) of replicates ± standard deviation

These show the different results obtained from the samples collected from the five different points selected along the Densu River basin during the dry season.

4.4 MICROBIOLOGICAL QUALITIES OF WATER FROM THE DENSU RIVER DURING THE DRY SEASON

The results of the microbiological quality indices of water from the Densu River during the dry season are as shown on Table 4.6 below. These show the different results obtained from the samples collected from the five different points selected along the Densu River basin during the dry season.

Table 4.6 : Microbiological qualities of water from the Densu River Basin during the dry season

Sample	Total Coliforms (TC) (Counts/100m1)	Faecal Coliforms (FC) (Counts/100ml)
Akwadum	1360 ± 16	520 ± 14
Asuboi	475 ± 10	110 ± 6
Nsawam	1630 ± 18	670 ± 12
Manhia	800 ± 12	70 ± 5
Weija	100 ± 4	30 ± 2

Mean values of replicates ± standard deviation

Similar to the observations made during the rainy season, microbiological quality in the basin during dry season is also poor except that it is slightly better than that of the rainy season.

4.5 EVALUATION OF THE PHYSICAL QUALITIES OF WATER FROM THE DENSU RIVER BASIN

4.5.1. Temperature

The temperature of water is one of the qualities that best determine the suitability of water for human consumption. Temperature generally, has no fixed range or guideline value. However water is said to taste best at room temperature that is 25°C. The temperature of water sampled from the Densu River Basin during the rainy and dry seasons are presented on Table 4.7.

Table 4.7: Temperature (°C) of water collected at various points in the Densu River Basin

Location	Seasonal Value (°C)		Guideline Value
	Rainy	Dry	
Akwadum	26.0 ± 1.5	29.0 ± 2.0	No Guideline Value
Asuboi	25.3 ± 2.0	33.0 ± 2.0	
Nsawam	27.5 ± 2.0	30.0 ± 2.0	
Manhia	26.0 ± 1.0	29.5 ± 1.0	
Weija	27.0 ± 1.0	30.0 ± 1.5	

Mean values (°C) of replicates ± standard deviation

The results on Table 4.7 show that the temperature of water from the basin in the rainy season does not deviate much from the ideal temperature of 25°C for water, but is much higher in the dry season, which is expected. It is evident therefore that taste and odour problems of water from the Weija reservoir would be more pronounced in the dry season, since microorganisms thrive better in warmer conditions than cooler ones. Also, treatment of water is likely to be more costly in the dry season than in the rainy season. This is because when temperature increases above room temperature, the vapour pressure of trace volatile compounds in drinking water also increases leading to odour problems. Besides, the solubility of oxygen decreases with increasing temperature and therefore affects DO values. This may increase the proliferation of pathogenic organisms present.

Analysis of variance (ANOVA) conducted on the data indicated that the temperature of water from the basin during the rainy season is significantly different ($p \leq 0.05$) from that of the dry season. This is due to the higher temperatures attained during the dry season. However, no significant differences were observed between the temperatures of water from the five different locations on the Densu River Basin (Table 4.8).

Table 4.8 : Table of F-ratios showing the ANOVA summary of some physical water quality indices

Process Variables	Temperature	pH	Conductivity	Turbidity
Season	58.824*	27.803	31.875*	10.624*
Location	1.450	32.007*	6.291*	3.024

* Significant F-ratios at $p \leq 0.05$

4.5.2 pH

Seasonal changes (rainy and dry) did not have significant effect ($p \leq 0.05$) on the pH as the water travels on its course from Akwadum to Weija. From Nsawam to Weija there was a gradual increase in the pH during the rainy season. From Table 4.9 below, there was a difference of 0.20 between the rainy and dry seasons at Nsawam, 0.27 at Manhyia and 0.44 at Weija. The difference in pH was not very remarkable since there was no particular trend observed. The average pH across the basin for both dry and rainy seasons was 7.93, which was within the guideline value stipulated.

Table 4.9: pH of water collected at various points in the Densu River Basin

Location	Seasonal Value (mg/L)		Guideline Value
	Rainy	Dry	
Akwadum	7.96 ± 0.46	7.60 ± 0.12	Variable 6 - 9
Asuboi	8.07 ± 0.28	8.10 ± 0.41	
Nsawam	7.80 ± 0.31	7.60 ± 0.20	
Manhia	7.87 ± 0.44	7.50 ± 0.83	
Weija	8.42 ± 0.24	8.20 ± 0.50	

Mean values of replicates ± standard deviation

However, a significant difference ($p \leq 0.05$) was observed between the pH of water obtained from the different locations on the basin. The pH at Asuboi and Weija were however relatively quite high, with the average pH of 8.07 and 8.42 respectively during the rainy season. The high pH at Asuboi could be explained in terms of the fact that the water passes through rocks and therefore may have a high mineral content. Also, upland waters that originate or pass through rock formations of limestone or dolomite are usually non-acidic. However the relatively higher pH at Weija could be as a result of eutrophication, which is a major effect of impounded rivers. This normally results from non-point nutrient input sources, which is difficult to control. Besides, the fishing methods used at Weija which involve the use of explosives, Lead bars and other deadly weapons which could also contribute to the high pH observed at Weija. The pH of 8.4 at Weija during the rainy season, could have a serious implication on treatment. According to Colerangle (1994), pH seems to be one of the major problems of the Weija dam. This is because the pH has to be brought down to an optimum level in order to have an efficient treatment process, which involves cost. The effect of pH therefore might have serious implications on the high cost of treating Weija water.

4.5.3 Conductivity

From the result of the study, generally conductivity increases down the basin except the deviation at Weija in the dry season as shown on Table 4.10. Apparently the conductivity varied from location to location and also between the seasons. Conductivities were generally higher in the dry season than in the rainy season. Locational variations were more prominent in the dry season and this could be attributed to the effect of temperature since increasing temperature favours salt dissolution. In some areas like Nsawam and Manhia, conductivity of the dry season more than doubled compared to that of the rainy season (Table 4.10).

Table 4.10: Conductivity of water collected at various points in the Densu River Basin

Location	Seasonal Value (µg/cm)		Guideline Value
	Rainy	Dry	
Akwadum	162 ± 9	284 ± 12	400 at 20°C
Asuboi	248 ± 10	369 ± 14	
Nsawam	246 ± 8	599 ± 21	
Manhia	298 ± 11	681 ± 18	
Weija	303 ± 14	425 ± 8	

Mean values (µg/cm) of replicates ± standard deviation

ANOVA conducted on the data indicated that the season and location both had significant effect ($p \leq 0.05$) on the conductivity of water from the basin (Table 4.8). The relatively high conductivity values recorded in the dry season could be as a result of evaporation, which led to increased concentration of ions and hence the high conductivity. When compared to the guideline value, the observed values can be said to be quite high. This could be due to the geographical location of the Densu River basin which flows into the Gulf of Guinea at Bortianor. Subsequently, sea water intrusion could account for the high conductivity an effect which decreases as you move further away from the sea, as evident in Table 4.10. Again when compared to other water sources like Dalun in the northern region and Kpong dam, the values can be said to be relatively very high. Dalun for example has a range of about 80-90 µg/cm on the average in the rainy season and about 110 – 120 µg/cm in the dry season (GWCL Records, 1999), whilst Weija recorded 303 and 425 µg/cm in the rainy and dry seasons respectively.

4.5.4 Turbidity

Turbidity in water is caused by the presence of suspended matter such as clay, silts, colloidal organic particles, plankton and microscopic organisms. The results of the study (Table 4.11) showed that turbidity was quite high across the basin when compared to the guideline value. The data confirm the trend that except at Nsawam and Manhia where a deviation occurred in the rainy season, all the studied variable showed similar high values. The latter could partly be as a result of erosion and leaching and partly from the presence of micro-organisms.

Table 4.11: Turbidity (NTU) of water collected at various points in the Densu River Basin

Location	**Seasonal Value (mg/L)**		**Guideline Value**
	Rainy	**Dry**	
Akwadum	20 ± 1.6	20 ± 0.6	5
Asuboi	18 ± 1.2	10 ± 0.4	
Nsawam	54 ± 2.2	8.9 ± 0.6	
Manhia	30 ± 1.8	7.1 ± 0.8	
Weija	6.8 ± 0.4	6.0 ± 0.4	

Mean values (NTU) of replicates ± standard deviation

The high turbidity recorded at Nsawam in the rainy season also possibly reflects the effect of human activity on the vegetative cover, which then causes the topsoil to be eroded and washed into the river resulting in the high turbidity in the rainy season.

However, it was not that turbid in the dry season with presumably a similar measure of human activities and this might be due to the fact that the subsoil contains substantial proportions of dispersive clays, which disperse with rain and thus increasing the turbidity. The encounter at Akwadum where seasonal changes did not seem to affect the turbidity may be due to both human activity and the soil type.

On the contrary, at Asuboi, though the people drink the raw river water, the stream is quite far from human settlement and people who go to fetch are taught to handle the stream with care. Besides, the stream lies in the dense forest where people do not defecate around so the water is free from massive microbial contamination, which could also be a source of high turbidity hence, the low turbidity. Besides this, the water passes over a rocky area, which may contain little or no dispersive clays and therefore rather increase the mineral contents and not the turbidity. The turbidity at Weija in both seasons was quite low and rather stable than those of the river basin, which may be due to the effect of impoundment of river water.

Analysis of variance conducted on the data showed that the season had significant effect ($p \leq 0.05$) on the turbidity of the water, whereas the location did not affect the turbidity (Table 4.8).

4.5.5. Colour

The results obtained for colour of the water during the rainy and dry seasons are presented in Table 4.12. Colour of raw water was quite high across the ridge, ranging from 50-90 TCU, with Weija recording the lowest values during both seasons. These values obtained are very high when compared to the maximum guideline value given for colour of water.

Table 4.12: Colour of water collected at various points in the Densu River Basin

Location	Seasonal Value (TCU)		Guideline Value
	Rainy	Dry	
Akwadum	70 ± 2.0	50 ± 1.0	15
Asuboi	90 ± 2.0	75 ± 1.0	
Nsawam	75 ± 1.0	80 ± 2.0	
Manhia	90 ± 3.0	85 ± 2.0	
Weija	50 ± 1.0	30 ± 0.2	

Mean values (TCU) of replicates ± standard deviation

The high colour values recorded during the rainy and dry seasons might be due to dissolved organic matter and probably inorganic substances like iron and manganese which are abundant in the basin and are not easy to precipitate. A lot of coagulant is therefore needed to take care of this problem which to a large extent contributes to the high cost of treating Weija water.

The colour problem is one of the greatest setbacks of Weija water. At Kpong, the average colour is about 5 TCU, which is much less than the recommended guideline and therefore only needs disinfection to become wholesome (Amuzu, 1976). At Dalun, in the Northern Region the colour is basically due to humic substances, which can also be removed by sedimentation and filtration. At Weija, a lot of effort is needed to remove the colour from the water and this is usually done through the addition of chemical coagulants to form flocs, which are filtered before disinfection, followed by other chemical treatments which eventually make the water wholesome.

The presence of true colour however can be caused by a lot of factors. It can be due to natural pollution processes such as the decay of leaves, pieces of plant parts, or the dissolution of dust which is enhanced by the intrusion of rain water which contains impurities including carbon dioxide (CO_2) in the form of weak acid as well as from soil erosion. It can also be man-made through the release of contaminated coloured wastewater from domestic and industrial activities including agriculture. The presence of true colour normally results from non-point source pollution, which is not easy to control and it is normally the poor quality of water that deters consumers to seek alternative sources, which may not be safe.

ANOVA conducted on the results indicated that both the season and location significantly affected ($p<0.05$) the colour of water from the Densu basin (Table 4.13).

Table 4.13: Table of F-ratios showing the ANOVA summary of some physical water quality indices

Process variables	Colour	Total Solids	Suspended Solids
Season	16.734*	106.500*	0.337
Location	41.973*	19.288*	18.143*

* Significant F-ratios at $p \leq 0.05$

4.5.6. Total dissolved solids (TDS)

The results of the study show that TDS content of the Densu river increases as the water travels down the river to Weija. The only exceptions were observed in the dry season where the values for Manhia was slightly higher than that of Weija Table 4.14.

Table 4.14: Total Dissolved Solids of water collected at various points in the Densu River Basin

Location	Seasonal Value (mg/L)		Maximum Guideline Value
	Rainy	Dry	
Akwadum	150 ± 6.0	234 ± 6.4	1000
Asuboi	216 ± 8.0	270 ± 4.6	
Nsawam	212 ± 4.0	344 ± 4.0	
Manhia	222 ± 12.0	388 ± 8.0	
Weija	266 ± 8.0	384 ± 10.0	

Mean values (mg/L) of replicates ± standard deviation

This can be attributed to the "laking effect" on the volume and quality of water. One distinguishing characteristic of lakes is that, the volume of water in the basin is proportionally greater than its annual inflow or outflow. Consequently the water in lakes develops unique chemical and physical characteristics that make them respond less quickly to changes in water quality (AWWA, 1990). This is what is described as laking effect.

It was observed that generally, TDS is higher in the dry season than the rainy season and this could be attributed to the effect of evaporation which increases the salt concentration of the water. Basically TDS is a reflection of the salt content of water. By

WHO guidelines, any water with TDS less than 300 mg/L is excellent and that between 300 mg/L to 600 mg/L is good. Therefore in the rainy season TDS content of water in the Densu basin can be said to be excellent and in the dry season with an average of 324 across the Densu basin can be said to be good. In general however the dissolved salt contents of water in the Densu basin can be said to be very good.

Statistical analysis showed that both season and location significantly affected ($p<0.05$) the TDS of the water during the study (Table 4.13). However, this results does not have any effect on the quality of the water since they are within the guideline limits.

4.5.7. Suspended Solids (SS)

The results of the suspended solids of the water from the basin are as shown (Table 4.15). No general trends were observed for the suspended solids as the water flows down the basin from Akwadum to Weija during both the rainy and dry seasons.

Table 4.15: Suspended Solids (SS) of water collected at various points in the Densu River Basin

Location	Seasonal Value (mg/L)		Guideline Value
	Rainy	Dry	
Akwadum	13.0 ± 1.4	14.0 ± 2.0	0
Asuboi	7.0 ± 1.1	11.0 ± 2.5	
Nsawam	17.0 ± 1.0	16.0 ± 4.0	
Manhia	26.0 ± 2.1	38.0 ± 6.0	
Weija	14.0 ± 1.6	3.8 ± 2.4	

Mean values (mg/L) of replicates ± standard deviation

The only exception was observed at Manhia where very high mean values of 26.0 and 38.0 mg/L were noted for the rainy and dry seasons respectively. However, with a mean SS of 14mg/L observed at Weija in the rainy season, treatment of water in the Weija Dam could be affected. This is because any water having a suspended solids content of more than 10mg/L needs to go through an initial primary stage of either roughing filtration or clarification thereby increasing the cost of treatment as in the case of the Weija (Stephenson, 1979).

ANOVA conducted on the data showed that the location significantly affected ($p \leq 0.05$) the suspended solids whereas season had no significant effect on it (Table 4.13). Multiple range analysis showed that the significant difference observed was due to the high values obtained at Manhia during both the rainy and dry seasons.

4.6 EVALUATION OF THE CHEMICAL QUALITIES OF WATER FROM THE DENSU RIVER BASIN

4.6.1 Sodium (Na)

The result of the study (Table 4.16) showed no observable trend for sodium during the rainy and dry seasons even though the values were different with the different locations. However, sodium levels across the basin were within acceptable range because all the values were below the guideline value. It was observed that the sodium contents of the water seem to be higher across the basin in the dry season than the rainy season and this could be as a result of evaporation during the dry season.

Table 4.16: Sodium (Na) levels of water collected at various points in the Densu River Basin

Location	Seasonal Value (mg/L)		Guideline Value
	Rainy	Dry	
Akwadum	19.56 ± 2.1	28.5 ± 2.2	200
Asuboi	12.20 ± 1.2	64 ± 4.1	
Nsawam	17.46 ± 1.4	13 ± 1.1	
Manhia	5.46 ± 0.6	71 ± 5.1	
Weija	20.56 ± 1.8	32.0 ± 2.6	

Mean values (mg/L) of replicates ± standard deviation

Analysis of variance conducted on the data showed that the season significantly affected ($p \leq 0.05$) the sodium levels whereas location had no effect (Table 4.17). Multiple range analysis revealed that the differences in season observed resulted from the relatively high sodium levels of 64 and 71 mg/L reported at Asuboi and Manhia, respectively, during the dry season.

With the low sodium levels in the Densu River Basin, treatment of the water with regard to sodium concentrations would not pose any problem.

Table 4.17: Table of F-ratios showing the ANOVA summary of some chemical water quality indices

Process variables	Sodium	Potassium	Calcium	Magnesium	Iron	Chloride
Season	12.623*	107.466*	24.458*	149.238*	1.218	221.201*
Location	1.378	3.964*	8.307*	12.111*	4.267*	9.598*

* Significant F-ratios at $p \leq 0.05$

4.6.2 Potassium (K)

The potassium levels observed during the study were also within the acceptable range across the basin, that is, they were all lower than the guideline value. No particular trend was observed across the basin. However, potassium levels were exceptionally low at Weija for both seasons. This possibly confirms the rather slow response of lakes to changes in quality. Treatment also seems to have little influence on potassium levels as shown in Table 4.18 below.

Table 4.18: Potassium (K) levels of water collected at various points in the Densu River Basin

Location	Seasonal Value (mg/L)		Guideline Value
	Rainy	Dry	
Akwadum	3.98 ± 0.81	8.6 ± 0.40	30
Asuboi	3.94 ± 0.64	14.2 ± 0.60	
Nsawam	2.99 ± 0.14	10.6 ± 0.25	
Manhia	2.11 ± 0.12	10.4 ± 0.40	
Weija	3.15 ± 0.10	6.9 ± 0.20	

Mean values (mg/L) of replicates ± standard deviation

In general potassium level was low across the basin. However in the rainy season the trend change a little at Weija and this could be because, as a characteristic, lakes respond rather slow to changes in quality (Downing and Crowley, 1979). In general, like sodium, potassium levels were generally higher in the dry season. Sodium and potassium levels however seem to have little or no influence on the treatment.

Statistical analysis showed that both season and location significantly affected ($p \leq 0.05$) the potassium levels of the water during the study (Table 4.17). However, this observation would not have any effect on the quality of the water with respect to potassium concentrations because of their relatively lower levels.

4.6.3 Calcium (Ca)

The calcium levels of the water from both the Densu River Basin and the Weija Dam are presented in Table 4.19 below. The results revealed a very interesting trend in the level of calcium across the basin. Generally, calcium levels across the basin showed a decreasing trend, with the exception of Akwadum which showed relatively lower values as compared to Asuboi. However, all the calcium levels were within the acceptable range since they were all below the guideline value.

Table 4.19: Calcium (Ca) levels of water collected at various points in the Densu River Basin

Location	Seasonal Value (mg/L)		Guideline Value
	Rainy	Dry	
Akwadum	15.79 ± 0.40	16.0 ± 1.0	200
Asuboi	21.00 ± 0.25	33.7 ± 1.4	
Nsawam	20.84 ± 0.80	22.5 ± 0.8	
Manhia	19.96 ± 0.60	28.9 ± 0.6	
Weija	14.67 ± 1.2	24.8 ± 1.6	

Mean values (mg/L) of replicates ± standard deviation

It was also observed that Asuboi recorded the highest value in both seasons and this could be attributed to the geographical and hydrological nature of this locality. Like the other ions, calcium levels were also higher in the dry season compared to that of the rainy season.

Statistical analysis showed that both season and location significantly affected ($p \leq 0.05$) the calcium levels of the water during the study (Table 4.17).

4.6.4 Magnesium (Mg)

The detailed results of the magnesium levels in both the Densu River Basin and the Weija Dam are as shown on Table 4.20.

Table 4.20: Magnesium (Mg) levels of water collected at various points in the Densu River Basin

Location	Seasonal Value (mg/L)		Guideline Value
	Rainy	Dry	
Akwadum	5.6 ± 0.2	13.1 ± 0.6	150
Asuboi	7.9 ± 0.4	15.9 ± 0.2	
Nsawam	7.2 ± 0.2	14.6 ± 0.4	
Manhia	8.4 ± 0.4	19.9 ± 0.5	
Weija	10.0 ± 0.4	24.8 ± 1.2	

Mean values (mg/L) of replicates ± standard deviation

Generally magnesium level increases down the basin except for the deviation at Asuboi. The level of magnesium is also generally within the acceptable limits across the basin during both the rainy and dry seasons. As well, it was noted that the calcium levels were relatively higher in the dry season than in the rainy season. These increasing concentrations of calcium during the dry season might have occurred as a result of evaporation of water from the river thereby increasing the calcium concentrations.

Analysis of variance conducted on the data showed that both season and location significantly affected ($p \leq 0.05$) the calcium levels of the water during the study (Table 4.17). However, these observed trends would not have any effect on the treatment of the water since the concentrations were all within the acceptable value.

4.6.5 Iron (Fe)

The results of the iron levels in the Densu River Basin and the Weija Dam are as presented in Table 4.21 below. Generally, the iron levels were high across the basin during both the rainy and dry seasons with values exceeding the guideline value of 0.3 mg/L. However, no observable trend was noted between the seasons and the locations with the exception of Weija, which showed relatively lower concentrations during both seasons

Table 4.21: Iron (Fe) levels of water collected at various points in the Densu River Basin

Location	Seasonal Value (mg/L)		Guideline Value
	Rainy	Dry	
Akwadum	0.53 ± 0.04	0.34 ± 0.02	0.3
Asuboi	0.52 ± 0.02	1.59 ± 0.04	
Nsawam	0.52 ± 0.02	0.51 ± 0.03	
Manhia	0.51 ± 0.02	0.51 ± 0.05	
Weija	0.31 ± 0.01	0.20 ± 0.01	

Mean values (mg/L) of replicates ± standard deviation

Statistical analysis showed that the seasons did not have any significant effect ($p \leq 0.05$) on the iron levels of the water during the study, but location affected the iron levels significantly (Table 4.17). Multiple range analysis conducted showed that the significance in location was due to the comparatively lower values noted for Weija during both seasons.

4.6.6 Chloride (Cl)

Chloride levels generally increase down the basin during both the rainy and dry seasons (Table 4.22). This could be a result of marine intrusion since Weija is close to the Gulf of Guinea at Bortianor. Like all the other ions, values are much higher in the dry season presumably due to evaporation. Even though the levels across the basin are lower than the guideline value they are indicative of some level of pollution since normally for unpolluted water chloride level is less than 10mg/L as reported by Amuzu (1976).

Table 4.22: Chloride (Cl^-) levels of water collected at various points in the Densu River Basin

Location	Seasonal Value (mg/L)		Maximum Guideline Value
	Rainy	Dry	
Akwadum	9.2 ± 0.6	67.4 ± 0.8	250
Asuboi	15.6 ± 0.2	74.0 ± 1.2	
Nsawam	21.0 ± 0.4	95.4 ± 1.6	
Manhia	36.0 ± 0.3	112.0 ± 1.8	
Weija	40.4 ± 0.6	74.8 ± 0.8	

Mean values (mg/L) of replicates ± standard deviation

A little after the rains in the month of May, values obtained at Weija gave an average of 40.4 mg/L. Meanwhile this was much lower compared to the dry season when the average was about 74.8 mg/L. However according to WHO (1993), the level of chloride in unpolluted water are often less than 10 mg/L and may often be less than 1 mg/L. Therefore, even though the levels of chloride recorded across the basin were less than the guideline value, the relatively higher values obtained for the Densu basin and the Weija dam are indicative of some level of pollution.

The presence of chloride in Densu water can be attributed to dissolution of salt deposits which might have resulted from discharge of effluents from industries probably in and around Koforidua and Nsawam, sewage dislodges, agricultural wastes, and contamination from refuse leachates, as well as sea water intrusion.

4.6.7 Manganese (Mn)

The results of the manganese levels observed during the study is presented on Table 4.23 below. No general trend was observed for manganese during both the rainy and dry seasons. However, the levels of manganese noted across the basin were lower than the guideline value.

Table 4.23: Manganese (Mn) levels of water collected at various points in the Densu River Basin

Location	Seasonal Value (mg/L)		Guideline Value
	Rainy	Dry	
Akwadum	<0.02	<0.02	0.1
Asuboi	0.02	0.03	
Nsawam	0.01	0.02	
Manhia	<0.02	<0.02	
Weija	0.02	0.03	

LSD = ± 0.005

This implies that the manganese contents of water in the basin were all within the acceptable limit and can be described as good.

4.6.8. Lead (Pb)

The results obtained for lead levels in the Densu River Basin and the Weija Dam showed no observable trend with the different locations across the basin with the exception of Manhia which showed values slightly higher than the other locations during both the rainy and dry seasons (Table 4.24). This could be as a result of the methods of fishing employed by some inhabitants of the area who use nets with lead stripes at the end for fishing thereby increasing the lead concentrations of that part of the river.

Table 4.24: Lead (Pb) levels of water collected at various points in the Densu River Basin

Location	Seasonal Value (mg/L)		Guideline Value
	Rainy	Dry	
Akwadum	<0.01	<0.02	0.01
Asuboi	<0.01	<0.02	
Nsawam	<0.01	<0.02	
Manhia	<0.02	<0.03	
Weija	<0.01	<0.03	

LSD = ± 0.005

The results on Table 4.24 also shows that the lead levels realized during the dry season were quite higher than those of the rainy season as well as the guideline value given. This observation is suspected to have resulted from the evaporation of the river during the dry season resulting in increasing concentrations of lead across the basin.

4.6.9 Sulphate ($SO4^{2-}$)

The results of the sulphate levels showed a very interesting trend during the study (Table 4.25). Generally, sulphate levels increased down the basin upto Manhia and decreased at Weija in both seasons. As well, the levels noted during the dry season were higher than those observed during the rainy season and this is attributed to the high rate of evaporation of the river during the dry season.

Table 4.25: Sulphate (SO_4^{2-}) levels of water collected at various points in the Densu River Basin

Location	Seasonal Value (mg/L)		Guideline Value
	Rainy	Dry	
Akwadum	17.25 ± 0.24	26.2 ± 0.42	250
Asuboi	17.86 ± 0.18	29.8 ± 0.61	
Nsawam	19.47 ± 0.12	41.2 ± 0.32	
Manhia	28.33 ± 0.26	52.6 ± 0.84	
Weija	14.23 ± 0.18	29.0 ± 0.74	

Mean values (mg/L) of replicates ± standard deviation

The values observed in both seasons were all well below the guideline value, making the sulphate contents of the river acceptable. Statistical analysis conducted on the data indicated that both the location and season significantly affected ($p \leq 0.05$) the sulphate levels of the river (Table 4.26). These observations however, do not have any implication on the quality of the water with respect to sulphate concentrations since all the values were within the acceptable range.

Table 4.26: Table of F-ratios showing the ANOVA summary of some chemical Water quality indices

Process variables	Sulphate	Nitrate	Bicarbonate	Phosphate	Flouride
Season	103.109*	7.164*	589.817*	4.454	13.765*
Location	19.863*	3.003	12.013*	12.346*	29.632*

* Significant F-ratios at $p \leq 0.05$

4.6.10 Bicarbonates (HCO_3^-)

The results of the bicarbonate levels in the Densu River Basin and the Weija Dam are as presented on Table 4.27. The data suggest that bicarbonate levels in the basin are very high, with averages higher than the maximum guideline value, during both the rainy and dry seasons.

Table 4.27: Bicarbonate (HCO_3^-) levels of water collected at various points in the Densu River Basin

Location	Seasonal Value (mg/L)		Maximum Guideline Value
	Rainy	Dry	
Akwadum	95.2 ± 1.4	205.0 ± 4.0	30
Asuboi	146.0 ± 1.2	239.0 ± 6.0	
Nsawam	129.3 ± 2.4	202.0 ± 4.2	
Manhia	122.0 ± 1.8	212.0 ± 2.0	
Weija	114.7 ± 2.2	225.0 ± 4.4	

Mean values (mg/L) of replicates ± standard deviation

It was also observed that the bicarbonate levels of the river are higher during the dry season than in the rainy season which may be attributed to the evaporation of the river resulting in increasing salt concentrations during the dry season.

Analysis of variance conducted on the data showed that both season and location significantly affected ($p \leq 0.05$) the bicarbonate levels of the water during the study (Table 4.26). These observations would affect treatment of the water since the bicarbonate concentrations were all higher than the acceptable value. Much of the hardness in the river basin may therefore be due to bicarbonate salts.

4.6.11 Nitrates (NO_3)

The results of the study showed that the nitrate levels observed during the rainy season were all higher than those observed for the dry season (Table 4.28).

Table 4.28: Nitrate (NO_3) levels of water collected at various points in the Densu River Basin

Location	Seasonal Value (mg/L)		Guideline Value
	Rainy	Dry	
Akwadum	0.14 ± 0.02	0.08 ± 0.01	1.0
Asuboi	0.10 ± 0.02	0.07 ± 0.01	
Nsawam	0.52 ± 0.04	0.03 ± 0.01	
Manhia	0.18 ± 0.06	0.09 ± 0.01	
Weija	< 0.01	< 0.01	

Mean values (mg/L) of replicates ± standard deviation

However, the nitrate levels were all within the acceptable range because all the values were below the maximum guideline value. No observable trend was noted across the basin in both the rainy and dry seasons, except Weija where relatively lower values were noted during both seasons.

Statistical analysis showed that the season significantly affected ($p \leq 0.05$) the nitrate levels of the water during the study (Table 4.26). However, this observation would not have any effect on the quality of the water with respect to nitrate concentrations in both seasons due to their lower levels as compared to the guideline value. The location did not have any significant effect on the nitrate levels. Nitrate levels of water in the Densu basin can therefore be said to be good.

4.6.12 Phosphate (PO_4)

Phosphate level in river water is normally associated with nutrient enrichment. The results of the phosphate levels observed during the study are presented in Table 4.29. Generally, the phosphate levels decreased across the basin during both the rainy and dry seasons. However, the phosphate levels showed no observable trend between the seasons and no guideline value was given for phosphate.

Table 4.29: Phosphate (PO_4) levels of water collected at various points in the Densu River Basin

Location	Seasonal Value (mg/L)		Guideline Value
	Rainy	Dry	
Akwadum	0.33 ± 0.02	0.71 ± 0.14	No guideline Value
Asuboi	0.54 ± 0.04	0.81 ± 0.10	
Nsawam	0.44 ± 0.08	0.36 ± 0.04	
Manhia	0.35 ± 0.05	0.24 ± 0.02	
Weija	0.08 ± 0.01	0.18 ± 0.02	

Mean values (mg/L) of replicates ± standard deviation

Analysis of variance conducted on the data showed that location significantly affected ($p \leq 0.05$) the phosphate levels of the water during the study (Table 4.26) whereas season had no significant effect. Phosphate level across the Densu River Basin can therefore be said to be high.

4.6.13 Fluoride (F)

The result of the study showed a fluctuating trend for fluoride during the rainy and dry seasons (Table 4.30). The fluoride contents of the water seem to decrease across the basin in both seasons with the exception of Nsawam where the values obtained during the rainy and dry seasons were relatively high. However, the levels across the basin were all within the acceptable range since they were all below the guideline value.

Table 4.30: Fluoride (F) level of water collected at various points in the Densu River Basin

Location	Seasonal Value (mg/L)		Guideline Value
	Rainy	Dry	
Akwadum	0.04 ± 0.001	0.06 ± 0.004	1.5
Asuboi	0.02 ± 0.001	0.03 ± 0.002	
Nsawam	0.06 ± 0.002	0.08 ± 0.006	
Manhia	0.02 ± 0.001	0.04 ± 0.002	
Weija	0.03 ± 0.003	0.02 ± 0.003	

Mean values (mg/L) of replicates ± standard deviation

Analysis of variance conducted on the data showed that both season and location significantly affected ($p \leq 0.05$) the fluoride levels of the water during the study (Table 4.26). However, these observations would not affect the quality of the water since the concentrations were all lower than the acceptable value and the levels recorded may not be significant in water quality considerations.

4.6.14 Alkalinity

The detailed results of alkalinity levels of water in the Densu River Basin are presented in Table 4.31 below. The results reveal that alkalinity levels of the basin water are relatively higher compared to the guideline value. Generally, alkalinity increased down the Densu basin except at Asuboi where relatively higher values were noted both during the rainy and dry seasons. These high values observed at Asuboi could be the result of algal blooms, which has been identified as one of the problems of water quality reported in the area (Amuzu, 1976).

Table 4.31: Alkalinity levels of water collected at various points in the Densu River Basin

Location	Seasonal Value (mg/L)		Guideline Value
	Rainy	Dry	
Akwadum	78 ± 2.0	168 ± 4.0	30
Asuboi	120 ± 3.8	196 ± 4.2	
Nsawam	106 ± 2.0	166 ± 6.0	
Manhia	104 ± 3.5	174 ± 2.0	
Weija	108 ± 1.6	184 ± 6.0	

Mean values (mg/L) of replicates ± standard deviation

Also, the high alkalinity values recorded could be partly due to the high bicarbonate levels recorded in the area. Statistical analysis showed that both season and location significantly affected ($p \leq 0.05$) the alkalinity levels of the river (Table 4.32).

Table 4.32: Table of F-ratios showing the ANOVA summary of some chemical Water quality indices

Process variables	Alkalinity	Hardness	BOD	Dissolved Oxygen
Season	705.885*	49.060*	54.315*	75.095*
Location	15.018*	4.770*	2.816	17.564*

* Significant F-ratios at $p \leq 0.05$

4.6.15 Total Hardness

The details of the results of total hardness are shown in Table 4.33 below. It was noted that the levels of total hardness obtained for the water collected at the various points in the dry season were comparatively higher than those of the rainy season. This observation agrees with the grading system reported by WHO (1996), that water in the Densu basin can be said to be of medium hardness in the rainy season with an average of 78 mg/L and hard in the dry season with an average of 124 mg/L. This may be attributed to the high salt concentrations noted during the rainy season.

Table 4.33: Total Hardness levels of water collected at various points in the Densu River Basin

Location	**Seasonal Value (mg/L)**		**Guideline Value**
	Rainy	**Dry**	
Akwadum	62.8 ± 2.2	122.0 ± 2.8	60
Asuboi	85.2 ± 3.0	154.0 ± 4.2	
Nsawam	81.8 ± 2.4	100.0 ± 2.6	
Manhia	84.4 ± 3.4	150.0 ± 3.4	
Weija	78.0 ± 2.8	94.0 ± 2.2	

Mean values (mg/L) of replicates ± standard deviation

Analysis of variance conducted on the data showed that both season and location significantly affected ($p \leq 0.05$) the hardness levels of the water during the study (Table

4.32). These high hardness levels observed in the basin water during both seasons will cause increases in the treatment cost of the water from the basin.

4.6.16 Dissolved Oxygen (DO)

The results showing the level of dissolved oxygen in the Densu basin are presented in Table 4.34. Generally, the values fall within the acceptable values for tropical rivers.

Table 4.34: Dissolved Oxygen (DO) levels of water collected at various points in the Densu River Basin

Location	Seasonal Value (mg/L)		Guideline Value
	Rainy	Dry	
Akwadum	7.4 ± 1.2	3.6 ± 0.2	No Guideline Value
Asuboi	7.5 ± 0.8	6.2 ± 0.4	
Nsawam	6.9 ± 0.6	1.9 ± 0.2	
Manhia	6.1 ± 0.8	1.6 ± 0.6	
Weija	9.4 ± 0.4	7.2 ± 0.4	

Mean values (mg/L) of replicates ± standard deviation

Generally DO levels across the basin in the rainy season can be said to be good with ranges within the acceptable values for tropical rivers. Colerangle (1994) reported that DO concentrations of 5.0 mg/L is the minimum required for a tropical river to maintain a varied fish fauna in good condition. Concentrations of 3.0 mg/L or less is regarded as hazardous or lethal. By these requirement, DO concentrations in the dry season with an average of 4.1 mg/L across the basin fall below the minimum required to maintain the river in good condition. It is therefore evident that the low values recorded at Manhia and Nsawam (Table 4.34) suggest high pollutions at these locations, since DO level is one of the most important indicators of river water quality.

Analysis of variance conducted on the data showed that both season and location significantly affected ($p \leq 0.05$) the DO levels of the water during the study (Table 4.32). These high DO levels observed in the basin water during both seasons will not pose any problem to the treatment of the water in the basin during both seasons since the mean value across the basin falls above the stipulated minimum for maintaining tropical river quality.

4.6.17 Biological Oxygen Demand:

The results of the biological oxygen demand (BOD) in the Densu River Basin are shown on Table 4.35. From the results, no general trend was observed for BOD across the different locations of the river basin. These values provide a true indication of the level of organic pollution at the five specific locations along the river. It was noted that Nsawam has the highest BOD in both the rainy and dry seasons with Manhia having the lowest.

Table 4.35: Biological Oxygen Demand (BOD) levels of water collected at various points in the Densu River Basin

Location	Seasonal Value (mg/L)		Guideline Value
	Rainy	Dry	
Akwadum	4.4 ± 0.2	6.9 ± 0.1	No guideline value
Asuboi	4.3 ± 0.3	9.3 ± 0.2	
Nsawam	4.7 ± 0.3	9.9 ± 0.4	
Manhia	4.3 ± 0.1	6.3 + 0.3	
Weija	5.4 ± 0.2	6.8 ± 0.2	

Mean values (mg/L) of replicates ± standard deviation

Generally, higher values of BOD were observed in the dry season than the rainy season. This is probably due to increased accumulation of organic constituents as well as the availability of optimum conditions for microbial activity due to increased temperature and sunlight in the dry season. Statistical analysis showed that the season significantly affected ($p \leq 0.05$) the BOD levels of the water during the study (Table 4.32), whereas location had no significant effect on the BOD levels.

4.7 EVALUATION OF THE MICROBIOLOGICAL QUALITIES OF WATER FROM THE DENSU RIVER BASIN

4.7.1 Total coliforms (TC) and Faecal coliforms (FC)

The detailed results of the microbiological examination involving the total coliform and faecal coliform counts are presented in Tables 4.36 and 4.37. Generally, total and faecal Coliform counts were high across the basin for both seasons. It was observed that Nsawam and Akwadum recorded the highest total coliform and faecal coliform counts during both the dry and rainy seasons. These observations are suspected to have resulted from the level of urbanization in both areas as compared to the other locations on the river basin. Comparatively, the faecal coliform counts were much lower than the total coliform counts as indicated in Tables 4.36 and 4.37. This indicates that a great number of the coliforms present are not from faecal sources but from other sources in the environment, presumably from the soil, decaying vegetation, or other decaying organic matter present.

The total coliforms normally have greater power of survival and since they are much more than the faecal coliforms, they become a point to worry about when the efficiency of the treatment process employed for the treatment of water from the Densu comes into mind. It is therefore indicative that even though the basin is faecally polluted it experiences much more pollution from non-faecal or non-point sources in the environment. This however complicates the problem since policy makers would not know the exact angles from which the problem can be tackled.

Table 4.36: Total Coliform (TC) counts of water collected at various points in the Densu River Basin

Location	Seasonal Value (Counts / 100mL)		Guideline Value
	Rainy	Dry	
Akwadum	1860 ± 24	1360 ± 16	Zero
Asuboi	710 ± 14	475 ± 10	
Nsawam	1940 ± 18	1630 ± 18	
Manhia	540 ± 12	800 ± 12	
Weija	240 ± 8	100 ± 4	

Mean values (Counts/100mL) of replicates ± standard deviation

Table 4.37: Faecal Coliform (FC) counts of water collected at various points in the Densu River Basin

Location	Seasonal Value (Counts / 100mL)		Guideline Value
	Rainy	Dry	
Akwadum	420 ± 12	520 ± 14	Zero
Asuboi	198 ± 8	110 ± 6	
Nsawam	590 ± 16	670 ± 12	
Manhia	250 ± 6	70 ± 5	
Weija	47 ± 4	30 ± 2	

Mean values (Counts / 100mL) of replicates ± standard deviation

Nevertheless, the results of the study confirm the sanitary conditions and practices in some of the towns within the Densu basin. For example, at Akwadum around the bridge area where the samples were collected, the residents fetch their domestic water directly from the river and there is also an old refuse dump at the bank of the river. The presence of faeces at the banks was also noticed, even though the extent of defecation was not as high as Nsawam. The river however is the main source of domestic water supply since residents lack pipe-borne water.

At Nsawam on the other hand, the situation is compounded by the huge refuse dump right at the bank of the open water a little after the bridge upstream. Whilst dumping of refuse has been banned around the Nsawam bridge, the dumpsite has been relocated at this new site. Here, the riverbanks serve as a secondary public toilet facility for both the old and young. Most people carry out a number of their domestic activities that involve the use of water here, like washing and bathing. The high count recorded at this site is therefore a true indication of the insanitary conditions at the Nsawam township.

Contrary to the organic matter content, Manhia recorded a much lower level of total coliform counts. Also, the relatively lower total and faecal coliform counts at Asuboi is due to the fact that the river does not pass through the main settlement areas of the town even though it serves as the main source of water for the inhabitants.

Table 4.38: Table of F-ratios showing the ANOVA summary of the Microbiological quality indices

Process variables	Total Coliforms	Faecal Coliforms
Season	7.009*	0.525
Location	79.713*	58.695*

* Significant F-ratios at $p \leq 0.05$

Analysis of variance conducted on the data showed that both season and location significantly affected ($p \leq 0.05$) the total coliform counts of the water during the study (Table 4.38) whereas only location significantly affected ($p \leq 0.05$) the faecal coliform counts during the study. This indicates that all the different locations on the basin have high microbiological counts during both the rainy and dry seasons. These high total and faecal coliform counts would affect the cost of treatment of the water from the Densu River.

4.8 COMPARATIVE STUDIES ON TREATED AND UNTREATED WATER FROM THE WEIJA DAM DURING THE TRANSITIONAL SEASON

4.8.1 Evaluation of the physical quality indices of treated and untreated water

The physical quality indices of water from the surface and bottom levels of the Weija dam were compared with treated water from the Ghana Water Company Limited treatment plant on the Weija dam. The detailed results of the physical quality indices are as presented in Table 4.39. The results indicated that the surface temperature of water from the river is higher than that at the bottom level. The temperature of treated water was however within the acceptable temperature limit of 25°C for consumption.

Table 4.39 : Physical Qualities of treated and untreated water from the Weija Dam

Parameter	**Source of water**		
	Bottom	**Surface**	**Treated (GWCL)**
Temperature (°C)	21.0 ± 1.0	28.0 ± 1.0	24.0 ± 0.8
pH	8.5 ± 0.6	8.5 ± 0.8	6.3 ± 0.2
Conductivity (µg/cm)	291 ± 2.4	295 ± 8.6	425 ± 4.8
Turbidity (NTU)	12.0 ± 0.4	5.7 ± 0.3	1.5 ± 0.2
True Colour (TCU)	30.0 ± 2.0	40.0 ± 1.4	10.0 ± 0.3
Total Dissolved Solids (mg/L)	198.0 ± 2.8	228.0 ± 4.5	318.0 ± 3.2
Suspended Solids (mg/L)	20.0 ± 0.6	18.0 ± 0.4	7.4 ± 0.2

Mean values of replicates ± standard deviation

The results of the pH, conductivity and dissolved oxygen showed no much variation between the water from the surface and bottom levels of the dam. However, the surface water was observed to have higher values for colour and suspended solids than the bottom water. This is suspected to be due to the dissolution of organic matter and the presence of water weeds on the surface of the water thereby increasing the colour and suspended solids contents of the water. With the exception of conductivity and total dissolved solids, all the measured physical quality indices showed relatively lower values for the treated water as compared to the water from the surface and bottom levels of the dam. The high conductivity and total dissolved solids levels observed are the results of the chemical treatment employed during the treatment of water in the Weija Dam.

Table 4.40 : Table of F-ratios showing the ANOVA summary of some physical water quality indices

Process Variables	Temperature	pH	Conductivity	Turbidity
Source of water	458.824*	27.803*	31.875*	10.624*
Replicates	321.450	132.007	260.291	543.024

* Significant F-ratios at $p \leq 0.05$

Table 4.41 : Table of F-ratios showing the ANOVA summary of some physical water quality indices

Process Variables	Colour	Total Dissolved Solids	Suspended Solids
Source of water	268.124*	27.803*	31.875*
Replicates	411.250	232.407	160.250

* Significant F-ratios at $p \leq 0.05$

Statistical analyses of the data revealed that in each of the indices measured, the source of water significantly affected ($p \leq 0.05$) the values obtained from the study (Tables 4.40-4.41). Multiple range analysis of the data showed that in each case the difference was from the values obtained from the treated water. This implies that colour and turbidity are the most important physical parameters that can be used as indicators of water quality. The results revealed that in most of the parameters, the levels of treated water were lower as compared to the untreated water, except for conductivity and dissolved solids which indicate the level of chemicals added during treatment (Amuzu, 1976).

4.8.2 Evaluation of the chemical quality indices of treated and untreated water

An examination of Table 4.42 shows a great disparity in the chemical quality of both raw and treated water from the Weija reservoir in terms of quality indices such as calcium, bicarbonate, alkalinity and carbonate hardness where treated water showed values quite lower than those of the raw water. The high levels of these indices in the raw water is probably an indication of the extent of mineralization of water in the Weija dam. However, the high values observed for calcium hardness in treated water, may be due to the addition of calcium hydroxide in regulating the pH of the water during treatment. Stephenson (1979) reported that sulphuric acid and calcium hydroxide are used in regulating the pH of water during treatment. This therefore suggest why water from the Weija dam attracts more consumer complaints and is more expensive to treat. The quality of water from both the surface and bottom levels of the Weija dam showed no much variation in all the chemical indices.

Apart from the parameters discussed above which showed varied differences in the chemical contents, all the other indices studied showed no much differences in the chemical contents of the raw and treated water (Table 4.42).

Table 4.42: Chemical Qualities of treated and untreated water from the Weija Dam

Parameter	Source of water		
	Bottom (untreated)	Surface (untreated)	Treated (GWCL)
Sodium (Na)	19.4 ± 0.3	19.7 ± 0.2	19.5 ± 0.3
Potassium (K)	4.3 ± 0.2	4.3 ± 0.2	4.7 ± 0.3
Calcium (Ca)	14.9 ± 1.4	14.7 ± 1.0	30.4 ± 1.2
Magnesium (Mg)	9.5 ± 0.4	8.1± 0.2	9.2 ± 0.6
Ammonia (NH_3)	0.46 ± 0.05	0.36 ± 0.04	0.12 ± 0.02
Chloride (Cl)	26.8 ± 1.4	37.0 ± 2.1	29.6 ± 2.0
Sulphate (SO_4)	<1.0	<1.0	<1.0
Bicarbonate (HCO_3)	101.0 ± 2.6	102.0 ± 0.8	26.8 ± 0.6
Nitrate (NO_4)	0.05 ± 0.002	0.08 ± 0.006	<0.02
Phosphate (PO_4)	0.20 ± 0.02	0.15 ± 0.01	0.11 ± 0.02
Silica (SiO_2)	1.8 ± 0.4	1.2 ± 0.2	2.3 ± 0.3
Total Alkalinity	83.0 ± 3.2	84.0 ± 1.8	22.0 ± 0.6
Total Hardness	76.4 ± 2.7	78.4 ± 4.0	114.0 ± 2.6
Magnesium Hardness	39.1 ± 1.8	41.6 ± 1.4	38.0 ± 2.1
Calcium Hardness	37.3 ± 0.8	31.8 ± 0.2	76.0 ± 2.5
Carbonate Hardness	76.4 ± 1.6	78.4 ± 1.3	22.0 ± 0.3

Mean values (mg/L) of replicates ± standard deviation

4.9 EVALUATION OF WATER QUALITY OF THE DENSU RIVER BETWEEN THE PRE-IMPOUNDMENT ERA AND CURRENT STUDIES

A close examination of Table 4.43 revealed that the levels of most of the key parameters studied during the pre-impoundment era and current studies are comparable. There seem to be no much changes in most of the parameters.

Table 4.43 : Comparative analysis on the water quality of the Densu River between the pre-impoundment era and current studies

Parameter	Period of study			
	Pre-impoundment era *		Current Studies	
	Lower-Upper limits	Mean Value	Lower-Upper limits	Mean Value
pH	6.96 – 7.55	7.26	7.50 – 8.04	7.72
Chloride	8.9 – 116.4	62.65	9.2 – 112.0	60.6
Iron	0.34 – 2.24	1.04	0.20 – 1.59	0.90
B O D	0.77 – 4.03	2.40	4.30 – 9.90	7.10
Dissolved Oxygen	3.1 – 9.7	6.4	1.6 – 9.4	5.5
Colour	25 - 70	47.5	30 – 90	60.0
Sulphate	10 - 134	72.0	14.25 – 50.60	32.43
Phosphate	0.01 – 1.2	0.65	0.08 – 0.91	0.62

* Source : Amuzu (1976)

The values obtained for pH, chloride, iron, DO, and phosphate were all comparable with the exception of BOD, colour and sulphate which showed only slight changes between the two periods. This reveals that there have not been any remarkable changes in the quality of raw water from the Densu River between the pre-impoundment era and the current status. The only remarkable changes were observed in colour and BOD levels. These high colour and BOD values obtained in the current studies are more probably due to the presence of increased organic matter contents of water in the Densu River Basin ,as a result of the increased human activities within the Densu River Basin. Even though phosphate levels were comparable between the two periods, phosphate levels in the basin are still high and this will continue to pose treatment problems to the Ghana Water Company Limited as predicted by Amuzu (1976). The mean concentration of dissolved inorganic phosphate prior to the impoundment of the Weija Lake in 1977 was observed to be over 0.6 mg/L. This was said to be high as compared to that of the Volta River at the time of formation of the lake. According to Amankwa (1993), this was the result of washing of phosphate-rich fertilizers from farms in the catchment zone into the Densu River. Amuzu (1976) in his pre-impoundment studies also stated that the Densu river contained the same level of phosphate as that of the highly eutrophic lake Barekese in the Ashanti Region. He went further to argue that if phosphate levels recorded for the river during the survey were maintained after the lake had filled up, then eutrophication and its attendant problems of taste, colour and short filter runs amongst others will pose water treatment difficulties for the agencies responsible for the treatment of the water.

In an attempt to compare the changes that have occurred in the Densu River Basin during these two periods under study, the mean values of the ranges given were calculated and analyzed using analysis of variance. The statistical analysis revealed that with the exception of colour and BOD, all the physical and chemical parameters studied showed no significant changes ($p \leq 0.05$) between the quality of water from the Densu River Basin during the pre-impoundment era and current studies (Table 4.44).

Table 4.44 : Table of F-ratios showing the ANOVA summary of water quality Indices between the pre-impoundment era and current studies

Process variables	F-ratio
pH	424.544
Chloride	562.782
Iron	267.453
BOD	124.564*
Dissolved Oxygen	456.624
Colour	146.076*
Sulphate	136.613
Phosphate	602.234

* Significant F-ratio at $p \leq 0.05$

The dramatic increases in BOD levels reflect the rate of increase in organic matter content over the years since the pre-impoundment era. This coupled with the increase in pH and the high temperature form a good platform for algal blooming and microbial activity. Algal blooming is probably the most serious problem of the Densu River and the Weija Lake apart from microbiological contamination from human and animal wastes as well as the various non-point sources in the environment. This results in the high microbiological load and high pH of water in the Densu river basin and therefore needs to be given optimum attention. Finding suitable solutions to curb the problem of algal blooming in the lake will help minimize quite a number of other water quality problems of the Densu River and the Weija Lake to an appreciable extent. This is because generally waterweeds reduce the aesthetic value of river water and cause changes in a number of quality parameters.

The problem of algal blooming results from the process of nutrient enrichment and subsequent eutrophication of the river. This phenomenon is a natural process that takes place in a lake and involves a progressive increase in fertility and productivity without which the lake may eventually die. However this natural ecological phenomenon may be accelerated by man's activities leading to reduction of the quality of the water.

The natural enrichment process results from the flooding of valleys after an impoundment. Flooding initiates leaching of nutrients from valley soils and also from decaying vegetation, which causes an initial increase in the nutrient content of the impounded water. Human activities such as the discharge of sewage effluents into streams and rivers, which feed the lake, as already stated, and the siting of the refuse dumps close to the riverbanks accelerate this process. This appears to occur at Nsawam and Akwadum where effluents are discharged directly into the Densu River. However, it is suspected that the main problem is with the rate of eutrophication, which determines the rate and extent of algal blooms.

It is therefore evident that the predictions and recommendations of reports of early studies on the quality of water in the Weija Lake and Densu River had not been taken seriously or adhered to, otherwise, the problem of algal blooms, though inevitable, could have been reduced to the barest minimum and its attendant problems curbed.

There is therefore no doubt that BOD level, which gives an indication of the extent of aerobic biodegradation of organic matter more than doubled over the same period under discussion.

As already stated the rate of nutrient enrichment has been greatly enhanced by human activities within the basin. These include agricultural activities, industrial activities, effluents from sewage plants, dumping of excreta directly into the Densu river, other domestic activities, as well as activities of fishermen and shoreline squatter communities. More critical here is the pineapple cultivation which is done all year round with massive application of fertilizers, the sanitary conditions as well as the activities of the fishermen. Algogenic taste and odour are the characteristics of the lake water as it stands today.

5.0 CONCLUSIONS AND RECOMMENDATION

5.1 CONCLUSIONS

1. The physical, chemical, biological and microbiological qualities of raw water from the Densu River Basin and the Weija Dam.

a. On the physical qualities, water in both the Densu River Basin and the Weija dam can be described as poor since most of the quality indices evaluated had values above the guideline value stipulated for acceptable water quality. However, the physical quality of water in the Weija dam is much better than the Densu River. It can therefore be concluded that the physical quality of water in the Densu River Basin is poor.

b. On the chemical qualities, water in both the Densu river and the Weija reservoir were good since most of the indices were within the guideline value except for iron which was slightly above the guideline limit. Even though chloride was below the guideline value there were indications of some level of pollution. It can therefore be concluded that the water in the Densu River Basin and the Weija Dam are polluted but within acceptable limits.

c. On the nutritive qualities, water in the Densu River Basin and the Weija Dam is acceptable since almost all the indices were within limits. Sulphate, nitrate and fluoride levels are much below the guideline values. Bicarbonate and phosphate levels are high due to the presence of algal blooms in the basin as a result of eutrophication. It can therefore be concluded that the nutritive quality of water in the basin has not changed much since the impoundment of the river.

d. On the biological quality, chlorophyll A levels, though not excessive, gave a good indication of the algal biomass in the Densu River basin. The biological quality of the water in the Densu River Basin and the Weija Dam can be said to be acceptable.

e. On the microbiological quality, massive microbial contamination of the basin water was observed. This is a reflection that the Densu basin lacks adequate sanitary facilities and good sanitary practices. It can therefore be concluded that the microbiological quality of water in the Densu River Basin is poor due to lack of adequate sanitary practices.

Generally, levels of the physical and chemical parameters measured were higher in the dry season than in the rainy season except for turbidity, pH, DO and chlorophyll A. This could be attributed to the evaporation process that occurs during the dry season leading to increased salt concentrations of the water. However turbidity is high during the rainy season and this could be a result of the inappropriate land use along the stretch of the basin, which has affected the vegetative cover and therefore washes the topsoil into the river whenever it rains besides the indication that sanitary conditions along the stretch of basin is poor.

2. Trends of water quality along the Densu River Basin

The quality of water in the Densu River basin decreases across the basin from Akwadum to Manhia as indicated by most of the parameters measured. However, the quality of water in the Weija Dam is better than that of the Densu River Basin.

3. Comparison of the qualities of raw and treated water from the Weija Dam

The quality of both the raw and treated water from the Weija Dam can be said to be acceptable. However, the quality of the treated water is a reflection of the quality of the raw water from the Weija Dam as indicated by high pH, alkalinity, turbidity, colour and BOD values which were above the WHO guideline values. It can therefore be concluded that the quality of raw water from the Weija Dam as well as the process used in treating the raw water influence the final quality of treated water from the Weija Dam. This is because relatively more chemicals have to be employed to bring down the high pH, turbidity and colour through the clarification and disinfestation stages, which finally affect the taste and odour characteristics of water from the Weija Dam.

4. Changes in quality of water from the Weija Dam between the pre-impoundment era and current studies

With regard to the past and present qualities of the Densu River, it can be concluded that the quality of water in both the Densu River and the Weija reservoir has not changed much even though there has been some increased levels of BOD and colour in the present studies. In general however, the water quality of both the present and pre-impoundment era can be described as a good source of water supply by Todd's classification, even though the quality has deteriorated to some extent.

In summary, water from the Densu River Basin and the Weija Dam can be classified as acceptable sources of water supply since most of the quality indices measured are still comparable to those of the pre-impoundment era, which was classified as an acceptable source of water using Todd's classification. However the quality can be said to have deteriorated slightly through the various human activities and the poor sanitary condition in the Densu River Basin.

5.2 RECOMMENDATIONS

Based on the results of the study, the following recommendations are made:

1. In order to minimize the problems associated with algal blooming, regulations regarding fishing in the lake must be enforced and strictly adhered to.

2. District Assemblies within the basin must be empowered to become watchdogs over their waters. They must ensure that refuse dumps are not sited close to the banks of the river. They must also ensure that the riversides are made restricted areas as much as possible to reduce the degree of human contact with the water since women and children are often seen bathing, swimming and washing at the riversides. This situation is most critical at Nsawam. For efficient results the district assemblies must work in conjunction with the traditional authorities and these groups must be educated on the problems of water quality in the Densu River basin as well as its consequences. They must also ensure that the dumping of faeces directly into the Densu River and the discharge of untreated sewage must be prohibited. Introduction of the calcamite digester septic tank, which is new on the Ghanaian market, can help solve this problem. This digester is said to turn human waste into odourless effluents. It is also believed to generate biogas, which can be used for lighting purposes. The District Assemblies within the basin should also make the provision for adequate toilet facilities, refuse collecting bins situated at appropriate places and provision of good drainage systems their priority.

3. The Water Resources Commission must speed up the process of coming out with a nation-wide water policy in the form of strategies, national water master plans which will be specific to the needs of every water resource, mechanisms for inter-sectorial coordination and conflict resolution. This is because the problem of water management is not only in the Densu River basin, but in general is multi-faceted and therefore needs a holistic approach. Water Quality Management especially in the Densu Basin has not been very successful because the organizations responsible for the management process have over the past years been working in isolation. With a master plan and policy for the Densu basin these organizations can liaise with each other and work towards a common goal.

4. Since the quality management problem within the Densu River basin is not only linked to irrigation but also partly rest on agricultural practices in general, due to the fact that the basin economy is basically agrarian, it may be expedient for the Ministry of Food and Agriculture to become more involved in the quality management process than it is at the moment. Thus, agricultural extension services need to be intensified within the Densu River Basin.

5. The role of women in the management of water in the basin must not be under-estimated, since water is basically women's issue. Besides, in the case of the Densu basin in particular, most people in the villages as well as the urban poor people depend on the raw river water for domestic use and therefore go to the riverside to perform a host of activities. It will therefore be appropriate to involve women in decision making and

planning of quality management processes of water in the Densu River Basin if the policies and plans are to be successful.

6. In-depth studies must also be conducted on the biology of the types of weeds especially algae, within the Densu basin. This will make planning of the control and management easier.

LIST OF ABBREVIATIONS

1. EPA: Environmental Protection Agency.
2. WHO: World Health Organisation
3. WARM: Water Resources Management Study [Ghana].
4. AWWA: American Water Works Association.
5. APHA: American Public Health Association.
6. TON: Threshold Odour Number
7. TDS: Total Dissolved Solids
8. DO: Dissolved Oxygen
9. S.S: Suspended Solids
10. BOD: Biological Oxygen Demand
11. COD: Chemical Oxygen Demand
12. E.E.C: European Economic Community
13. GWSC: Ghana Water and Sewerage Corporation.
14. GWCL: Ghana Water Company Limited
15. ATMA: Accra-Tema Metropolitan Area
16. T.C: Total Coliform
17. EDTA: Ethylene Diamine Tetraacetic Acid.
18. GEMS: Global Environmental Monitoring Systems.
19. TCU: True Colour Units

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APPENDICES:

APPENDIX 1: Analysis of variance for Temperature

Source of variation	Sum of squares	d.f.	Mean square	F-ratio
Main effects	87.888000	5	14.648000	10.771
Season	80.000000	1	80.000000	58.824
Location	7.888000	4	1.972000	1.450
Residual	17.680000	13	1.3600000	
Total (Corr.)	105.56800	18		

APPENDIX 2: Analysis of variance for pH

Source of variation	Sum of squares	d.f.	Mean square	F-ratio
Main effects	1.923000	5	.3206167	25.972
Season	.3432200	1	.3432200	27.803
Location	1.580400	4	.3951200	32.007
Residual	.1604800	13	.0123446	
Total (Corr.)	2.0841800	18		

APPENDIX 3: Analysis of variance for Conductivity

Source of variation	Sum of squares	d.f.	Mean square	F-ratio
Main effects	387096.80	5	64516.13	9.507
Season	216320.00	1	216320.00	31.875
Location	170776.80	4	42694.20	6.291
Residual	88224.000	13	6786.4615	
Total (Corr.)	475320.80	18		

APPENDIX 4: Analysis of variance for Turbidity

Source of variation	Sum of squares	d.f.	Mean square	F-ratio
Main effects	2522.5800	5	420.4300	3.787
Season	1179.6480	1	1179.6480	10.624
Location	1342.9320	4	335.7330	3.024
Residual	1443.4120	13	111.03169	
Total (Corr.)	3965.9920	18		

APPENDIX 5: Analysis of variance for Colour

Source of variation	Sum of squares	d.f.	Mean square	F-ratio
Main effects	6675.0000	5	1112.5000	30.771
Season	605.0000	1	605.0000	16.734
Location	6070.0000	4	1517.5000	41.973
Residual	470.00000	13	36.153846	
Total (Corr.)	7145.0000	18		

APPENDIX 6: Analysis of variance for Total Dissolved Solids

Source of variation	Sum of squares	d.f.	Mean square	F-ratio
Main effects	105852.00	5	17642.000	30.609
Season	61383.20	1	61383.200	106.500
Location	44468.80	4	11117.200	19.288
Residual	7492.8000	13	576.36923	
Total (Corr.)	113344.80	18		

APPENDIX 7: Analysis of variance for Suspended Solids

Source of variation	Sum of squares	d.f.	Mean square	F-ratio
Main effects	1454.3600	5	242.39333	12.152
Season	6.7280	1	6.72800	.337
Location	1447.6320	4	361.90800	18.143
Residual	259.31200	13	19.947077	
Total (Corr.)	1713.6720	18		

APPENDIX 8: Analysis of variance for Sodium

Source of variation	Sum of squares	d.f.	Mean square	F-ratio
Main effects	5102.6684	5	850.4447	3.023
Season	3551.6455	1	3551.6455	12.623
Location	1551.0229	4	387.7557	1.378
Residual	3657.7749	13	281.36730	
Total (Corr.)	8760.4433	18		

APPENDIX 9: Analysis of variance for Potassium

Source of variation	Sum of squares	d.f.	Mean square	F-ratio
Main effects	273.65150	5	45.60858	20.554
Season	238.46418	1	238.46418	107.466
Location	35.18732	4	8.79683	3.964
Residual	28.846520	13	2.2189631	
Total (Corr.)	302.49802	18		

APPENDIX 10: Analysis of variance for Calcium

Source of variation	Sum of squares	d.f.	Mean square	F-ratio
Main effects	533.80300	5	88.96717	9.614
Season	226.32992	1	226.32992	24.458
Location	307.47308	4	76.86827	8.307
Residual	120.30028	13	9.2538677	
Total (Corr.)	654.10328	18		

APPENDIX 11: Analysis of variance for Magnesium

Source of variation	Sum of squares	d.f.	Mean square	F-ratio
Main effects	641.27600	5	106.87933	32.947
Season	484.12800	1	484.12800	149.238
Location	157.14800	4	39.28700	12.111
Residual	42.172000	13	3.2440000	
Total (Corr.)	683.44800	18		

APPENDIX 12: Analysis of variance for Iron

Source of variation	Sum of squares	d.f.	Mean square	F-ratio
Main effects	1.5560800	5	.2593467	3.047
Season	.1036800	1	.1036800	1.218
Location	1.4524000	4	.3631000	4.267
Residual	1.1063200	13	.0851015	
Total (Corr.)	2.6624000	18		

APPENDIX 13: Analysis of variance for Chloride

Source of variation	Sum of squares	d.f.	Mean square	F-ratio
Main effects	20899.344	5	3483.224	43.265
Season	17808.512	1	17808.512	221.201
Location	3090.832	4	772.708	9.598
Residual	1046.6080	13	80.508308	
Total (Corr.)	21945.952	18		

APPENDIX 14: Analysis of variance for Sulphate

Source of variation	Sum of squares	d.f.	Mean square	F-ratio
Main effects	2367.6936	5	394.6156	30.427
Season	1337.2666	1	1337.2666	103.109
Location	1030.4270	4	257.6068	19.863
Residual	168.60212	13	12.969394	
Total (Corr.)	2536.2957	18		

APPENDIX 15: Analysis of variance for Nitrate

Source of variation	Sum of squares	d.f.	Mean square	F-ratio
Main effects	.2403000	5	.0400500	3.196
Season	.0897800	1	.0897800	7.164
Location	.1505200	4	.0376300	3.003
Residual	.1629200	13	.0125323	
Total (Corr.)	.4032200	18		

APPENDIX 16: Analysis of variance for Bicarbonate

Source of variation	Sum of squares	d.f.	Mean square	F-ratio
Main effects	49110.130	5	8185.022	106.312
Season	45410.450	1	45410.45	589.817
Location	3699.680	4	924.920	12.013
Residual	1000.8800	13	76.990769	
Total (Corr.)	50111.010	18		

APPENDIX 17: Analysis of variance for Phosphate

Source of variation	Sum of squares	d.f.	Mean square	F-ratio
Main effects	.7582000	5	.1263667	8.973
Season	.0627200	1	.0627200	4.454
Location	.6954800	4	.1738700	12.346
Residual	.1830800	13	.0140831	
Total (Corr.)	.9412800	18		

APPENDIX 18: Analysis of variance for Flouride

Source of variation	Sum of squares	d.f.	Mean square	F-ratio
Main effects	.0069200	5	.0011533	22.049
Season	.0007200	1	.0007200	13.765
Location	.0062000	4	.0015500	29.632
Residual	6.8000E-004	13	5.23077E-005	
Total (Corr.)	.0076000	18		

APPENDIX 19: Analysis of variance for Alkalinity

Source of variation	Sum of squares	d.f.	Mean square	F-ratio
Main effects	32335.200	5	5389.200	127.660
Season	29799.200	1	29799.200	705.885
Location	2536.000	4	634.000	15.018
Residual	548.80000	13	42.215385	
Total (Corr.)	32884.000	18		

APPENDIX 20: Analysis of variance for Total Hardness

Source of variation	Sum of squares	d.f.	Mean square	F-ratio
Main effects	14415.080	5	2402.513	11.357
Season	10378.568	1	10378.568	49.060
Location	4036.512	4	1009.128	4.770
Residual	2750.1120	13	211.54708	
Total (Corr.)	17165.192	18		

APPENDIX 21: Analysis of variance for BOD

Source of variation	Sum of squares	d.f.	Mean square	F-ratio
Main effects	62.594000	5	10.432333	10.930
Season	51.842000	1	51.842000	54.315
Location	10.752000	4	2.688000	2.816
Residual	12.408000	13	.9544615	
Total (Corr.)	75.002000	18		

APPENDIX 22: Analysis of variance for Dissolved Oxygen

Source of variation	Sum of squares	d.f.	Mean square	F-ratio
Main effects	109.26000	5	18.210000	24.225
Season	56.44800	1	56.448000	75.095
Location	52.81200	4	13.203000	17.564
Residual	9.7720000	13	.7516923	
Total (Corr.)	119.03200	18		

APPENDIX 23: Analysis of variance for Total Coliforms

Source of variation	Sum of squares	d.f.	Mean square	F-ratio
Main effects	7956045.0	5	1326007.5	54.310
Season	171125.0	1	171125.0	7.009
Location	7784920.0	4	1946230.0	79.713
Residual	317400.00	13	24415.385	
Total (Corr.)	8273445.0	18		

APPENDIX 24: Analysis of variance for Faecal Coliforms

Source of variation	Sum of squares	d.f.	Mean square	F-ratio
Main effects	988793.00	5	164798.83	39.218
Season	2205.00	1	2205.00	.525
Location	986588.00	4	246647.00	58.695
Residual	54628.000	13	4202.1538	
Total (Corr.)	1043421.0	18		

Appendix 25 : Table of F-ratios showing the ANOVA summary of some chemical water quality indices

Process variables	Sodium	Potassium	Calcium	Magnesium	Ammonia	Chloride
Source of water	412.623*	237.516*	422.470*	428.282*	241.568*	421.201*
Replicates	441.378	323.964	668.307	512.111	234.267	299.568

* Significant F-ratios at $p \leq 0.05$

Appendix 26 : Table of F-ratios showing the ANOVA summary of some chemical water quality indices

Process variables	Bicarbonate	Nitrate	Phosphate	Silica	Alkalinity	Hardness
Source of water	212.423*	512.262*	341.235*	438.984*	346.264*	297.951*
Replicates	231.478	387.424	657.327	342.972	256.836	386.828

* Significant F-ratios at $p \leq 0.05$

Appendix 27 : Table of F-ratios showing the ANOVA summary of some chemical water quality indices

Process variables	Magnesium hardness	Calcium hardness	Carbonate hardness
Source of water	322.123*	246.236*	232.270*
Replicates	421.274	420.542	298.290

* Significant F-ratios at $p \leq 0.05$