KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOOGY

COLLEGE OF ENGINEERING

DEPARTMENT OF MATERIALS ENGINEERING

ASSESSING THE IMPACT OF MANAGEMENT ACTIVITIES ON THE DENSU RIVER BASIN - GHANA

BY

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DECLARATION

I hereby declare that, except for the references of the work of other researchers which have been fully and dully acknowledged, this piece of work is the results of my own investigation and to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University.

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(Head of Department) Signature Date

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DEDICATION

I dedicate this work to my late father Alhaji Imoro Zakari may his soul rest in absolute peace and to my lovely mother Wumbei Salamatu for her financial, moral and spiritual support.

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ABSTRACT

The Densu River takes its source from the Atewa Range and flows for 116 kilometers into the Weija Reservoir before entering the sea through the Densu Delta Ramsar Site (Sakumo Lagoon). The objectives of the study were to assess the performance of management activities on the Densu River Basin. The specific objectives included identifying key management activities, determination of the water quality of the basin, and determination of trends in chemicals consumption at the Koforidua, Nsawam and Weija Headworks. Field and laboratory measurements and assessments were carried out on selected Physico-chemical water quality parameters. Field measurements included Temperature, pH and Transparency, while Conductivity, Total Suspended Solids (TSS), Nutrients, Major Ions and Trace Metals were measured in the laboratory. The pH of the waters in the Densu basin ranged from 6.5 - 8.4. Dissolved Oxygen (DO) of the waters ranged from 4.05 - 7.23 mg/l. BOD values at all the sampled stations exceeded the upper limit of the TWQR of 2 mg/l, indicating organic pollution loads into the waters are prevalent. The concentrations of Nitrate-nitrogen ranged from 0.47 - 4.20 mg/l which were all within the TWQR of 0 - 6.0 mg/l NO_3-N. This indicates that the Nitrate-nitrogen concentrations in the river basin are not currently alarming. Turbidity values of the rivers ranged from 15.4 - 54.4 NTU. High Turbidity values were recorded at all the sampling stations. The high levels of turbidity and total suspended solids recorded are a reflection of the nature of suspended bed load transport in the basin. Electrical Conductivity (EC) values ranged from 191 - 254 μS/cm. Conductivity values were above the TWQR of 0 – 70.0 μS/cm. All the trace metals determined were below their respective TWQRs in all the stations except Iron (Fe). Concentration of Fe was high in the waters, ranging from 0.95 - 1.16 mg/l. These are above the TWQR of 0.3 mg/l. The Water Quality Index classification of the waters at the three stations on the Densu River indicated that Koforidua and Weija were of Class II or fairly good water quality, while Nsawam was of Class III or poor water quality. The rate of Alum, Lime and Chlorine consumptions at Koforidua, Nsawam and Weija Water Treatment Plants could not give a clear pattern in chemical consumption; however there was general decreasing trend in those chemicals.

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LIST OF ABBREVIATIONS/ACRONYMS

AMD	Acid Mine Drainage
BOD	Biochemical Oxygen Demand
CBO	Community Base Organization
DRB	Densu River Basin
EPA	Environmental Protection Agency
EU	European Union
GWCL	Ghana Water Company Limited
GWP	Global Water Partnership
IRC	International Water and Sanitation Centre
ISSER	Institute of Statistical, Social & Economic Research
IWRM	Integrated Water Resources Management
MWHR	Ministry of Works and Housing, Ghana.
NGO	Non-Governmental Organization
NTU	Nephelometric Turbidity Unit
SPSS	Statistical Package for Social Scientists
TDS	Total Dissolved Solids
TSS	Total Suspended Solids

TWQR UNCED	Target Water Quality Range
UNDP	United Nations Development Programme
UN-HABITAT	United Nations Human Settlements Programme.
USDA	United States Department of Agriculture
WHO	World Health Organisation
WQI	Water Quality Index
WRC	Water Resources Commission
WRI	Water Research Institute
UNCED:	United Nations Conferences on Environmental Developments

CHAPTER ONE

1.0 INTRODUCTION

Water is super abundant on the planet as a whole, but fresh potable water is not always available at the right time and at the right place for human or ecosystem use. The importance of water is underscored by the fact that many great civilizations in the past sprang up along or near water bodies. The development of water resources has often been used as a tool for health which is necessary for the production of food, economic growth and the support of the environment, among many nations worldwide. However, pollution of water often negates the benefits obtained from the development of these water resources (Ansa-Asare, 1992).

Over the past years, the pressure on the limited freshwater resources has considerably increased due to growing demand and abuse of catchment areas. The increasing pressure on land, forests and other natural resources continues to cause large–scale destruction of the environment and disruption of the hydrological cycle.

Many countries have already been categorized as suffering from "water stress'' and the list continues to grow (UN HABITAT, 2003). The problem has further been aggravated by pollution from various economic sectors, notably, agriculture and industry. Particular concern is human settlement in urban areas where social infrastructure development lags far behind the population growth. In the absence of proper water supply and sanitation facilities, the problems are more acute in such settlements, which call for prudent and innovative ways of managing the available water resources in a sustainable manner. In most developing societies, water has not been effectively and efficiently managed over the last decade because water has been traditionally perceived to be a free commodity. The outcome is pollution that tends to threaten the aquatic environment and the life it supports. The Densu River Basin is no exception of this case (Tetteh, 2010). Over the past decades, human activities in the river catchment area have increased tremendously as a result of the unprecedented physical infrastructural development and demographic growth of Accra and its peri-urban communities (Aikins, 2003). This infrastructural development in Accra has also produced observable patterns of horizontal expansion towards the Northern, Western and Eastern peripheries, with the Northern and Western peripheries lying in the Densu Catchment (Yeboah, 2000). These changes have attracted public attention, particularly in terms of water supply to urban Accra, as well as other communities in the catchment area.

1.1 Problem statement

The Densu River faces conflicting water uses, such as providing public water supply at Koforidua, Nsawam and Weija, with water for agricultural, tourism and recreational uses, whilst maintaining the quality of water for supply (WARM, 1998 and WRC, 2000).

These anthropogenic activities within the Densu Basin have resulted in serious ecological problems accounting for erosion due to farming within the catchment area of the river, with its attendant siltation, causing occasional serious flooding; extensive deforestation particularly along the river banks as a result of lumbering, fuel wood extraction and clearing of land for farming; nutrient contamination of surface waters from inefficient use of agro-chemicals ; growth of aquatic weeds in the river due to unapproved use of chemicals for fishing and the introduction of domestic and industrial waste disposal and general loss of biological diversity has been observed in certain parts of the basin (Nii Consult, 2001).

1.2 Objectives of the study

The overall objective of the study was to assess the performance of an integrated water resources management of the Densu Basin.

1.2.1 Specific objectives

- To identify the key management activities of the basin.
- To determine the water quality of the river basin.
- To determine trends in chemicals consumption at the Treatment Plants at Koforidua, Nsawam and Weija.

1.3 Justification

The Densu River is the main source of drinking water supply for the Western part of Accra. The cost of treating water from the Densu River is about ten times that from the Volta River at Kpong (Emmanuel, 2005).

Water shortages are experienced frequently in the whole basin especially in the upper most section in the dry season, when demand for drinking water cannot be met from the intake weir at Koforidua due to low water levels and poor water delivery structures which have, over the years, been producing below their installed capacities due to worn out mechanical parts (WRC, 2000). The resultant effects of these environmental problems within the basin culminated in a public outcry over the quality and quantity of water supplied from the Weija Reservoir (Daily Graphic, 2001) and a call to use water resources judiciously. These problems are also exacerbated by lack of institutional capacity for water resources management by Government.

Information on the water resources of the basin is a prerequisite tool for the orderly development and management of the resources for socio-economic advancement (Opoku

& Forson, 1998). In augmenting the baseline data of the basin, it is critical to collect, update, evaluate, integrate, and analyze quantifiable datasets of the basin to help understand the changes that are taking place within the watershed.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 River Basin

River basin is the extent of the land where water from rain drains downhill into a body of water such as river, lake, reservoir, wetland, estuary, sea or ocean. The drainage basin includes both the streams and rivers that convey the water as well as the land surfaces from which the water drains (WRC, 2008).

The drainage basin acts as a funnel by collecting all the water within the area covered by the basin and channeling it into a waterway. Each drainage basin is separated topographically from adjacent basins by a geographical barrier such as a ridge, hill or mountain, which is known as a watershed (Debary, 2004).This is shown in figure 2.1 below.

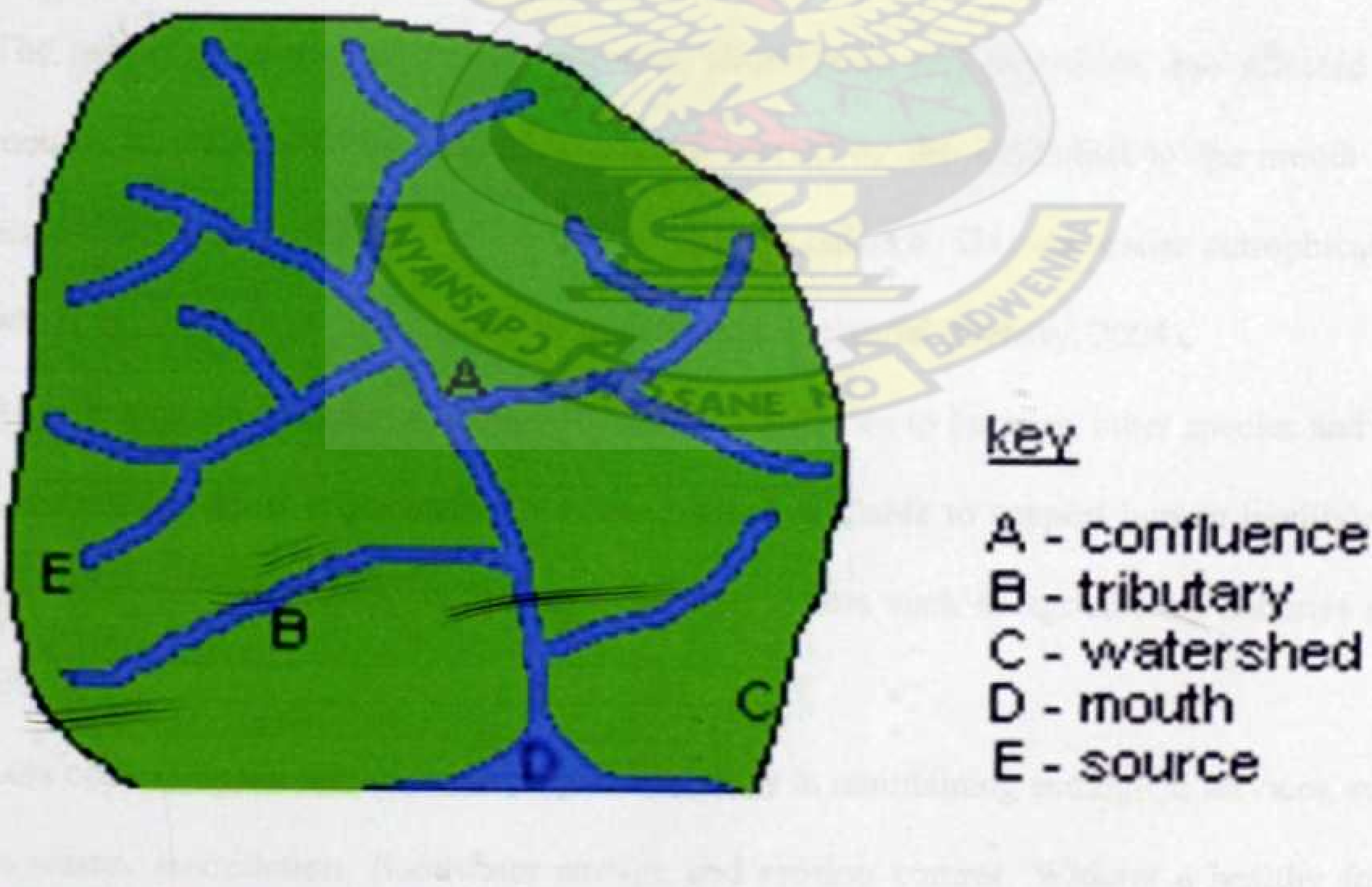

Figure 2.1: Main Features of River Basin

2.2 Importance of River Basins

Drainage basins have importance for determining territorial boundaries, particularly in regions where trade by water has been important. In hydrology, the drainage basin is a logical unit of focus for studying the movement of water within the hydrological cycle, because the majority of water that discharges from the basin outlet originated as precipitation falling into the basin. A portion of the water that enters the groundwater system beneath the drainage basin may flow towards the outlet of another drainage basin because groundwater flow directions do not always match those of their overlying drainage network.

Drainage basins are the principal hydrologic unit considered in fluvial geomorphology. A drainage basin is the source for water and sediment that moves through the river system and reshapes the channel.

The use of fertilizers, containing nitrogen, phosphorus, and potassium, has affected the mouths of watersheds as these minerals are carried by the watershed to the mouth and accumulate thereby disturbing the natural mineral balance. This can cause eutrophication where plant growth is accelerated by the additional material (Debary, 2004).

River basins also provide a myriad of functions and uses to humans, other species and the environment. Most importantly, they make water available to support human livelihoods, providing the essential basis for key economic sectors such as agriculture, fisheries and tourism.

Less obvious is the role of natural aquatic systems in maintaining ecological services, such as wastes assimilation, floodwater storage and erosion control. Without a healthy fresh water ecosystem, these functions and uses will be lost or impaired. This loss will predominantly affect poor communities, since they tend to rely disproportionately on subsistence and resource based economies (Barrow, 1998).

2.3 Water Resources Development and Management

Water is a subject in which everyone is a stakeholder. According to the GWP (2000) "Real participation only takes place when stakeholders are part of the decision-making process. This can occur directly when local communities come together to make supply, management and use choices" or occasionally through the use of appropriate pricing systems. Participation should go beyond mere consultation. It should be an instrument that can be used to pursue an appropriate balance between a top-down and a bottom-up approach in IWRM. There should be effective participation where all the stakeholders democratically elected or otherwise accountable spokespersons at all levels of social structure and at different levels of water management are represented, and have an impact on the decisions taken.

Effective participation must be able to exploit all the available consultative mechanisms and stakeholders must recognize that, the sustainability of water resource is a common problem and that all parties must be willing to sacrifice some desires as a means for achieving long-lasting consensus and common agreement. For this to be possible there should be an enabling environment which includes the creation of mechanisms for stakeholder consultation, awareness creation, confidence building and education, the provision of economic resources needed to facilitate participation and the establishment of good and transparent sources of information at all levels of the society, including the marginalized social groups such as the women and youth (Ransom, 2001).

2.3.1 River Basin/Catchment Management

In a catchment, much of the surface is land and a smaller portion consists of the river channel. Catchment management or river basin management is therefore viewed as land–water management and it involves the management of the river and the surrounding land (Krhoda, 2000). It is a process of strategic decision-making about the allocation of land and water resources within a water catchment area. The proper management of water resources is of critical importance to the twin issues of pollution control and sustainable development.

2.3.1.1 Community Involvement in Catchment Management

To ensure sustainability and availability of quality water, it is necessary to find ways and means for the management of catchment areas. Conventional sectoral approaches for pollution control, water supply and sanitation have served limited purpose. Community involvement for catchment management can serve as a useful instrument for addressing the problems in a holistic manner (Barrow, 1998).

2.3.2 Problems Associated with River Basin

River basin management is faced with complex problems that are characterized by uncertainty and changes. In trans-boundary river basins, historical, legal, finance, cooperation and cultural differences add to the complexity (Timmerman and Langaas, 2005). In the past, river basins management was often the exclusive realm of hydraulic engineers, who managed the river for a single purpose only, such as navigation or hydropower. Nowadays, river basin management is often multi-purpose and basin-wide, and involves many more actors (Ridder *et al.,*2005).

Moreover, river basin management has to deal with increasing rates of human-induced changes and increasing concerns about the causes and consequences of these changes (Pahl-Wostl, 2004).

Where a river basin traverses a number of countries, it can also have implications for stability in the region. In most countries, the arbitrariness of prevailing property rights for water resources, combined with the failure of markets to capture the value of many watershed services, is leading to a highly inefficient and inequitable distribution of water resources. River basin management is particularly complex due to the separation of threatening processes from their impacts, and the contribution of all activities in a catchment to the river basin's health (Ratner, 2000).

2.4 Types of River Systems in Ghana

Ghana is well endowed with perennial rivers and ground waters, although seasonal shortages are quite common. The mean annual rainfall ranges from 2,150 mm in the extreme southwest of the country, reducing progressively eastwards and northwards to 800 mm in the southeast (Nii Consult, 1998).

These water sources are drained by three main river systems; the Volta basin, the southwestern basins and the coastal basins river systems, which cover 70, 22 and 8 percent respectively, of the total area of Ghana. The Volta River system is shared with Côte d'Ivoire, Burkina Faso, Togo, Benin and Mali. Two river basins in the southwestern system are also trans-boundary. Bia River is shared with Côte d'Ivoire, while the lower reaches of the Tano river form part of the boundary with Côte d'Ivoire. The total annual runoff of the river basins is 56.4 billion m^3. The Volta, southwestern and coastal systems contribute 73.7, 29.2 and 6.1 percent respectively, of the annual runoff originating from

Ghana. The major sub-basins of the Volta include the Black and White Volta Rivers, the Oti River and the Lower Volta, including Lake Volta. The South-Western Rivers System comprises the Bia, Tano, Ankobra and Pra Rivers, while the Coastal Rivers System is made up of Ochi-Amissah, Ochi-Nakwa, Ayensu, Densu and Tordzie/Aka Rivers (MWRH, 1998).

The groundwater resources of the country are found in two main rock formations. The sedimentary formation made up of mainly Voltaian origin, which occupies about 43 percent of the total area of the country, with yields of 1.0-12.0 m^3/ha at depths of 20 to 80 m. The non-sedimentary formation made up mainly of the crystalline basement complex of Precambrian origin, which occupies 57 percent of the total area of the country with yields of 1.5 to 32.0 m^3/ha at depths of 20 to 100 m. The quality of groundwater resources in Ghana is generally good except for some cases of localized pollution with high levels of iron and fluoride, as well as high mineralization with total dissolved solids, especially in some coastal aquifers (WRC, 2000).

Impoundments and reservoirs have been constructed for hydropower generations and water supply at Akosombo, from the Volta, the Kpong Headwork. Other important Impoundments are the Weija from the River Densu and Owabi Reservoirs from the Offin, respectively (WRC, 2000).

2.5 Water Resources Management in Ghana

The Ghana Water Resources policy Act 522(section 37) defines water resources as 'all water flowing from any river, spring, stream or natural lake or part of swamp or in or beneath a watercourse and all underground water but excluding any stagnant pan or swamp wholly contained within the boundaries of any private land' (Act 522,1996).

Water resources management can be described as all activities and programmes geared towards the allocation, distribution and conservation of water and its associated biophysical factors (Owusu and Asamoah, 2005).

2.6 Concepts of Integrated Water Resource Management (IWRM)

Debate on water resources management has been ongoing for decades, water resources management (WRM) was globally discussed for the first time in the United Nations Water Conference in Mar del Plata in 1977 but it was not until the early nineties when it was really put on the international agenda with a significant number of meetings such as the 1990 New Delhi meeting, the 1991 Nordic Freshwater Initiative in Copenhagen, the 1992 Dublin meeting and the 1992 UNCED meeting in Rio de Janeiro (UNDP, 1992).

However, there was is an increasing recognition that in order to safeguard water resources from depletion and degradation, concerted effort is needed at all fronts, including the different sectors such as; agriculture, forestry, industry, transport, urban and spatial planning, population planning and based on a participatory management. Such a holistic approach is what is being referred to as integrated water resources management (IWRM). "IWRM is necessary to combat increasing water scarcity and pollution" and methods, which include water conservation and re-use, water harvesting and wastes management. An appropriate mix of legislation, pricing policies and enforcement measures is essential to optimize water conservation and protection (UNDP, 1991).

2.6.1. Definition of Integrated Water Resources Management (IWRM)

IWRM have been defined and applied at various stages by different actors and users of water resources, the objective is to ensure the optimal and sustainable use of water resources for economic and social development, while protecting and improving the ecological value of the environment. As such, different regions and nations have developed their own IWRM practices using the collaborative framework emerging globally and regionally.

The Global Water Partnership (2002) provides a more comprehensive understanding of IWRM and refers to it as a process, which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems''.

This management practice addresses the entire water and land system as well as the human system. By considering the different functions of water and the different stakeholders, this can be considered as means to reach a better sharing of water resources.

Approaches such as capacity building, participatory approaches and public awareness strategies are key tools for the full understanding, acceptance and implementation of concepts of IWRM (Tetteh, 2010).

2.6.2 Factors Affecting the Performances of IWRM

Various institutions from the national level down to the community level have been established to regulate the use of natural resources. Programmes and strategies have been developed; however, these have not been effective in arresting environmental degradation in the River Basin. This is attributable to institutional inability to:

i) Coordinate and integrate plans at the local level;

ii) Offer alternative means of livelihood or incentives for arresting degradation and over exploitation of natural resources;

iii) Remove weaknesses in local level institutions and

iv) Effectively linking up with the relevant local institutions and implement the programmes for the benefit of the local communities.

The performance of the various institutions is further hampered by lack of trained staff, logistics and funding. It is patently clear that a formula has to be worked out to address the key issues so that a participatory and integrated approach can be adopted for effective management of the environmental problems in the Densu River Basin (UN-HABITAT, 2000; Adom and Ampomah, 2003).

2.7 The Legal Regime for Water Resources Management

Until recently it was difficult to identify a separate water resources management law in Ghana prior to the promulgation in1996 of the Water Resources Commission Act522. It must be stated that natural water was managed as an appurtenance of land and therefore whoever owns a portion of land automatically may exercise certain rights over the waters to the land (Opoku-Agyeman, 2001).

Several single purpose state agencies pursued their individual mandates with little co-ordination and without thought about other water users. Less emphasis was placed on the management and conservation of the water resources and little attention was also placed on the economic value of producing and conserving the resources. There was nonexistence of effective regulation of the water sector, these practices culminated in unsustainable management of the water resources (Tetteh, 2010).

Water Resources Commission (Act522, 1996) mandates the commission to act on behalf of the president, in whom all water rights are vested in trust of the people of Ghana. Under the act no person or organization exerts the authority to divert, dam, store, abstract or use water to develop or maintain any works for the use of water resources, without the commission's consent (Mensah, 1999). The WRC is to integrate and harmonize the various legal instruments which are the results of the former sectoral approach to water resources management in Ghana.

2.7.1 Akan Customary Water Law

Under this customary water law, surface water such as rivers, lakes and streams, are considered community property which can never be individually owned. Water, as part of the customary landholding is vested in stools, communities and families (Ollennu, 1962). Where water is in abundance, a member of a community or family or a subject of a stool may be able to utilized, stream or a pond which is naturally on his land. As pertains to traditional landholding, a person has only usufructuary rights to water but is not considered the owner. Under customary law, water is a free common good; everyone is entitled in principle, this same principle applied to groundwater (Ofori- Bonteng, 1997).

2.8 Coordination of Water Resources Management and Policies

In 1996, a significant step was taken by government to address the diffused state of functions and authority in water resources management and to put them into an integrated form. The Water Resources Commission (WRC) was established by an Act of Parliament (Act 522 of1996), with the mandate to regulate and manage the country's water resources and coordinate government policies in relation to them. The commission is comprised of the major regulators and users in the water sector and provides a forum for the integration and balancing of different interests.

The composition of WRC is made up of technical representatives of key institutions involved in water utilization and water services delivery. They include Hydrological Services, Water Supply and Irrigation Development, Water Research Institute, Environmental Protection Agency, Forestry Commission and Minerals Commission. Chiefs, NGOs and Women are represented in order to take care of civil society interest.

WRC mandate are outlined in Section 2 (2) of the Act, which are categorized as follows:

- Processing of water rights and permits.
- Planning for water resources development and management with river basins (catchments) as the natural units of planning.
- Collating, storing and disseminating data and information on water resources in Ghana.
- Monitoring and assessing activities and programmes for the utilization and conservation of water resources.

In practical terms the WRC seeks to achieve the aims and pursue its responsibilities through:

- Adopting the process of Integrated Water Resources Management (IWRM) in the management and regulation of the nation's water resources (including shared resources with riparian neighbours).
- Establishing adequate and cost effective organization, which can assist and guide the government of Ghana in order to achieve the goals of IWRM and monitor the achievements.
- Establishing good working relations with all stakeholders in the water sector.
- Inviting existing institutions and the private sector to participate, through outsourcing and contracting of specific tasks, in establishing its tools and procedures.

2.9 Decisions in Water Resources Management

Governance structures are important for decision-making and the implementation of decisions. With regard to water resources management, these decisions fall under two major types of (1) decisions on investment and maintenance of infrastructure and (2) regulatory decisions regarding water use and water quality.

The use of water resources involves various externalities, both with regard to water quality and quantity. The typical upstream-downstream problems, which appear at different scales, are important examples. Overuse of water resources may also affect water availability of future generations, thus causing negative externalities for them. Dealing with these externalities requires regulatory decisions. The authority for making these regulatory decisions may rest with different community organizations or state agencies. Analyzing the way in which these regulatory decisions are made and implemented is an important aspect of analyzing water-related governance structures (Rose C. M, 2005).

2.10 The Densu River Basin and its Management

2.10.1 The Densu Basin Environment.

The Densu basin is of favourable and significant natural and human systems. These systems show distinctive pattern of variation which ranges from upstream, midstream and downstream within the basin (Tetteh, 2010).The basin spans through eight Administrative districts in its catchment area, as shown in Table 2.1 below.

Table 2.1. Densu Basin Environment in Relation to Areas of District within the Basin

Level	Districts	Catchment Area Within basin (km^2)	Area outside Basin (km^2)	Total administrative District (km^2)	% area within basin
Upstream	Akwapin North	146	391	537	27
	Suhum-Kraboa-Coaltar	763	215	978	78
	East Akim	334	1144	1478	23
	New Juaben	209	7	216	97
Midstream	Akwapim South	322	62	384	84
	West Akim	88	753	841	10
Downstream	Ga	556	88	644	86
	Awutu-Efutu-Senya	122	690	812	15

Source: (WRC, 2007)

2.10.2 Common Land Uses and its Associated Pollution Problems

2.10.2.1 Human Settlement

The Densu river basin is now one of the most highly populated river basins in Ghana, with an area of 2,490 km^2 with a total population approaching 600,000, equivalent to 240 persons per km^2. This is considerably higher than the national average of about 100 persons per km^2 (ISSER, 2003).

Over the last three decades, human activities in the watershed have increased dramatically as a result of the unprecedented physical infrastructural development and demographic growth of Accra and its peri-urban communities (Aikins, 2003). The nature of infrastructural development in Accra has also produced observable patterns of horizontal expansion towards the northern, western and eastern peripheries, with the northern and western peripheries lying in the Densu Catchment (Yeboah, 2000).These high-density areas are prone to pollution due to inadequate water and sanitation infrastructure, vandalism of sewer networks and poor maintenance of existing drainage systems leading to faecal contamination of surface and ground water resources. Seepage or overflow from pit latrines, dumping of faecal matter in storm water drains or garbage heaps and faecal matter from 'bush toilets' are major causes of surface water pollution (Attua, 2003). This exposes the human population living downstream to health risks due to water borne diseases. An additional concern is the enrichment of water sources with nitrates and phosphates present in the sewage. In the built up areas, there is increased surface run off from the large paved areas, which contributes to flooding and associated problems (Adom and Ampomah, 2003).

2.10.2.2 Agricultural Activities

The Densu catchment is considered as one of the most productive agricultural zones (Gyasi *et al*., 1994). It is now one of the most intensively cultivated river basins in Ghana, giving rise to a complex mosaic of land cover categories (Attua, 2003). Agricultural activities in the area have not only been intensified but also become pervasive to the extent that most of the landscape has been dramatically transformed in the process into a patchwork of land cover classes (Attua, 1996).

As indicated by Agyepong and Kufogbe (1996), land use changes in the basin have progressively shifted from cocoa cultivation to food crop farming over the last two decades. Both cocoa cultivation and farming of staple crops have contributed significantly to both qualitative and quantitative degradation of the watershed which was known for its rich floristic composition (Attua, 2003).

The original ecology of the Densu basin was moist semi-deciduous forest with thick undergrowth of rich flora and fauna. However human induced activities, have greatly transformed the forest ecology of dense forest cover to semi-forest, scattered trees and scrub. This has resulted in increased erosion, leading to siltation of the river channel and consequently flooding. This developed into a situation of occasional water shortages (Densu River Basin Integrated Water Resources Management, 2007).

Agro-chemicals containing nitrates and phosphates as well as pesticides used for intensive farming in the areas are notable sources of pollution. Animals including dogs, poultry and cattle kept by communities' residents produce manures, which are washed into river courses during rains. These manures contribute to the organic pollution of the water sources and also expose humans and animals living downstream to the risk of contracting infectious diseases (Greathead and Ashcroft, 1987).

In other areas, the propagation of invasive alien vegetation along the riverbanks is of great concern. In some cases, the introduced species pose a threat to local biological diversity. For instance; introduction of Eucalyptus tree species has been associated with significant losses of water in catchments (Gaudet, 1977).

Enrichment of water with nitrates and phosphates results in proliferation of algae and plants which die and decompose in the water. This depletes the oxygen present in the water resulting in death of the aquatic life and consequent loss of biodiversity. It also results increased cost of purifying the water.

Soil transportation to the river especially by rain water is commonly encountered where riparian areas and wetlands have been interfered with. Degraded lands which have lost vegetation covers due to logging, clearing, overgrazing or open quarrying are prone to soil erosion. These are also known to cause increased turbidity and silting of the river (Krhoda, 2000).

2.10.2.3 Industrial Zones

High pollution risk in these zones is due to discharge of industrial effluents into storm water networks. The effluents may contain high levels of various toxic or harmful chemicals. These pollutants may increase the salinity of the water and cause changes in pH depending on whether it is acidic or alkaline. This may adversely affect the biological diversity in the habitat.

Some industries discharge hot waters which can cause temperature rise in the receiving water and may result in the death of many aquatic organisms. Large paved areas that are characteristic of these zones result in increased storm water runoff which washes solid wastes, including non biodegradable plastics and other litter, into the river (Kithia, 1992).

Food related industries including pineapple processing plants; agro-chemicals and slaughter houses are major polluters of the basin. Where the effluents are not treated before they are discharged into water courses, the organic matter present in the effluents increases the Biochemical Oxygen Demand (BOD) which is harmful to the aquatic organisms in the receiving water bodies (Singh, 2002).

High salinity is another serious form of water pollution. The increased content of inorganic ions such as sulphates present in Acid Mine Drainage (AMD) increases the purification costs of water. Saline water is unsuitable for domestic use and crop irrigation and it has a negative impact on biological diversity in the receiving water. Poor drainage, fine grain size and high evaporation cause concentration of salts in the irrigated soils of arid and semi-arid areas. In some cases, salinity ingress takes place from the landscape due to clearance of vegetation and increased infiltration (Biswas, 2003).

Discharges of toxic chemicals of industrial effluents into water course results in the degradation of the water resource and it may cause the total loss of biological diversity at the effluent receiving site. It also increases heavy metal pollution of the water due to increased solubility of metal ores and makes the water unsuitable for use. Such chemicals include fluids from electrical transformers, Pesticides and other hazardous chemicals (Maclaren*et al*., 2002).

2.10.2.4 Landfill Sites and Solid Wastes

Dump sites are sources of various toxic compounds which eventually find their way to the water sources posing health risks to water consumers and aquatic life. Increase in organic pollutants due to faecal contamination of the water or leachate from landfill sites raises its BOD of water due to biodegradable pollution and promotes eutrophication of water bodies. It also increases the health risks of the consumers by exposing them to water borne diseases such as cholera and certain types of hepatitis (UN-HABITAT, 2003).Solid waste causes loss of aesthetic appeal and also blockage of drains and conduits under bridges resulting in flooding. A typical example is shown in figure 2.2 below.

The process was also facilitated through the establishment of a WRC basin office (Densu Basin Secretariat) according to needs and agreed procedures in the Densu Basin.

2.11.1 Awareness Creation and Education

One of the key fundamental solutions identified to improve the ecological health of the Densu Basin was effective public awareness and educational campaigns. The Densu Basin Secretariat organised targeted public awareness creation activities such as publication and dissemination of IWRM messages and educational materials and supporting local stakeholders, particularly NGOs and Community Based Organisations (CBO) to organise catchment fora and other awareness creation activities in the basin.

The Secretariat has been involved in the education of seventeen (17) key communities within the Basin. Additionally seminars and workshops have been organized for all the Eight District Assemblies within the Basin. These interactions have gradually led to the establishment of strong linkages between the DBB and the Districts towards adapting joint solutions in tackling water resources management issues (DRB, 2007).

2.11.2 Achievements and Impacts

As a result of the concrete activities so far undertaken in the Densu Basin, favourable and significant ecological and environmental changes have been realized which needs to be followed up. Such realized ecological changes include:

- Slight general improvement in the raw water quality especially at the downstream of the Basin. Ghana Water Company has indicated the reduction in the cost of water treatment especially the western parts of Accra (WRC, 2007).

- Some degraded parts of the river catchment that were left fallow are gradually gaining their vegetative cover (natural re-growth).
- Significant tree planting activities have been undertaken at several parts of the basin especially at the mid-stream portion of the basin.
- A number of clean-up exercises and the phasing out of outmoded technologies for managing faecal matter/ liquids and solid wastes such as Pan Latrines have been executed.

More communities are becoming aware of the consequence of the degradation of the river basin, pollution of water bodies and the attendant diseases, high cost of treatment of the diseases, poverty, and loss of livelihood.

In Nsawam, for instance a youth award scheme on the activities for the protection and conservation of water resources have been instituted by an NGO which is increasing the enthusiasm of youth organizations in the basin. Some District Assemblies and communities are also working hard at instituting better wastes management and land use schemes to conserve the basin.

2.11.3 Degraded Sites Restored and Buffer Zone established Along Catchment Area

Small woodlots may be established on degraded sites of river banks to provide buffer zones and to protect the river corridors from farming and other land degrading practices. Local tree species should be planted because they are already well adapted to the soils and are unlikely to disrupt the ecosystem. These woodlots serve as buffer zones and protect the riparian areas from direct erosion and other degradation effects (DWAF, 2001). This is shown in figure 2.3 below.

Figure: 2.3: Trees grown along mid-stream at the bank of the Densu river(Source: *WRC, 2008)*

2.11.4 Water Abstraction in the Catchment Area

The Densu River is one of the most exploited rivers in Ghana. The river is used for domestic water supply, industrial and agricultural purposes. Water is abstracted at New Tafo, Apedwa, Akwadum, Koforidua, Nsawam, Suhum and Weija for treatment and supply to several communities within and around the Basin (WRC, 2010). Other small settlements such as Kukua, Akraabu and Aboatunpan also depend on untreated water from the Densu River and its tributaries (Kusimi, 2008).

Excessive abstraction of surface water may significantly reduce the flow of the stream or river, thus, raising the concentration of pollutants in the water and reducing the capacity of the river to assimilate the pollutants. Over-exploitation of ground water resources may result in saline intrusion in the productive aquifers making the water unsuitable for domestic use or crop irrigation (Biswas, 2003).

Ghana ground water resources contribute a very significant role for socio-economic development as evidenced by large number of boreholes and wells constructed in communities within catchment areas. The heavy dependence on ground water have resulted in the vigorous exploitation of ground water resources within the catchment area of the basin and hence the need for the rational managements and development of the resources to promote sustainable economic growth and protection of vital ecosystems (WRC, 2008).

2.11.5 Water Quality of the Densu Basin

Water quality is commonly defined by its physical, chemical, biological and aesthetic (appearance and smell) characteristics, with respect to its suitability for a particular purpose (WRC, 2007). Good water quality supports a rich and varied community of organisms and protects public health. Healthy water contains essential balanced amount of nutrients and has normal fluctuations in salinity and temperature. It also contains a lot of dissolved oxygen for aquatic organism and little suspended sediments, so that water grasses (aquatic weeds) receive enough sunlight to grow.

A stream can be contaminated by a range of materials from adjacent land, this include soil particles (sediments), nutrients such as nitrogen and phosphorus, salt, material from crops, chemicals and microbes. In most areas eroded soil and associated nutrients are the most important and widespread causes of reduced water quality (Tetteh, 2010).

2.11.5 Water Quality Degradation of the Densu River

The river Densu has been subjected to point and non-point discharges of wastes and materials, this practice has degraded the quality of water in the river (Nii consult, 2003).

Factors that accelerate the degradation of water quality in the river includes; erosion, siltation and pollution of the river, garbage and human wastes and excreta disposal, effluent from industries, motor garages and mechanical shops. These poor and unsustained agricultural activities in the basin have caused considerable damage to the environment and also reduced the vegetation cover along streams; these have resulted in increased sediment and nutrient loading of the streams coupled with an accelerated pollution from domestic and in some cases industrial wastes, implies a marked decrease in the quality of the natural water bodies (Yorke, 2006).

Human contact and the use of the water for bathing, washing, Swimming, irrigation and gardening are intense in the basin. These situations have resulted in siltation and pollution. Industrial wastes from fruit processing factories are discharged into the river. These practices have significantly contributed to both qualitative and quantitative degradation of the river (Attua, 2003).

As results of these anthropogenic activities, the river has become less suitable for drinking and less able to support aquatic ecosystems. Contaminated drinking water has to be filtered and treated before public use, which is increasingly becoming more expensive to do with more polluted water (WRC, 2003).

2.11.5 Improvement in Water Quality of the Densu Basin

The Water Resources Commission embarked on a systematic water quality monitoring programs in the Densu Basin to determine the trends in water quality. Water Quality Index (WQI) was used for the assessment. This index was developed for the Solway River Purification Board by Bolton *et al.*, 1978) adapted and modified by Ansa-Asare (1998). To interpret measurements of ambient water quality parameters (dissolved oxygen, biological oxygen demand, ammonia, faecal coliform, pH, nitrate, phosphate, suspended solids, electrical conductivity and temperature). The index is classified into four categories: good, fairly good, poor, and grossly polluted. The index thus indicates the degree to which the natural water quality is affected by human activities (Ansa-Asare, 1998).The WQI's basically use as a management tool in monitoring the general quality of a water body in a consistent manner.

2.12 The Weija Waterworks

Accra's urban population is increasing at a fast rate and as such much pressure has been put on the existing water supply system which is already over stressed (GWCL, 2003).The Weija waterworks is one of the sources of water supply for the city of Accra which is located on the Densu River Basin. It is located 15 km west of Accra. The raw water is drawn from the Densu River impounded at the Weija Dam. From the intake, the water is pumped to the treatment works via two pumping station.

CHAPTER THREE

3.0 METHODOLOGY

3.1Baseline Descriptions

3.1.1 Physical, Demographic and Socio-Economic Features

The Densu River traverses a highly densely populated part of Ghana and it is one of the most exploited rivers in the country considering its size. The basin is characterized by an accelerating land and water quality degradation and is marked by occasional water shortages in an otherwise perennial river system, among other factors by the rapid population increase due to proximity to Accra metropolitan area.

3.1.2 Location, Topography and River Network

The Densu River basin is about 120 km long with a catchment area of 2554 km^2 and located between latitudes 5^0 30'N and 6^0 17 `N and longitude 0^0 10'W and $0^0$37'W. The catchment of the river measures about 82.5 km long (North - South) and about 40 km wide (West - East). The river has six major tributaries that run through 54 major towns and 529 villages. With a population density of about 200 to 400 persons per square kilometer (Ghana Statistical Service 2000).The River is bounded to the east and north by the Odaw and Volta basins respectively. The boundary to the northwest is shared with the Birim basin and to the west with the Ayensu and Okrudu basins. The highest part of the basin reaches about 750 m above sea level and occurs along the north-western basin boundary.

The Densu River belongs to the coastal River system group and the basin takes its source from the Atewa range and flows from its upstream sections in an easterly direction towards the Akwadum –Koforidua area, from where the river gradually changes its course and flows in a southern direction into the Weija reservoir. When the Weija reservoir is full excess flows discharges into Densu delta (Sakumono) lagoon and salt pans complex, which constitutes one of Ghana's internationally recognized protected areas (Ramsar sites), before discharging into the bay of Guinea (Atlantic ocean).

3.1.3 Vegetation, Geology and Climate

The basin is made up of four vegetation belts, namely the wet semi-deciduous forest (Northern catchment), coastal thicket, grassland and strand and mangrove along the coast. The wet semi-deciduous forest contains most of the country's valuable timber and other tropical plants. Most of the trees in this zone exhibit deciduous characteristics during the dry season, when the influence of the harmattan is much intense (Dickson & Benneh, 1988).

Agricultural activities within the basin are favored by geophysical conditions such as warm temperatures, heavy rainfall and good soil conditions. The highest mean monthly temperature of about 30°C occurs between March and April and the lowest of about 26 °C is felt in August. Mean annual rainfall varies from about 800 mm near the coast to about 1600 mm in the source area.

The rainfall regime is the double maximum type, which enables farming all year round. The first rainy season is from April to June, with the heaviest rainfall in June and the second rainy season is from September to November. Further, this dual rainfall regime coupled with well drained loamy soils developed over granitic rocks, favor cocoa, oil palm and staple food production (Adu & Asiamah, 1992).

3.1.4Administrative Structures, Population, Economic and Settlement Pattern

The administrative fabric of the relatively small Densu River Basin can be characterized as rather complex, with three administrative regions and 8 districts represented within the basin, including part of the Accra metropolitan area. Approximately 72% of the basin (the northern portion) lies within the Eastern Region, 23% within the Greater Accra Region and the remaining 5% within the Central Region. Among the 8 administrative districts, the portions of the five districts of East Akim, New Juaben, Suhum/Kraboa/Coaltar, Akwapim South and Ga West constitute together close to 85% of the basin area. The Fanteakwa, Yilo Krobo and Kwaebibirim districts in the north of the basin constitute only about 1% of the basin area. Only small portion of the Ga East district is located within the basin.

The major economic activities in the catchment area of the basin include cultivation of crops such as cocoa, maize, cassava, vegetables, pineapples and cocoyam as well as the rearing of livestock and fishing. The communities around the river use the water extensively for drinking and other domestic purposes without prior treatment.

Figure 3.1: Map of the Study Area

3.2 Data Collection

3.2.1 Observations

Selection of the communities was based on the proximity of the communities to the Densu river. Critical observations were made to determine the impact of activities of riparian communities on the quality of the water body.

3.2.2 Use of Questionnaire

Questionnaire was administered to the target group (MOFA, EPA, WRC, MMDAs etc) and the riparian communities within the Densu catchment area. This was aimed at getting both quantitative and qualitative data on the impact of their activities on the catchment area of the river and to seek their opinion on the watershed management in their various communities.

The main features of the questionnaire for the riparian communities were demographic data of the respondents, waste management information of the respondents and the information on farming activities of the respondents. The main features for the questionnaire for MOFA, EPA WRC and MMDAs looked at, the regulatory framework put in place by the stakeholders, capacity of the stakeholders and collaboration among the stakeholders.

Table 3.1: Selected Communities and Institutions used for the Study

Stakeholders	Community/Institution	Number of Questionnaire	Remarks
Communities along the Densu Basin	Densuso	10	Questionnaire
	Akwadum	10	
	Adoadjiri	10	
	Nsawam	10	
	Mangoase	10	
	Weija	10	
Government Institution	MOFA	5	Interview
	WRC	1	
	EPA	2	
	DMA	7	
	Assembly members	3	Focus Group
(Source: field data2011*)*		Total=78	

3.2.3 Focus Group Discussion

Focus groups discussion was held with three assembly members and within the riparian farming communities at Mangoase, Akwadum, and Adoadjiri. This was to ascertain the impact of their livelihood activities of their constituents on the river and the management activities being put in place to help control pollution of the river.

3.2.4 Water Sampling

Two different types of sampling bottles were used, one for $BOD_5$and one for the rest of the other parameters. The sampling bottles was properly cleaned (to remove grease and other materials), the sampling bottles was first washed with detergent , then soak in acid overnight, rinsed several times with distilled water and stored dilute acid in it and used the next day . At the sampling site the acid is discarded and the bottle rinsed several times with the water. Samples were taken from the three existing water treatment plants within the basin. These were Koforidua at the upstream, Nsawam from the midstream and Weija at the downstream.

Each station was sampled two times in a month for a period of six months, from December 2010 to May 2011. At each site two samples were taken directly from the river and acidified with 5% of nitric acid for preservation.

The pH and temperature of the water samples were measured in-situ. All samples were stored in an ice-chest at 4^oC and transported to Ghana Water Company Limited and analysed at their water quality laboratory at Suame in Kumasi.

3.2.4 .1 Water Quality Analysis

The following laboratory analyses were carried out on the water samples for selected physical and chemical parameters determination of the samples given in the table 3.2.

Table 3.2: Some Water Quality Parameters and their Methods of Determination.

Water Quality Parameter	Instrument / Method of Determination
pH	pH–Meter Model CG818
Temperature	Digital Thermometer
Colour	Spectrophometer
Turbidity	Turbidity meter (Hach 2100P Turbidimeter model)
Conductivity	Conductivity meter Cyber Scan 510 model
Alkalinity	Titration using HCl & methyl orange
TDS	Conductivity meter
TSS	Spectrophometer
BOD_5	5-day incubation
DO	D O meter (Winkler method)
Hardness	EDTA – Titrimetric Method
Phosphate	Palintest photometer
Fluoride	Palintest photometer
Potassium	Palintest photometer
Nitrate	Palintest photometer
Chloride	Titration using potassium chromate & Silver Nitrate
Metals	Atomic Absorption Spectrophotometry (AAS) Model

Source: field data 2011

3.2.5 Secondary Data

Data on cost of water treatment and quantity of chemicals used in the treatment of water were also obtained from Ghana Water Company Limited.

CHAPTER FOUR

4.0 RESULTS

4.1 Introduction

The results of the Physico-chemical analysis of the water samples from the three stations, Weija, Nsawam and Koforidua in the Densu Basin are shown in Table 1 below. The results show the mean concentrations and standard deviations of some selected physical and chemical parameters at the sampling stations on the Densu river. The results reflect the prevailing condition of the water quality of the river at the sampling stations during the study period.

Table 4.1: Mean Concentrations of some selected Physical and Chemical Parameters

	SAMPLING STATIONS		
PARAMETER	Weija	Nsawam	Koforidua
Physical Parameters			
Color (Hz)	135.0± 11.8	258.0± 54.9	80.6 ± 23.7
pH	7.27 ± 0.06	7.60 ± 0.27	7.02 ± 0.36
Turbidity (NTU)	15.4 ± 1.69	54.4 ± 5.72	16.9 ± 6.13
Conductivity (μS/cm)	191.4 ± 32.1	254 ± 77.1	315 ± 130
TDS (mg/l)	97.2 ± 22.1	129 ± 13.6	178 ± 78.1
TSS (mg/l)	14.7 ± 2.94	21.2 ± 3.56	11.1 ± 2.46
Chemical Parameters			
DO (mg/l)	5.59 ±1.32	4.05 ± 1.07	7.23± 0.92
BOD (mg/l)	4.36 ± 1.35	6.25± 0.22	3.88 ±1.78
Nitrate-N (mg/l)	2.11±2.35	4.20± 0.53	0.47±0.38
Phosphate-P (mg/l)	3.02 ± 0.53	3.76 ± 0.13	0.19 ± 0.15
Fe (mg/l)	1.16 ± 0.04	0.95 ± 0.09	1.15 ± 0.05
Mn (mg/l)	0.34 ± 0.11	0.28 ± 0.02	0.30 ± 0.02
Pb (mg/l)	0.04 ± 0.01	0.04 ± 0.05	0.02 ± 0.04
Zn (mg/l)	0.05± 0.01	0.04 ± 0.05	0.28 ± 0.02
Alkalinity (mg/l)	85.1 ± 10.6	110 ± 21.6	57.2 ± 25.1
Chloride (mg/l)	43.1 ± 10.5	52.3 ± 7.87	57.7 ± 4.25

4.1.2 Mean Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD) Concentrations

From table 4.1 above mean DO concentrations at Weija, Nsawam and Koforidua ranged from 4.05 mg/l - 7.23 mg/l. The lowest DO value of 4.05 mg/l was observed at Nsawam which was below the TWQR of 5.0 - 8.0 mg/l for raw water (WRC, 2003).

BOD_5values at the sampling stations ranged from 3.8mg/l to 6.25mg/l. Nsawam recorded the highest value of BOD of 6.25 mg/l. All the sampling stations recorded values above the threshold limit of 2.0 mg/l.

4.1.3 Mean Nitrate-Nitrogen and Phosphate-P Concentrations

Nitrate and phosphate are the major causes of the eutrophication of the Densu basin and these patterns were observed. Nitrate values ranged from 0.47 mg/l - 4.2 mg/l (Table 4.1), with the upstream (Koforidua) recording the least mean value of 0.47 mg/l. Nsawam recorded a mean value of 4.2 mg/l, while a mean value of 2.11mg/l was recorded in the Weija Reservoir.

Phosphate values ranged from 0.19 mg/l - 3.76 mg/l during the period of the study. The values for phosphate followed a trend similar to that of nitrate; Nsawam recorded the highest mean phosphate value of 3.76 mg/l, followed by Weija of 3.02 mg/l and Koforidua recording the least value of 0.19 mg/l.

4.1.4 Mean values of Color, Turbidity and Conductivity Concentrations

Table 4.1 above depicts the men values of colour, turbidity and conductivity in the waters at the three stations during the study period.

Color ranged from 80.6-258 Hz. Koforidua recorded the least value of 80.6 Hz followed by Weija of 135 Hz, while Nsawam recorded the highest value of 258 Hz. Turbidity values exhibited a similar pattern to that of colour and ranged from 15.4-54.4 NTU. Turbidity increased from the upstream section to the midstream section and then declined towards the downstream section of the basin. Weija recorded a value of 15.4 NTU, Nsawam 54.4 NTU and Koforidua 16.9NTU.

Conductivity values ranged from 191- 254μS/cm, which increased from the upstream to the midstream section of the basin, with a marked decrease at the downstream section (Table 4.1). The values of 221.2μS/cm were recorded at upstream (Koforidua), 254μS/cm recorded in the mid stream (Nsawam) and 191. μS/cm recorded at the downstream section of the basin in the Weija Reservoir.

4.1.5 TDS and TSS Concentrations in the Waters

Total Dissolved Solids (TDS) values measured portrayed an increasing pattern from the down stream to the upstream sections of the basin, which ranged from 97.2 mg/l to 178 mg/l. Total Dissolved Solids (TSS) values recorded were 14.7 mg/l at Weija, 21.2 mg/l at Nsawam and 11.1mg/l at Koforidua (Table 4.1).

4.1.6 Mean values of Fe, Mn, Pb and Zn Concentrations in the Waters

From table 4.1 above Fe values ranged from 0.95mg/l – 1.16 mg/l with all the three sampling points recording values above the threshold of 0.3 mg/l. Mn values ranged from 0.28 mg/l – 0.34 mg/l which is below the upper limit of TQWR 0-0.05 mg/l . Pb values in the waters also ranged from 0.02 mg/l -0.04 mg/l with Nsawam and Weija recording the same values of 0.04 mg/l. At all the sampling points, the values recorded for Pb was below TQWR 0 – 0.01 mg/l. The concentration of Zn in the water also felt below the upper limits values of TQWR 0 – 3 mg/l and the values ranged from 0.04 mg/l – 0.28 mg/l in the waters.

4.2 Application of Water Quality Index

4.2.1 Classification of Water Quality for the River Basins

The Water Quality Index (WQI) is a classification system that uses an index calculated from selected water quality parameters. The index classifies water quality into one of four categories: good, fairly good, poor, and grossly polluted. Each category describes the state of water quality compared to objectives that usually represent the natural state. The index thus indicates the degree to which the natural water quality is affected by human activity. The index can be used to describe the state of water quality as a whole in a body of water. It also indicates the suitability of water for various uses such as domestic, recreation and agriculture (i.e. irrigation and livestock watering), where such uses are naturally sustainable.

Table 4.2 below shows the description of the state of water quality based on the adapted classification system that uses a class system and a scale of (0 -100) in various ranges for the corresponding classes.

4.2.2: Solway Surface Water Classification Index

Table 4.2: Criteria for Classification of Surface Waters

Class	Range	Description
I	>80	Good – Unpolluted and/or recovering from pollution
II	50 – 80	Fairly good
III	25 – 50	Poor quality
IV	<25	Grossly polluted

(WRC, 2003).

Solway water Quality Index (weighted) is given as:

$$1/x(\sum_{i=}^{n} q_i w_i)^2$$

Where **x** represent the sum of the weighting of the parameters being considered, q_i and $w_i$representtheweighting, respectively of the nth parameter.

Table 4.3 below presents the results of the WQI calculations for the three sampling stations (Koforidua, Nsawam and Weija) along the Densu river from (2005-2010) respectively.

Table 4.3: Water Quality Classification of the Stations – 2005 - 2010 compared

Years	Sampling stations					
	Koforidua		Nsawam		Weija	
	Indices	Class	Indices	Class	Indices	Class
2005	64.5	II	32.5	III	59.3	II
2006	78.3	II	45.0	III	64.0	II
2007	75.3	II	43.6	III	57.8	II
2008	71.2	II	42.3	III	55.7	II
2009	68.9	II	42.1	III	52.1	II
2010	70.1	II	39.5	III	51.3	II
2011	72.1	II	43.4	III	58.9	II

The WQI at Koforidua ranged from 64.5-78.3, while that of Nsawam ranged from 32.5 – 45 and that of Weija ranged from 51.3- 64 as shown in table 4.3.

In 2005 Nsawam was in class III (poor quality) but the remaining stations were all classified as Class II (fairly good waters). In 2006 Nsawam was of Class III (poor quality), Koforidua and Weija still remained in the class II category (fairly good quality). Even though all the stations maintained their respective classes, there was a marked improvement in the quality of waters in 2006 as observed over 2005 figures. From 2006 to 2010 the midstream and downstream portion of the basin showed a downwards trend in their WQI figures. At Koforidua WQI values observed showed the same downward pattern from 2006 to 2009 and increased slightly in 2010 over 2009 values accordingly. The 2011 values in the table represent the water quality index calculated for the six month period in which the research was conducted. The WQI values of 2011 improved over the 2010 values although the values still remain in class II and III. The water quality indices calculated for the sampling stations is attached at appendix II.

4.3 Chemicals Consumption at the various Water Treatment Plants (Koforidua, Nsawam and Weija) from 2005-2010

The major water treatment plants located in the Densu basin are Koforidua, Nsawam and Weija. The three most widely used chemicals in the raw water treatment process are the Aluminum Sulphate for flocculation, Hydrated Lime for pH adjustment and Calcium Hypochlorite for disinfection.

4.3.1 Annual Chemicals Consumed at Koforidua Water Headworks

Figure 4.5 below presents the annual consumption pattern of Aluminum sulphate, Hydrated lime and Hypochlorite at the Koforidua water Headworks spanning from 2005-2010

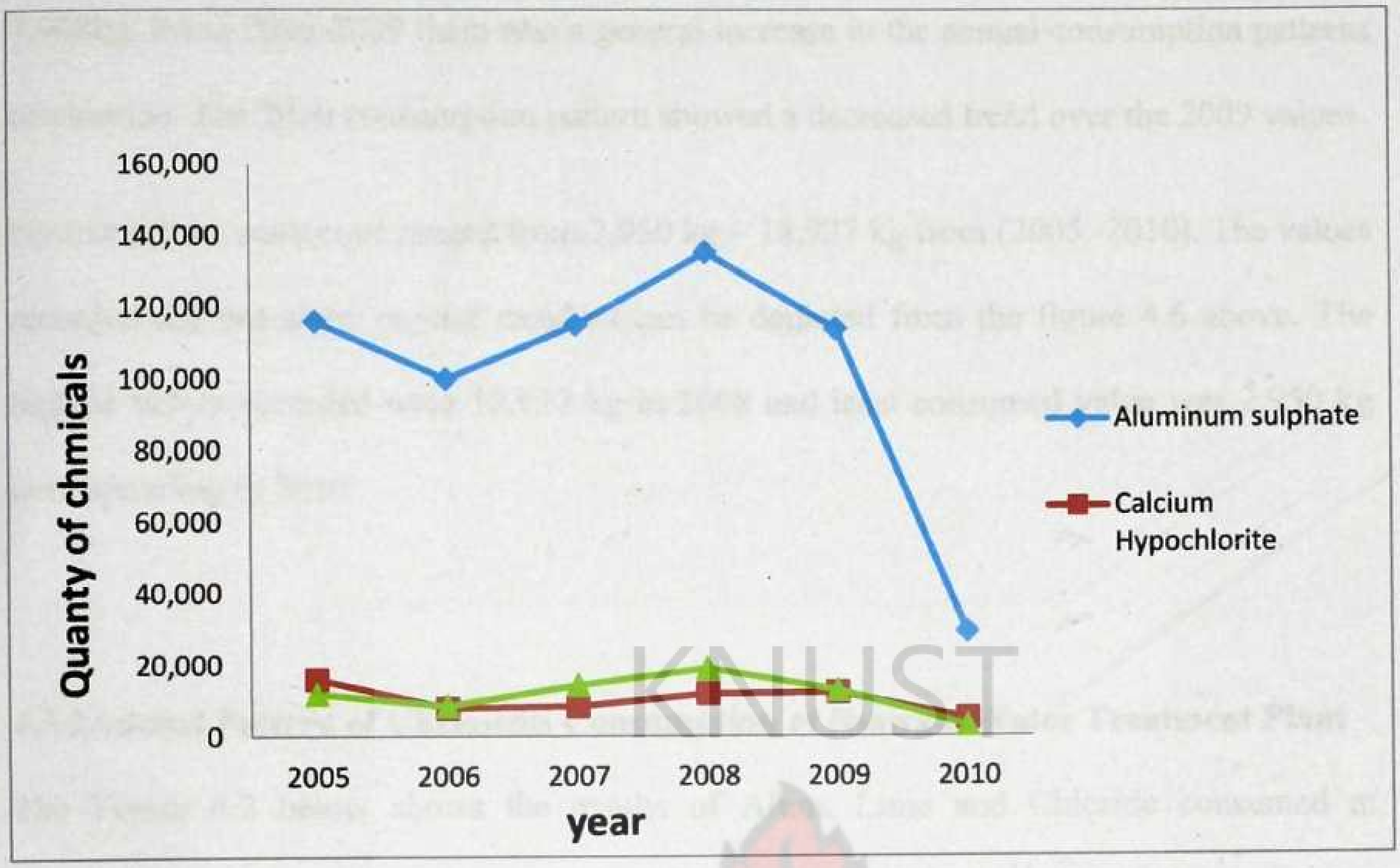

Figure 4.1: Trend of Chemicals Consumption at Koforidua Treatment Plant.

As can be observed from the Figure 4.1 above, the annual aluminum sulphate consumed ranged from 29,135 -135,200 kg. The year 2010 consumed the least aluminum sulphate with value of 29,135 kg and the year 2008 recorded the highest alum consumption during the period of 2005 to 2010.

Annual alum consumed decreased from 2005 to 2006 with the values of 115,980kg and 99,970kg, respectively. From 2006-2008, annual alum consumption showed an increased trend with their corresponding values of 99,970kg, 115,065kg and 135,200kg. And from 2009 to 2010 the consumption pattern decreased from 113,885kg and 29,135kg, respectively.

Calcium hypochlorite consumption at Koforidua portrayed a similar trend compared to annual alum consumption. The annual chloride consumed ranged from 5,040 kg to 16,004 kg. Annual consumption values from 2005 decreased over 2006 values, of 16,004kg and

7,908kg. From 2006-2009 there was a general increase in the annual consumption patterns of chloride. The 2010 consumption pattern showed a decreased trend over the 2009 values.

Hydrated lime consumed ranged from 2,950 kg – 18,927 kg from (2005 -2010). The values recorded did not show regular trend as can be depicted from the figure 4.6 above. The highest values recorded were 18,927 kg in 2008 and least consumed value was 2,950 kg corresponding to 2010.

4.3.2Annual Pattern of Chemicals Consumption at Nsawam Water Treatment Plant

The Figure 4.2 below shows the results of Alum, Lime and Chloride consumed at midstream section of the Densu basin at Nsawam, from 2005-2010.

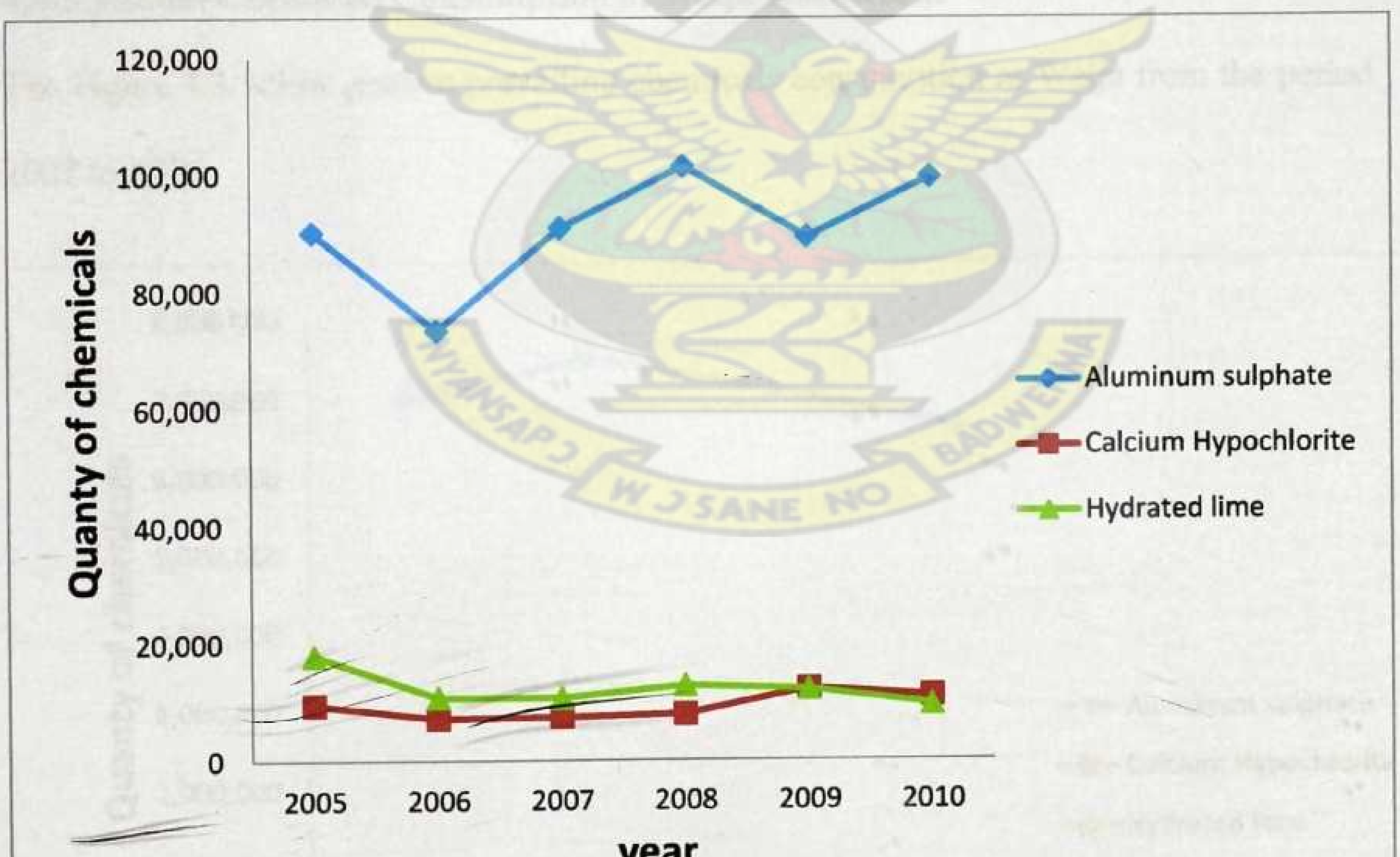

Figure 4.2: Trend of Chemicals Consumption at Nsawam Headwork's (2005-2010)

The annual Alum consumed from 2005-2010 ranged from 73,490kg -101,500kg with irregular consumption trend. The alum consumption at 2005 increased over 2006 values. From 2006 to 2008 the annual alum consumed showed an increased pattern. In 2009 consumption decreased from 2008 and also increased in 2010.

Calcium hypochlorite consumption ranged from 7,220 kg to 12,180 kg, from 2005-2010. 2005 and 2010 had values of 9,557kg and 10,920kg. As can be observed from the chart above, 2006-2009 showed an increased trend of annual chloride consumptions, 7,220kg, 7,475kg, 7,903kg and 12,180kg respectively.

Hydrated lime ranged from 9,500 - 17,987kg. A general decreased pattern of annual lime consumption was observed in 2005-2007, ranging from 17,987kg, 10,805kg and 10,700kg respectively. The same decreasing trend was also observed in 2008 – 2010 (Appendix 2).

4.3.3 Annual Chemicals Consumption at Weija Headworks

The Figure 4.3 below present prevailing chemicals consumption at Weija from the period 2007 to 2010.

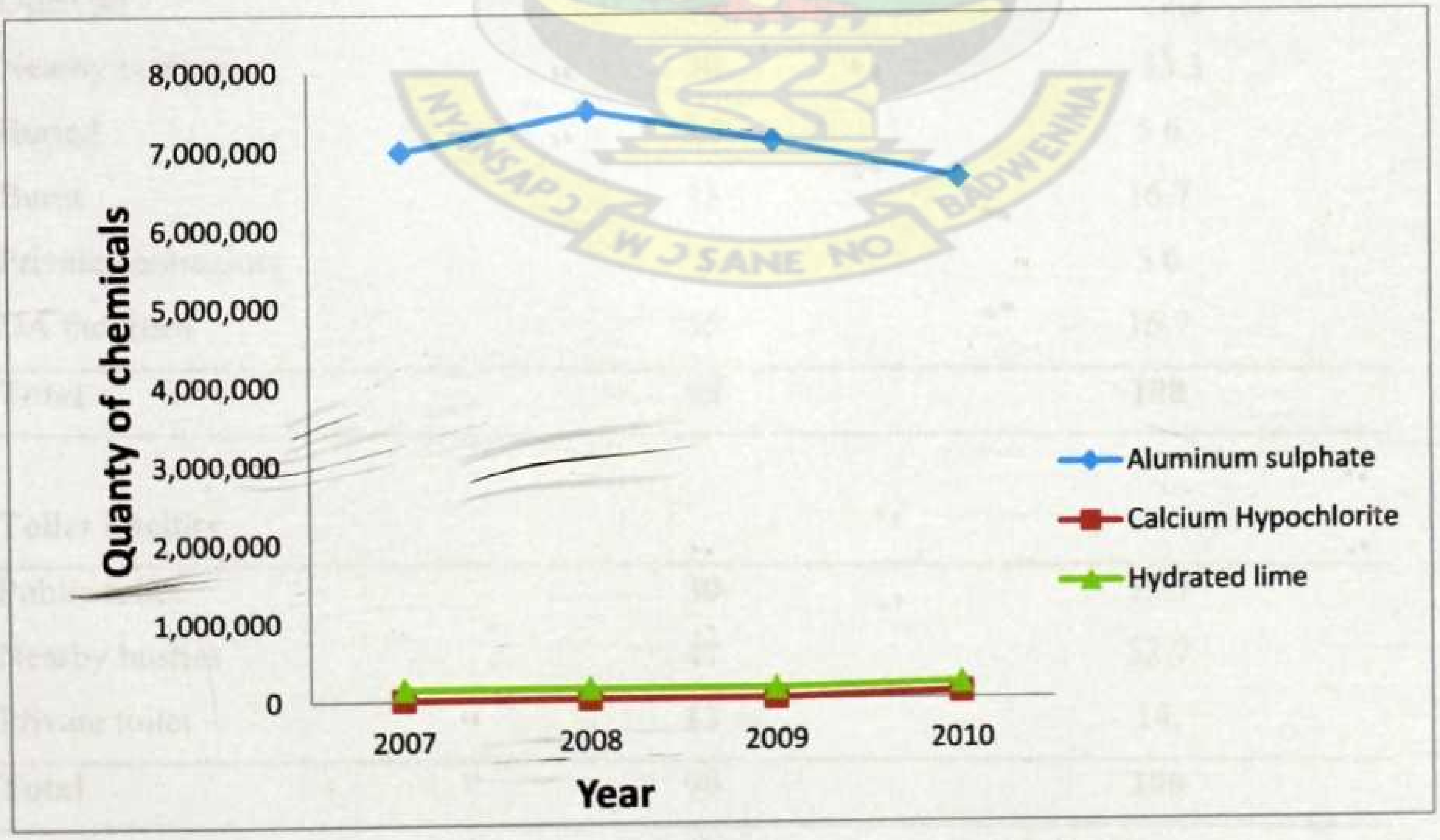

Figure 4.3: Trend of Chemicals Consumption Pattern at Weija Head Work (2007-2010)

The alum consumed at Weija Headwork's ranged from 6,625,891kg - 7,500,200kg. The alum consumed at the headwork showed decreased trend, the annual consumption pattern in 2007 was 6,985,100kg. In 2008-2010 the following consumptions were recorded (7, 500,200kg; 7,100,075kg and 6,625,891kg).

The annual hypochlorite consumption increased from 18,440kg in 2007 to 19,200kg in 2008and 2008 and also increased for 18,200kg - 82,700kg in the period 2009-2010.

Hydrated annual lime consumed ranged from 145,340kg - 199,200kg, there was a general decreasing trend in 2007-2008 (155,463kg and 152,395kg) and in the year2009-2010 there was an increase in annual lime consumption from 145,340kg - 199,200 kg.

Table 4.4: Waste Management of Respondents

Methods	Frequency	Percentage (%)
Solid Wastes		
Open pit	20	22.2
Nearby bushes	30	33.3
Buried	5.0	5.6
Burnt	15	16.7
Private contractors	5	5.6
DA facilities	15	16.7
Total	**90**	**100**
Toilet Facility		
Public toilet	**30**	33.3
Nearby bushes	**47**	52.7
Private toilet	**13**	14.
Total	90	**100**

From table 4.4 it was quite revealing that about 22.2% of the respondents disposed their waste by the open-pit method, 33.3% resort to using the nearby bushes in disposing wastes, 5.6% buried their wastes, while those who burnt their wastes constituted 16.7%. Some of the respondents also hired the services of other private waste collectors which represent 5.6%, while 16.7% of the respondents also patronized services provided by the District assemblies

From the research findings it was also revealed that majority of the respondents don't have access to toilet facilities and hence defecate in the bushes which represent 52.2 % of the respondents, 33.3% of the respondents also used public toilet facilities while the remaining 14.2% of the respondents have access to private toilet in their homes.

4.4: Impact of Farming Activities along the Banks of the Densu River by the Respondents

The impact of the farming activities on the river was determined and the findings are shown in the figure 4.4 below.

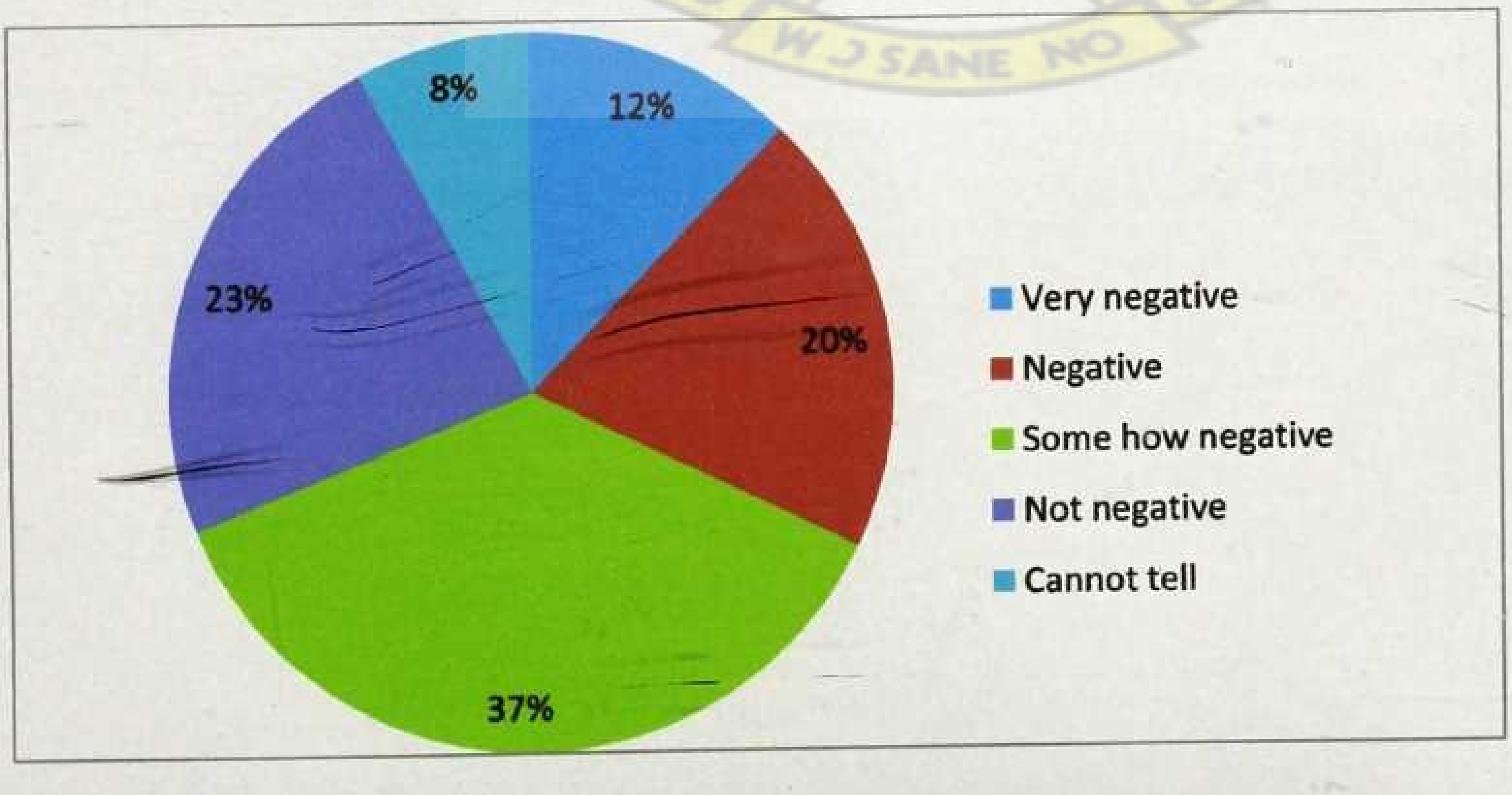

Figure 4. 4: Respondents views about the Impact of farming activities along the banks of river.

Opinions of the respondents were sort to determine whether their activities have any negative impact on the river? 12.2 % of the respondents said the farming activities close to the river have very negative effects on the river, 20% confirmed that activities have negative impact on the river, 36.7% of the respondents said their activities somehow impacted negatively on the river, 23.3% also held the view that their activities don't have any negative effect on the river, whiles 7.8 % cannot tell whether the farming activities impacts negatively on the river.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Key Management Activities of the Densu Basin

5.1.1 Awareness Creation and Education

One of the fundamental factors that were identified to improve the ecological state of the Densu basin was effective public awareness creation and educational campaigns. The Densu Basin Secretariat has organised various targeted public awareness activities such as publication and dissemination of IWRM messages and educational materials and supporting local stakeholders, particularly NGOs and Community Based Organisations to organise catchment fora and other awareness creation activities in the basin. The Secretariat has also been involved in the education of key communities within the Basin and organizing seminars and workshops for all the Municipal and District Assemblies within the Basin. These interactions have led to the establishment of strong linkages between the DBB and the various District Assemblies towards adapting joint solutions in tackling water resources management issues.

The secretariat are also involved in building capacities for women groups, media, traditional authorities and schools in the water quality monitoring programmes, mounting river billboards with water messages. The secretariat has also strengthened the collaboration between the police services for compliance and enforcement within the Densu Basin.

5.1.2 Regulation of Water Users

Part of the Water Resources Commission mandate is to regulate water use through the issuance of water use permits or granting of water rights. In this regard, activities in the Densu Basin have also focused on identifying major raw water users. More than 600 boreholes have so far been drilled in the Basin for domestic purposes, bottled water production and other industrial uses, and agricultural purposes. However, groundwater potential of the basin is generally low (WRC, 2007).

A significant benefit of this activity is that it is being used as a financial resource base to ensure sustainability of the IWRM process, which currently, depends on external financial support schemes. Indeed, proceeds so far generated from the issuance of the water use permit are being disbursed to support other micro programmes relating to awareness creation and education, waste management and catchment rehabilitation works in the basin.

5.1.3 Waste Management

Appropriate waste management is one of the key management activities being adopted by the MDA/Das in collaboration with WRC to mitigate the impact of inappropriate waste disposal on the Densu basin. The MDA/DAs within the Densu basin have relocated their wastes dumping site away from the river and other forms of waste disposal methods have been adopted by the Assemblies and the riparian communities.

The Research findings also revealed that 52.2% of the respondents do not have access to toilet facilities and hence, defecate in the bushes. The high patronage of the respondents using nearby bushes could be due to lack of waste disposing facilities by the Assemblies and lack of regular awareness creation among the riparian communities. This could also be due to the fact that toilet facilities are inadequate for the inhabitants and in some cases some of the facilities are not properly maintained to serve the needs of the peoples. Liquid wastes from households, abattoirs and food industries at Koforidua and Nsawam are discharged into the river.

5.1.4 Appropriate Agricultural Activities

The used of Agrochemicals by farmers to improve soil fertility and also to protect crops are washed directly into the river. And also the use of mechanical tillage method by the farmers for land preparation along the river banks contributes to erosion and the leaching of soil nutrients into the river, which cause pollution and siltation of the river.

Some of the farms in Densu basin are located as close as less than 10m to the river. Interaction with the farmers indicated that they farmed close to the river because of regular water supply. Others said the soil around the river is rich in organic matter, others also indicated that farming along the bank of the river is being influenced by the type of crop grown, since most of the farmers who farm close to the river are vegetable farmers.

Livestock (Cattle, Sheep, Goats etc.) and poultry in the settlements surveyed drink directly from the river and defecate in the river. It was also found out that, cattle owners living in the Ga District (Manhean, Afuaman, Ayikai, and Dobro etc) dumped their cow dung into the river.

Fishermen along the Densu river at Nsawam and Weija depend on the river for their economic sustainability; however use of hazardous chemicals like DDT and bad fishing methods have been banned but still being used by fishermen.

5.1.5 Ecological Monitoring

The WRC have identified four monitoring sites on the Densu River for its water sampling exercises, that is Potroase at the source of the river, Mangoase and Nsawam from the midstream section of the river and Weija at the downstream end of the river. Water samples are taken from all the identified sampling sites every month for analysis.

5.2 Physico-Chemicals Parameters

5.2.1 pH

The pH of the waters in the Densu basin ranged from 6.5 to 8.4. The Target Water Quality Range (TWQR) of pH for raw water is 6.0 - 9.0 (WRC, 2003). The pH values are therefore within acceptable limits, since only few values fell below the lower limit of 6.5. The pH of river water in most areas, not affected by pollution is between 6.5 and 9.0 (Hem, 1985). Both natural processes and human activities can affect pH. At high flows pH is influenced by many factors including substances over which the water run.

The mean pH recorded at the identified sampling stations were fairly constant; at Koforidua pH was 7.02, at the midstream section at Nsawam the pH value recorded was 7.60 whiles at downstream point at Weija the recorded values were 7.27.The pH was within the range stipulated for drinking and domestic purposes (WHO, 1993). The EU also sets protection limits of pH from 6 to 9 for fisheries and aquatic life (Chapman, 1996). The pH obtained in the river waters was within these ranges. The pH of the waters would therefore not adversely affect its use for domestic, recreational purposes and aquatic ecosystem.

5.2.2 Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD)

The Ghana Raw Water Criteria and Guidelines (WRC, 2003), has no DO TWQR for drinking water, but has set the TWQR of DO for waters of aquaculture use which is between 5.0 - 8.0 mg/l.

The low DO concentrations of 4.05mg/l observed at Nsawam could be attributed to high point source pollution which is partly due to increased inputs of organic materials into the river and also discharge of both solid and liquid wastes into the water since the river passes through Nsawam township. Work done by USDA (1992) reveals that, the level of oxygen depletion depends primarily on the amount of waste added, the size, velocity and turbulence of the stream, the initial DO level in the water and the temperature of the water. DO concentrations at the sampling stations at Koforidua and Weija were both above the lower limit of the TWQR. This indicates that the waters were well oxygenated and could support aquatic survival.

DO provide a broad indicator of water quality, DO concentrations in unpolluted water are normally about 8–10 mg/l at 25^0C (DFID, 1999). Concentrations below 5.0 mg / l adversely affect aquatic life.

The BOD values from all the sampling stations were all above the upper limit of the TWQR of 2 mg/l, indicating organic pollution loads into the waters are prevalent as a result of high inputs of both domestic and agricultural wastes into the river.

5.2.3 Nitrate and phosphate

Enrichment of water with nitrates and phosphates results in proliferation of algae and plants which die and decompose in the water. It depletes the oxygen present in the water resulting in the death of aquatic life and consequent loss of biodiversity. It also results in increased cost of purifying the water.

Nitrate-nitrogen is an indicator of both agricultural and domestic wastes in the basins. Its concentrations ranged from 0.47 - 4.2 mg/l. All the concentration values observed were within the TWQR of 0 - 6.0 mg/l NO_3-N. Therefore the Nitrate-nitrogen concentrations in the river basin are not quiet alarming; however, the average values observed in the basin may be considered high. This is because it is known that NO_3-N concentrations in excess of 0.2mg/l NO_3-N causes possible eutrophication in lakes (UNESCO/WHO/UNEP, 1996).

The high concentrations of nitrate-nitrogen observed at Nsawam may be as a result of high usage of agrochemicals by famers who farmed at the fringes on the banks of the river, which can be washed into the river through run-off. These relatively high values observed are the reflection of human impact in the river basin.

High Phosphate-P (PO_4-P) values were recorded at Weija and Nsawam. The high values observed at these two sampling points may be as a result of high inflows of domestic wastes and sewage, as well as agricultural wastes into the river along the Nsawam town, since it is an urban town. Farming close to the banks of the river, especially at Nsawam exposing the land surface to erosion by run-off. Also, average rates of bank erosion have been shown to increase with catchment size acting as a surrogate for discharge (Hooke, 1980; Brice, 1984).

5.2.4 Colour, Turbidity and Conductivity

Colour is an important physical parameter of water because of its implications for water supply and the need to reduce it to acceptable levels by water treatment is highly recommended. Increase in the colour of water in reservoirs results in increases in treatment cost. Colour varied between 80.6 – 258 Hz. These values are above 15 Hz which is the WHO guideline limit for colour. The colour recorded from all the stations were all above the permissible threshold value of 15Hz. At Koforidua the colour observed was the least compared to the other stations, which has less human impact, since it is at the upstream section of the river. Midstream section recorded the highest value which is due to high anthropogenic activities; which is partly due to peri urban nature of Nsawam. The values at Weija were below that of Nsawam which could be partly due to opening of the spill gates to spill water from the reservoir during the sampling period.

The Highly coloured nature of the river may be due to decaying vegetation and organic materials, which is normally leached in to the river; this is in line (Karikari and Ansa-Asare, 2004) finding that, Colour in natural water may usually result from the leaching of organic materials which is primarily the result of dissolved and colloidal humic and fulvic substances. Colour is also strongly influenced by the presence of iron and other metals, either as natural impurities or as corrosion products.

Turbidity of the river ranged from 15.4 - 54.4 NTU. High Turbidity values were recorded at all the sampling stations. The high levels of turbidity and total suspended solids recorded are a reflection of the nature of suspended bed load transport in the basin.

Soil erosion and runoff from the catchments may also be the source of high turbidity in the river. Farming along the river banks has a significant impact on soil erosion. Vegetation in this section of the basin is degraded into grassland and shrubs by anthropogenic activities. The poor vegetative cover implies loose soils and this is more prone to erosion. Eroded sediments are easily entrained into channels ending up in the river. This is ascertained by the high values recoded at Nsawam, as a result of high anthropogenic impacts on the river.

For water to have no adverse health effects and no aesthetic effects, the TWQR should range between 0 – 5 NTU (WRC, 2003). Thus all the waters may not be suitable for drinking or aesthetic use without further treatment. The excessive turbidity recorded confirms earlier work by Karikari and Ansa-Asare, (2004) which recorded values of (21.5-49.4 NTU).

The excessive turbidity in water causes problems with water purification processes such as flocculation and filtration, which may increase treatment cost. Elevated turbid water is often associated with the possibility of micro-biological contamination as high turbidity makes it difficult to disinfect water properly (DWAF, 1998).

Electrical Conductivity (EC) values were outside the TWQR of (0 – 70.0 μS/cm) recommended by the Water Resources Commission of Ghana (WRC, 2003) for raw waters. The mean conductivity of water in the Densu Basin showed a gradual increase from Koforidua which is close to the headwaters. The high conductivity could be because of domestic effluent discharges and surface run-off from the cultivated fields which might have increased the concentration of ions. In the Weija Reservoir conductivity was reduced as a result of dilution.

Generally, the conductivity of a river is lowest at its source and, as it flows along the course of the river, it leaches ions from the soils and also picks up organic material from biota (Ferrar, 1989). The average value of typical, unpolluted rivers is approximately 350 μS/cm (Koning &Roos, 1999).Therefore; conductivity of the waters is within the permissible threshold levels and does not give cause for concern.

5.2.5 TSS and TDS Values

The total suspended solids (TSS) values ranged from 11.1 - 21.2 mg/l, as can be observed from Figure IV.TSS values were above 5.0 mg/l at all the sampling stations, the upper limit of the TWQR of TSS of water for industrial purposes, Category 1 to Category 3 waters (WRC, 2003). All the waters are however, not suitable for drinking in terms of TSS, since water for domestic use is not supposed to contain any suspended solids (WRC, 2003). Even though high TSS values were observed from all the station, Nsawam had the highest value which is being attributed to increased run-off and point sources of pollution. However, these values are still within the Target Water Quality Range (TWQR) for Livestock Watering (1000 mg/l).

5.2.6 Trace Metals

Iron (Fe), lead (Pb), manganese (Mn) and Zinc (Zn) were the trace metals that were determined in the waters. All the metals were below their respective TWQRs in all the stations except Fe. Concentration of Fe was high in the waters, ranging from 0.950 mg/l to 1.16 mg/l. These were above the TWQR of 0.3 mg/l. Iron pollution in the basin is therefore evident and could be resulting from weathering of the bed rocks, auto garages, mechanicals shops and lorry station along the banks especially at Nsawam and also from iron-containing substances being dumped into the waters.

5.3 Classification of Water Quality Index of the Densu Basin.

The WQI values for the sampling sites along the Densu River reflect the prevailing situation of the water quality of the river from its upstream end towards its midstream and downstream sections.

As can be visualized from Table 4.3, the mean annual WQI from 2005-2011 at Koforidua was 71.4 (class II), Nsawam recorded 40.8 (class III) and Weija had values of 56.7 (class II).

There is generally marked improvement in the WQI values of 2006 at all the sampling station, which is an indications of the various IWRM activities initiated during the past few years (i.e. relocation of solid waste dump sites , river bank protection ,tree planting and public awareness creation activities) was implemented is yielding the results but the progressively decreasing patterns of WQI values from 2006 to 2010 as observed at Nsawam and Weija can be attributed to the fact that the various IWRM instituted in those years were not strictly implemented, which may be due to funding , institutional inability to implement the management activities outlined and the attitudinal behavior of the riparian communities along the basin. This also confirmed the high anthropogenic activities in the river basin. The slight increased in WQI values in 2010 over 2009 at Koforidua can be attributed to the sound managements activities strictly adhered to.

Furthermore the water quality after entering the Weija reservoir once again is found in class II category. Apparently the water source managed to ''recuperate'' some extent recover from the heavy pollutions load found at Nsawam. This phenomenon is most likely to be attributed to the effect of the large water body created by the dam with its wind action resulting in some water circulations, which may facilitate a self –purifying effect.

5.4 Chemicals Consumption at Koforidua, Nsawam and Weija Water Treatment Plants.

The consumption patterns of Aluminum sulphate, Hypochlorite and Lime clearly reflected the prevailing situation at the various treatments plants along the Densu river. The consumption pattern of these chemicals is expected to reflect the state of the quality of the water. The progressively increase in alum consumption at Koforidua and Nsawam treatment plant from 2006-2008 could be attributed to high organic matter decay content which are easily washed into the river during run-off. This is as result of the diffuse pollution sources such as ''free- range defecation'' poor disposal of household refuse, other solid waste and rudimentary agricultural activities, including un-checked use of agrochemicals (fertilizers and pesticides).

This followed a similar trend with the WQI value observed at the same sampling station. Chlorine consumption from Koforidua and Nsawam also increased from 2006-2008 which clearly depicted that the quality of the water is progressively being depleted, hence increasing the annual consumption rate and the cost of treatment.

Data on annual chemical consumption at Weija were not enough to explained the trend, even thorough the consumption pattern of chemicals was irregular however there was a general decreasing trend of alum, chlorine and lime consumption at Weija which was due to the fact that the various IWRM activities implemented such as fencing of the lake and the formation of Weija lake protection association squad has helped to reduce encroachment on the lake.

CHAPTER SIX

6. 0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Generally the water quality from the Densu river still remains poor as indicated by the research findings. Although industrial activities and factories in the basin have significant impact on the environment, the main threat to the ecological character of the river is the numerous and diffuse pollution sources, such as ''free-range defecation'', poor disposal of household refuse and other solid waste and rudimentary agricultural practices, including un-checked use of agro-chemicals (fertilizers and pesticides).

The Solway Water Quality Index for classifying the quality of raw water, adopted by Water Resources Commission (WRC) in 2003, was used to characterize the waters from the river basin. The WQI classification has shown that most of the waters are of Class II, that is, they are in "fairly good state". Nsawam remain in (class III) poor water quality. The assessment carried out revealed that the waters are currently not highly degraded.

The rate of Aluminum Sulphate (Alum), Hydrated Lime (Lime) and Calcium Hypochlorite (chloride) consumptions at the various treatment plants were irregular but with a general decreasing trend.

Majority of the riparian communities interviewed (52.2%) patronized the free range system of disposing off their feacal matter. The management activities been carried out by the WRC is impacting positively on the water quality of the basin but at a slow pace, hence the process should be sustained.

6.2 Recommendations

From the outcome of the research findings, the following recommendations were made:

- Farmers should be given adequate education on the application of agrochemicals and the use of organic manure on a consistent basis.
- Adequate toilet facilities should be provided by the various MMDAs and maintained to encourage the communities' members living along the basin to use it.
- Research should be conducted to assess stakeholders' participation in the management of the basin.
- District and Municipal Assembles should be able to enforce their bye-laws regarding waste management especially communities within the Densu river.
- WRC should intensify it awareness creation programmes and closely monitor the management activities instituted to assess it impact on the riparian communities along the Densu River.

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APPENDICES

APPENDIX I

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY-KUMASI

College of Engineering – Department of Materials Engineering.

Questionnaires for stakeholders and riparian communities along the catchment areas of the Densu River Basin.

Name of community.. Date ....

Please you are rest assured that the information you provide will be treated as confidential and will be used only for academic purposes. Thank you for your time and cooperation. Please tick or explain

Respondent Characteristics/Demographic data

1. Name ....
2. Sex. Male [ ] Female [ ]
3. Age. 20-40 [ ] 41-60 [ ] 61-80 [ ] 81-100 [ ] 100+ [ ]
4. Educational status. Primary [ ] J.H.S [ ] S.H.S [ ] Post secondary [ ] Tertiary [ ]
5. Occupation teaching [ ] farming [ ] petty trading [ ] others [ ]

Waste management of respondents

1. How do you dispose off your waste? Open pit [ ] Dumping in nearby bushes. [ ] Buried [ ] Use of private contractors. [ ] The use of the district assembly facilities and services [ ] others [ ]
2. Do you have a toilet facility in your house? Yes [ ] No [ ]
3. If no, what kind of toilet facility do use? The public toilet [ ] nearby bushes [ ]others [ ]
4. Have been educated on the need to manage your waste? Yes [ ]. No [ ]
5. If yes, what are some of the lessons?..

Farming Information

1. What is the distance of your farm to the river? less than 50m [ ] 60-100m [ ] 110-150m [ ] above 150m[ ]
2. What crops do you grow? cereals [ ] vegetables [ ] root and tubers [ ] fruits [ ] Pineapple field crops[ ] Okra [ ]
3. Do you use fertilizer on your farm? Yes [ ] No [ ]
4. If yes how often? Once every planting season [ ] twice [ ] three time every planting season [ ]
5. Do you use pesticides to spray the farm? Yes [ ] No [ ]
6. Have you been educated on the types and methods of chemicals application? Yes [ ] No [ ]
7. Why do you farmed along the banks of the river? Regular water supply [ ] rich in organic matter [ ] the types of crops grown [ ] other[ ]
8. What type of animals do you keep? Cattle [ ] sheep [ ] goat [ ] poultry [ ] donkey [ ] others [ ]
9. What livestock-watering source do you use for the animals? Wells [ ] borehole [ ] from the river [ ] others [ ]
10. Have you been given any form of education on the impact of farming along the river banks? Yes [ ] No [.
11. If yes who organised the educational fora? MOFA [ ] NGO [ ] Others [ ]
12. In your own opinion do you think farming activities close to banks of the river have negative effect on the water quality and quantity? Very negative[ ] negative [ ].somehow negative [ ] not negative [ ]
13. If yes are you prepared to move away from the banks of the river? Yes [ ] No [ ]
14. If no why? Not getting land to farm [ ] unless compensated [ ] is a family land [ ] others [ ]

Stakeholders' questionnaires

Districts /Municipals Assemblies (DMA)

1. What regulatory measures/ frameworks are put in place to protect the water bodies in the district main activities being undertaken to protect the water body?..
....
....
....
2. Has the Assemblies been strengthened to prepare and enforced bye laws to regulate the use of natural resources of the basin? Yes [ ] No [ ].
3. If yes how effective are these bye laws enforced in the district. very effective [ ] Effective [ ] somehow effective [ ] ineffective [ ] ineffective [ ] ineffective

   If no why..
4. How are your waste handled? Skips and Dumps [ ] landfills [ ] private contractors [ ] use of the district assembly facilities and services [ ] others [ ]
5. What are the some constraints you face with regards to waste management?...............................

Environmental Protection Agency (EPA)

1. Has there been any involvement in the management of the Densu Basin through?

Monitoring [ ] workshops organization [ ] Handbill [ ] others [

2. What are the main activities being under taken to protect the water body?...
3. How strongly you agree or disagree with the statement; industrial waste disposal and pollution are control/monitored? strongly agree [ ] agree [ ] somewhat agree [ ] disagree[ ] strongly disagree [ ]
4. What punishments are meted to offenders? Legal action [ ] fine [ ] polluter pay [ ] other [ ].

MOFA

1. Have there being any introduction of any environrnental and farmers friendly systems of farming along the catchment of the Densu basin? yes [ ] No [ ]
2. If yes name them……………………………………………………………………………
3. How is the rate of adoption of these systems by the farmers? Very strong [ ] strong [ ] not strong [ ]
4. What are the results achieved so far by these systems?...
5. What are the constraints with the regards of the adoption of these programs?

   ……………………………………………………………………………………………

6. What are the impacts of these systems on the farmer with regards to his yield? Increased

Production [ ] decreased in production [ ]

7. What are the effects of these systems on the quality and quantity of the river?

Densu Basin officer

1. What are the key management activities been undertaken with regards to the management of the river by the commission?……………………………………

   ……………………………………………………………………………………………

2. How often the identified activities are undertaken?...
3. What are impacts the commission achieved so far in line with quality and quantity of the river?...
4. What are the major constraints the commission faced with regards to the management of the river?..

   ……………………………………………………………………………………………

APPENDIX II

Calculation of water quality index for the Densu River 2010

Table 1: Calculation of WQI for Weija Reservoir

Parameter	Value	Score	Maximum Score
Dissolved Oxygen (% Saturation)	106	17	18
BOD (mg/l)	5.94	6	15
Ammonia-Nitrogen (mg/l)	0.298	7	12
Ph	7.21	8	9
NO_3-N (mg/l as N)	0.750	7	8
Faecal Coliform(Counts/100 ml)			
PO_4-P (mg/l as P)	0.021	7	8
Suspended Solids (mg/l)	10.6	6	7
Electrical Conductivity(μS/cm)	267	4	6
Temperature (°C)	27.2	5	5
Percentage Total Score (%)		67	88

Solway weighted WQI = $1/88 \times (67)^2 = 51.01$

Table 2: Calculation of WQI for Nsawam

Parameter	Value	Score	Maximum Score
Dissolved Oxygen (% Saturation)	99.5	18	18
BOD (mg/l)	6.26	5	15
Ammonia-Nitrogen (mg/l)	0.572	5	12
Ph	7.10	9	9
NO_3-N (mg/l as N)	1.06	6	8
Faecal Coliform(Counts/100 ml)			
PO_4-P (mg/l as P)	0.125	5	8
Suspended Solids (mg/l)	27.6	4	7
Electrical Conductivity(μS/cm)	338	3	6
Temperature (°C)	27.9	5	5
Percentage Total Score (%)		60	88

Solway weighted WQI = $1/88 \times (60)^2 = 40.9$

Table 3: Calculation of WQI for Koforidua 2010

Parameter	Value	Score	Maximum
Dissolved Oxygen (% Saturation)	97	18	18
BOD (mg/l)	2.34	13	15
Ammonia-Nitrogen (mg/l)	0.116	11	12
Ph	7.26	9	9
NO_3-N (mg/l as N)	3.260	6	8
Faecal Coliform(Counts/100 ml)			
PO_4-P (mg/l as P)	0.028	8	8
Suspended Solids (mg/l)	16.4	6	7
Electrical Conductivity(μS/cm)	171	7	6
Temperature (°C)	23.9	6	5
Percentage Total Score (%)		84	88

Solway weighted WQI = $1/100 \times (84)^2 = 70.56$

APPENDIX III

Annual Chemicals Consumptions at the various Water Treatment Plants (Koforidua, Nsawam and Weija) - 2005-2010

A. Koforidua

Chemical	2005	2006	2007	2008	2009	2010
Aluminum sulphate	115,980	99,970	115,065	135,200	113,885	29,135
Calcium Hypochlorite	16,004	7,908	8,426	11,917	12,200	5,040
Hydrated lime	11,885	8,550	14,302	18,927	12,770	2,950

B. Nsawam

Chemical	2005	2006	2007	2008	2009	2010
Aluminum sulphate	90,225	73,490	91,000	101,500	89,370	99,550
Calcium Hypochlorite	9,557	7,220	7,475	7,903	12,180	10,920
Hydrated lime	17,987	10,805	10,700	12,796	12,100	9,500

C. Weija

Chemical	2007	2008	2009	2010
Aluminum sulphate	6,985,100	7,500,200	7,100,075	6,625,891
Calcium Hypochlorite	18,440	19,200	18,200	82,700
Hydrated lime	155,463	152,395	145,340	199,200