CSIR WATER RESEARCH INSTITUTE (CSIR WRI)

Annual Report 2013

CSIR

WATER RESEARCH INSTITUTE

Annual Report

2013

Compiled by
Benson Kwabena Owusu
Marian A. Jiagge
Thomas K. F. Adom
Sylvis Amponsah

Edited by

Dr. Mike Osei-Atweneboana
Dr. Osmund D. Ansa-Asare
Dr. William A. Agyekum
Dr. K. Kankam-Yeboah
Dr. H. R. Dankwa

ISSN 0855-0794
ISBN 9964-85-285-1

QUALITY RESEARCH

SUSTAINABLE WATER USE FOR DEVELOPMENT

CSIR WATER RESEARCH INSTITUTE

ACCRA, GHANA

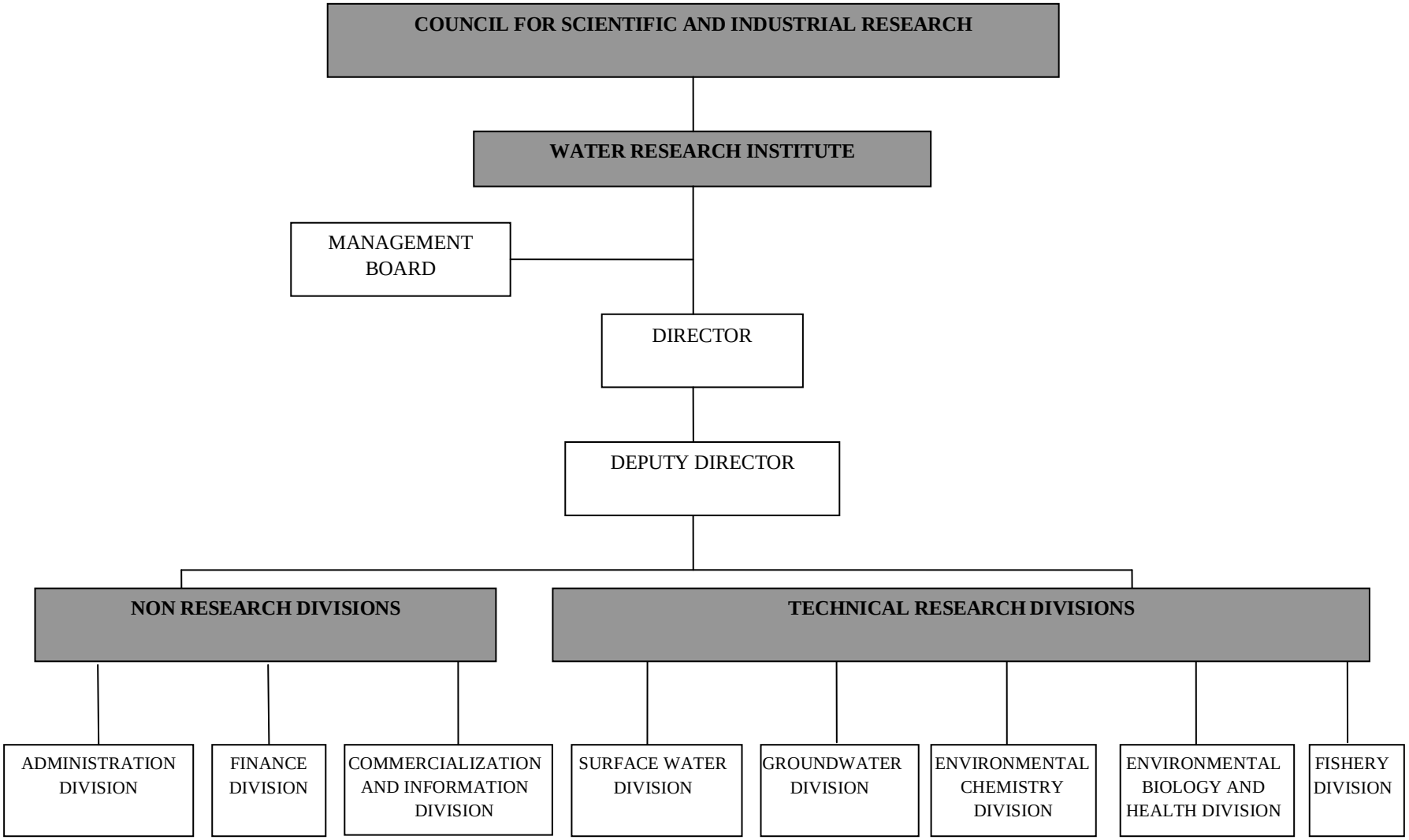
ACRONYMS

ARDEC	-	Aquaculture Research and Development Centre
ANFTS	-	African Network for Fish Technology and Safety
BOD	-	Biochemical Oxygen Demand
CCAA	-	Climate Change Adaptation in Africa
COD	-	Chemical Oxygen Demand
CPWF	-	Challenge Programme on Water and Food
CSIR	-	Council for Scientific and Industrial Research
CWSA	-	Community Water and Sanitation Agency
DFID	-	Department for International Development
DO	-	Dissolved Oxygen
DWL	-	Dynamic Water Level
ECD	-	Environmental Control Dam
EIA	-	Environmental Impact Assessment
EPA	-	Environmental Protection Agency
FC	-	Fisheries Commission
FCR	-	Food Conversion Ratio
FDC	-	Frequency Distribution Curve
FoE	-	Friends of the Earth
GAMA	-	Greater Accra Metropolitan Area
GIS	-	Geographic Information System
GWCL	-	Ghana Water Company Limited
GWSSA	-	Groundwater in Sub-Saharan Africa
GMET	-	Ghana Meteorological Agency
HSD	-	Hydrological Services Department
IAB	-	Institute of Aquatic Biology
IAEA	-	International Atomic Energy Agency
IDRC	-	International Development Research Centre
IGF	-	Internally Generated Funds
ILGS	-	Institute of Local Government Studies
IMC	-	Internal Management Committee
INI	-	Intelligence Nature International
ISSER	-	Institute of Statistical, Social and Economic Research
IWMI	-	International Water Management Institute
IWRM	-	Integrated Water Resources Management
KNUST	-	Kwame Nkrumah University of Science and Technology
NGGL	-	Newmont Ghana Gold Limited
NGO	-	Non-Governmental Organizations
OPCW	-	Organization for the Prohibition of Chemical Weapons
PBBs	-	Polybrominated Biphenyls
PCR	-	Polymerase Chain Reaction
PFC	-	Pioneer Food Cannery
PURC	-	Public Utilities Regulatory Commission
RCM	-	Regional Climate Model
RGU	-	Robert Gordon University
RLWRDS	-	Research Library and Water Resources Documentation System
SP-PAGIRE	-	Secrétariat Permanent au Plan d'Action et de Gestion Intégrée des Ressources en Eau

SSA	-	Sub-Saharan Africa
STMIE	-	Science, Technology and Mathematics Innovations Education
SWAT	-	Soil and Water Assessment Tool
SWL	-	Static Water Level
TDS	-	Total Dissolved Solids
TNA	-	Technology Needs Assessment
TSS	-	Total Suspended Solids
UDS	-	University for Development Studies
WAQUA	-	West African Quaternary Research Association
WATSAN	-	Water and Sanitation
WHO	-	World Health Organisation
WRC	-	Water Resources Commission
WRI	-	Water Research Institute
WRRI	-	Water Resources Research Institute
WSF	-	Water Storage Facility
WSSD	-	World Summit on Sustainable Development
WTP	-	Water Treatment Plant
WVI	-	World Vision International

TABLE OF CONTENTS

Organizational Chart



EXECUTIVE SUMMARY

This report contains an overview of research and commercialization activities undertaken by the Water Research Institute of the Council for Scientific and Industrial Research in 2013. The Water Research Institute (WRI) is one of the 13 institutes of the Council for Scientific and Industrial Research (CSIR). The overall goal of the CSIR WRI is to conduct research into all aspects of water resources (both living and non-living) in order to provide scientific and technical information and services as well as strategies for the sustainable development, utilization and management of such resources for the socio-economic advancement of the country.

The 2013 Annual Report consists of four (4) chapters namely Introduction, Administration, Research and Development Activities and Finance. The report has been compiled based on the research and development activities, commercialization of research and development activities through consultancy and advisory services, and administrative matters such as staff strength, appointments, promotions, national service recruitment, as well as financial and accounting matters during the year 2013.

The Institute undertook a total of 35 research projects during the year. These included: development of genetic markers for early detection and monitoring of ivermectin resistance in *Onchocerca volvulus* and its implication for onchocerciasis control; assessment of water sources used as drinking water in crèches in selected communities in Accra; cancer and non – cancer human health risk assessment from exposure to toxic chemicals in bottom ash and soil samples from e-waste recycling points in Agbogbloshie scrap yard, Ghana; impacts of mining operations on the ecology of River Ankobra in Ghana; hydrogeological consultancy services to delineate zones of high groundwater potential for the drilling of high yielding boreholes to supply sustainable potable water in some selected communities and small towns along the Fufulso-Sawla road in the Northern Region of Ghana; rainwater harvesting (RWH) for resilience to climate change impact on water availability in Ghana (RWH4Ghana); and sustainable management of Lake Bosomtwe in the Ashanti Region of Ghana – hydrology, anthropology and water quality.

A total of 29 technical reports, 11 conference papers, 26 consultancy reports and 40 Journal papers were authored by scientists of the Institute in collaboration with scholars worldwide.

1.0 INTRODUCTION

1.1 Establishment

The Water Research Institute (WRI) is one of the 13 research institutes of the Council for Scientific and Industrial Research (CSIR). It is a public institution established in 1996 by the CSIR Act 521. It was created by the merger of the Institute of Aquatic Biology (IAB) and the Water Resources Research Institute (WRRI), both of the CSIR, which were created in 1965 and 1982, respectively.

1.2 Vision

To become a centre of excellence in the provision of scientific research into water and related resources for sustainable socio-economic growth

1.3 Mission

To conduct research into all aspects of water resources (both living and non-living) in order to provide scientific and technical information and services as well as strategies for the sustainable development, utilization and management of such resources for the socio-economic advancement of the country

1.4 Values

Our core values include dedication to duty, commitment, loyalty to quality assurance and customer satisfaction

1.5 Key Objectives

The key objectives of the Institute are:

- To generate, develop and transfer appropriate technologies, information and services for sustainable development, utilization and management of surface water resources;
- To generate, process and disseminate information on the availability of groundwater, rate and volumes to be abstracted for various uses as well as the reliability and sustainability of its recharge;
- To generate, process and disseminate water and waste water quality information to end users;
- To enhance public health status through sound environmental management and water pollution control strategies;
- To increase local fish production through participatory research and technology transfer in aquaculture and sustainable management strategies in inland and coastal waters of Ghana; and
- To undertake commercialisation of research and development activities through consultancy and advisory services and the provision of water resources information, documentation and technical support services.

1.6 Divisions

The mandate of the Institute is realized through the research and development activities of five (5) Technical Divisions and three (3) Non-technical Divisions. The Technical Divisions are:

- Environmental Biology and Health
- Environmental Chemistry
- Fishery

- Groundwater
- Surface Water

The Non-technical Divisions are:

- Administration
- Commercialization and Information
- Finance

1.7 Branches

- Main office in Accra
- Branch office at Tamale in the Northern Region
- Aquaculture Research and Development Centre (ARDEC) at Akosombo in the Eastern Region (Figure 1)

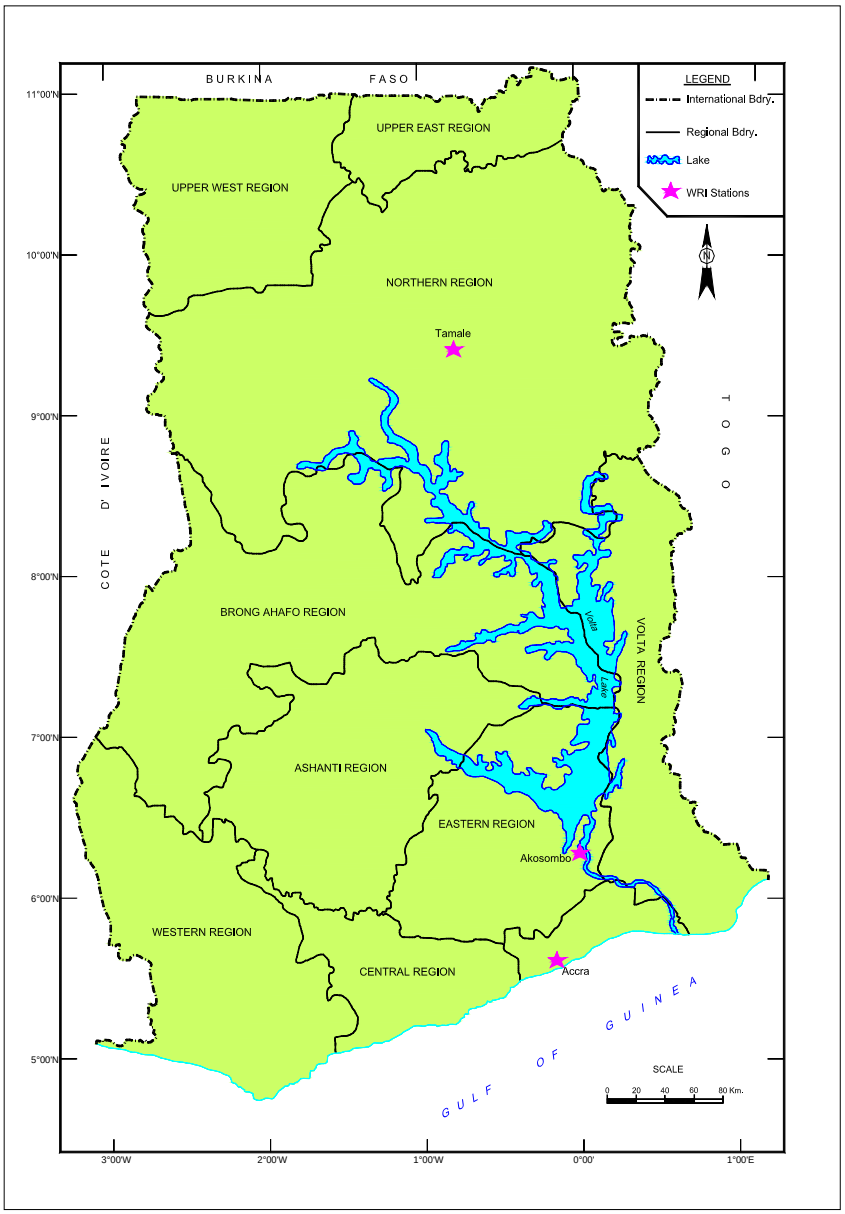


Figure 1: Location map showing branches of CSIR Water Research Institute

An overview of the major activities of the Institute during the year 2013 is herein presented. We shall be grateful to receive any comments and suggestions you may wish to make on any aspects of our activities or report. Kindly send them to the following address:

The Director,
CSIR Water Research Institute,
P. O. Box AH 38,
Achimota-Ghana

or

The Director,
CSIR Water Research Institute,
P. O. Box M 32,
Accra-Ghana

Telephone : ***(233-302) 775352, 779514, 779515***
Fax : ***(233-302) 777170, 761031***
E-mail : ***info@csir-water.com; wricidss@yahoo.com***
Website : ***www.csir-water.com***

2.0 ADMINISTRATION

The Administration provided services and support to staff, the divisions and outstations of the Institute to ensure effective and efficient work environment for the achievement of the objectives of the Institute. Eleven (11) applicants were interviewed for permanent appointments.

2.1 Management

There was no Management Board in place during the 2013 calendar year to see to the affairs of the Institute. However, policies, regulations and rules of the Council were implemented and decisions taken at Internal Management Committee (IMC) meetings. Members of the IMC are shown in Appendix I.

2.2 Staff Strength

Staff strength at the end of the year 2013 stood at 249. This was made up of 57 Senior Members, 94 Senior Staff and 98 Junior Staff. Staff distribution and the list of Senior Members and Senior Staff are presented in Appendix II.

2.3 Statistics on Human Resource Activities

The number of appointments, promotions/upgrading, resignations and retirements in 2013 is shown in Appendix III.

2.4 Human Resources Development

To enable staff acquire the necessary skills and knowledge for the enhancement of their performance in the Institute, and in conformity with the policy of CSIR to provide training opportunities for its staff, as at the end of 2013, ten (10) members of staff were offered variety of training and development opportunities at various levels both locally and abroad. Three (3) other members of staff who successfully completed their respective programmes during the year returned to post. The details are given in Appendix IV.

Short-term training programmes attended by some staff of the Institute were:

- National Disaster Management Course for Ghana, Accra, 28 January – 1 February 2013
- Sub- regional training course for customs authorities of state parties in North, West and Central Africa on technical aspect of transfer regime of the Chemical Weapon Convention, Organization for the Prohibition of Chemical Weapons (OPCW), Accra, 8 – 11 October 2013
- A short course on leadership and management, Quantum Shift Coaching Solutions, Accra, 9 – 11 December 2013
- Training on environmental management for sustainable cage aquaculture development, Accra, 26 February – 1 March 2013
- Training on TAGMI tool for agriculture water management, CGIAR Challenge Program, Tamale, 15 – 16 August 2013
- Short course on water harvesting and small scale irrigation, Australia Africa Awards Program, Australia, 9 October – 18 November 2013
- Short course on water harvesting and small scale irrigation, 9 October – 18 November 2013

2.5 Participation in Scientific Meetings

Some research and technical staff participated in a number of workshops, seminars and conferences held at the national, regional and international levels during the year. Among them were:

- 28th Biennial Conference of the Ghana Science Association, Accra, 14 – 19 July 2013
- Workshop on article XI of the Chemical Weapons Convention for member states of the African region, Nairobi, Kenya, 19 – 21 November 2013
- Workshop on science, technology and innovation information delivery towards sustainable development: The role of the CSIR-Ghana, Accra, 5 – 7 November 2013
- GIS and spatial workshop, Accra, 26 February – 1 March 2013
- Workshop on water management: decision making, environmental aspect and risk assessment, Jerusalem, 7 – 31 October 2013
- Research ethics conference in Ghana, Accra, 27 – 28 November 2013
- E-waste Academy- Scientists Edition (EWAS) meeting, Geneva, Switzerland, 1 – 10 December 2013
- National Agri-Food roundtable discussion on sustainable consumption and production, Accra, 20 August 2013
- E-waste and children's health, Geneva, Switzerland, 11 – 12 June 2013
- Water quality monitoring in West, Central and North Africa region: Challenges and opportunities, Accra, 12 – 14 March 2013
- Refresher workshop on water quality testing, Winneba, 26 – 27 March 2013
- Workshop on proposal writing, scientific writing, project management and intellectual property, Accra, 14 – 18 October 2013
- Workshop on White Volta flood hazard assessment and forecasting, Accra, 24 July 2013
- Validation workshop on risk analysis relating to imported strains of tilapia into West Africa, Accra, 29 – 30 July 2013
- 6th Africa agriculture science week and forum for agricultural research in Africa (FARA) general assembly, Accra, 15 – 20 July 2013
- Workshop on the establishment of national dam safety unit (NDSLD), Agona Swedru, 10 – 11 December 2013
- Workshop on climate change adaptation in agriculture, Accra, 5 – 6 November 2013
- Workshop on strengthening climate mitigation and adaptation in the Sahel and West Africa, Accra, 18 – 20 September 2013
- Workshop on groundwater futures in Sub-Saharan Africa–GROFUTURES, Morogoro, Tanzania, 9 – 13 September 2013
- Regional workshop on innovation and climate change in africa: advancing knowledge, technology, policy and practices, Nairobi, Kenya, 24 – 26 June 2013
- Pre-validation workshop on Ghana climate change policy framework, Accra, 16 October 2013
- Training workshop on experimental design and analysis for young female research scientists, Accra, 2 – 13 June 2013
- Workshop on SINTEF rainwater harvesting (RWH) for resilience to climate change impact on water availability in Ghana, Accra, 20 – 27 February 2013
- Monitoring meeting on ICT tools for the enhancement of irrigation efficiency in West Africa, Accra, 23 – 24 September 2013
- UNEP GEMS/Water regional workshop on water quality, Accra, 12 – 14 March 2013

2.6 Membership of Committees and Boards

Staff served on various committees and boards such as:

- CSIR WRI Editorial Committee
- CSIR-WRI Estate Committee
- CSIR-WRI Internal Management committee
- CSIR-WRI Procurement/Tender Committee
- CSIR-WRI Seminar Workshop Committee
- Editorial Committee for the Journal of the Ghana Institution of Engineers (GhIE)
- Ghana Atlas Team
- Ghana Chemical Society
- Ghana Coordinating Committee (GCC) of the Ghana Dams Dialogue and Development in Ghana
- Ghana Institution of Engineers (GhIE) Committee on Publications
- Ghana Institution of Engineers (GhIE) Committee on Research and Awards
- Ghana Institution of Engineers (GhIE) Subcommittee on Education and Training
- Ghana Science Association
- National Dam Safety Unit (Technical Committee on Dams)
- Research Staff Association
- Resources Centre Network (RCN) Ghana for WASH/Water resources issues through networking
- SAGA-EO Network Ghana Team
- Steering Committee of Ghana Forum For Agricultural Advisory Services (GFAASS)
- Technical Review Committee, CSIR WRI
- World Water Day National Committee

2.7 Long Service Recognition

The 2013 long service awards and end of year party took place on Friday 21st December 2013. Some staff were honoured for their contributions to the Institute (Table 1).

Table 1: Long service recognition in 2013

Name(s)	Years Served
Mrs. Wilhelmina Tetteh	40 Years
Dr. Philip Gyau-Boakye	34 Years
Dr. Alex A. Opoku Mr. James Owusu	33 Years
Mr. Johnson C. K. Eworde	32 Years
Nana Yaw Biritwum Mr. Musah Alhassan Mr. Peter Amina	23 Years
Mr. Mohammed A. Haruna	19 Years
Mr. Maleky Alhassan Mr. Ayaba Mohammed	15 Years
Mr. Samuel Asiedu	12 Years

2.8 National Service and Industrial Attachment

The Institute supported tertiary institutions towards training of students as part of its corporate social responsibility and national capacity building activities. The duration of the training programmes was between four (4) and twelve (12) weeks. The details are presented in Appendix V.

2.9 Staff Publications

Several technical and non-technical reports, conference and journal papers were produced by staff during the reporting year. Most of these reports/papers have been shelved at the Institute's library as reference materials. The details are given in Appendix VI.

3.0 RESEARCH AND DEVELOPMENT ACTIVITIES

3.1 ENVIRONMENTAL BIOLOGY AND HEALTH DIVISION

The main objective of the Environmental Biology and Health Division is to enhance public health status of the Ghanaian people through sound environmental management, water pollution control strategies, preventive and control strategies for water borne and other infectious diseases. The Division has expertise in the areas of microbiology, parasitology, entomology, aquatic flora and fauna, molecular biology and public health.

Activities of the Division include:

- Water quality monitoring through microbial, algal and macro-invertebrate analyses;
- Microbiological analyses of drinking water, waste water and other samples;
- Identification and management of invasive plants in Ghana;
- Isolation and production of entomopathogenic bacteria used in biological control of disease vectors;
- Environmental impact assessment and watershed management;
- Research into water-related/borne parasitic diseases and other infectious diseases;
- Research into water-related vectors of diseases of public health importance to develop innovative strategies for control and prevention;
- Molecular epidemiology studies and understanding the mechanism and genetics of drug resistance and the development of DNA based diagnostic tools;
- Consultancy in the establishment of science and medical laboratories; and
- Training of scientists, technologists and students.

3.1.1 Baseline Studies of Macro-Invertebrates of Some Rivers of Northern Ghana – Sustainable Land and Water Management Project (SLWMP)

(Project Staff: Dr. E. D. O. Ansa – Research Scientist and Mr. G. B. Amegbe)

This study was conducted in collaboration with Environmental Protection Agency, Accra. The objective was to establish baseline data on the distribution of macro-invertebrates of some selected rivers and streams in Northern Ghana.

In the year under review, sampling and habitat assessment were conducted. Macro-invertebrate fauna existing in some rivers and streams of the Upper East, Upper West and Northern regions were catalogued. Selected sites of the study area were sampled with a hand net over a defined area for a period. Samples from each selected site were preserved in formalin for further processing in the laboratory. Individual macro-invertebrates were identified up to the genus or species level with the aid of available taxonomic keys under the microscope and water quality values assigned to sensitive species. Rivers and streams in the study area were classified as clean, slightly polluted and polluted based on available literature on identified taxonomic species from the study area. Physical and biological factors prevailing in and around streams or rivers were used to describe the habitat of the water bodies as being optimal, sub-optimal, marginal or poor.

It was concluded from the study that all the rivers and dam sampled were clean based on sensitive taxa such as *Laccophilus sp. C95, Potamodytes sp. C118, Pseudagrion sp O.22, Gomphidae sp. O.24, Coenagriidae sp. O.11, Centroptilum sp. E31, Centroptilum sp. E34,*

Paragomphus sp. O.1, and Zygonyx torrida sp. O.27 observed at the study sites. Some species were absent during the dry season but present in the rainy season and vice versa due to seasonal variations in the relative abundance of these species. The number of species present at the study area is presented in Table 2.

Table 2: Number of species present at the study area

Region	River/Stream	Total number of species present	Number of sensitive species present
Upper West	Kongua at Kpaglaghe	12	3
	Kontobou at Konta	21	3
	Yaro dam	15	3
	Nakong at Navrawie	11	1
	Sissili at Sissili	26	3
	Nyiweli at Duwie	6	3
Upper East	Sissili at Doninga	8	3
	Sissili at Kaworo	13	1
	Sissili at Banu	20	4
	Namog at Namongu	10	3
	Yinduri at Yinduri	24	5
Northern	Nasia at Nasia	4	2
	Gbani stream at Gbani	18	3
	Takorayili	24	4
	Kparigu at Kparigu	26	5
	Boamasa	15	3
	Boakodoo	15	4

3.1.2 Development of Genetic Markers for Early Detection and Monitoring of Ivermectin Resistance in *Onchocerca volvulus* and its Implication for Onchocerciasis Control

(Project Staff: Dr. Mike Yaw Osei-Atweneboana – Senior Research Scientist, Mr. Samuel Armoo – Research Scientist, Mr. Edward Jenner Tettevi – Principal Technical Officer and Mr. Ernest Tawiah Gyan – Principal Technical Officer)

Onchocerciasis is a disease caused by the filarial nematode *Onchocerca volvulus* and transmitted by the black fly. The control and elimination programmes worldwide are largely dependent on the sustained efficacy of ivermectin (IVM) which remains the only drug available for the control of the disease. However, recent reports on sub-optimal responses to IVM treatment and evidence of genetic selection in *Onchocerca volvulus* has raised concerns about the possible emergence of IVM resistance. This has necessitated the need for the development of genetic marker for early detection and monitoring of IVM resistance. Therefore, in collaboration with Liverpool School of Tropical Medicine, United Kingdom and Noguchi Memorial Institute for Medical Research, Ghana, the study was initiated in 2010 and is expected to end in 2014. The main objective was to assess the parasitological response profile of *O. volvulus* in endemic communities, determine the correlation between worm phenotypes and genetic changes and develop genetic markers for early detection of IVM resistance and monitoring of resistance to prevent spread. The specific objectives were to assess the parasitological response profile of *O. volvulus* to semi-annual IVM treatment and determine specific genetic changes, including single nucleotide polymorphisms (SNPs) in Beta-tubulin and HG1 genes that are associated with worm phenotypes showing poor IVM response.

In the year under review, a cross-sectional study was conducted in 22 onchocerciasis endemic communities to assess the parasitological response profile of *O. volvulus* to IVM treatment in six districts in Ghana. A total of 2,105 subjects enrolled in the study had received between 10

and 23 years of annual ivermectin (IVM) treatment. All subjects were assessed for parasite burden before receiving IVM treatment and those found to be microfilariae (mf) positive were selected for the follow-up study. Based on the inclusion criteria, 324 subjects from 15 selected communities were followed-up in a fifteen month longitudinal study involving skin mf assessment at days 180, 270, 362 and semi-annual IVM treatments. Nodulectomies were then carried out at day 90 after the third study IVM treatment. Embryogramme analysis was carried out on 419 female worms and their reproductive status assessed to characterize the response profile of *O. volvulus* to IVM treatment. DNA was extracted from 312 individual worms and genetic analyses were conducted to identify single nucleotide polymorphism (SNPs) in β-tubulin genes associated with poor IVM response phenotype worms.

The epidemiological study showed that out of 2,106 subjects examined, 18.4 % (388) were microfilaridermic, 23.4 % (493) were positive for onchocercal nodules while 33.7 % (709) were microfilarial positive and/or nodule positive. Over 80 % of the study communities had community microfilarial load (CMFL) ≤ 1.0 mf/s while three communities: Agbelekeme-I, Takumdo and Dalado, had CMFL > 1 mf/s as shown in Table 3.

Table 3: Community microfilaria load (CMFL), nodule and microfilaria prevalence rates of *O. volvulus* before IVM treatment in 22 onchocerciasis endemic communities

Districts	Communities	No of subjects enrolled	Microfilarial prevalence	CMFL	Mf and/or nodule prevalence	Nodule prevalence
	Ohiampe	85	5.9	0.09	28.2	25.9
	Senyase	70	11.4	0.11	30	22.9
	Asubende	34	26.5	0.21	44.1	34
	Baaya	129	1.5	0.01	13.2	12.4
	Abua 1	65	7.7	0.12	20	12.3
	Abua II	73	9.6	0.08	23.3	15.1
	Tingamgam	87	16.1	0.16	31	19.5
Pru	Fawomang	100	8	0.83	19	12
	Agbelekeme-II	56	21.4	0.4	44.6	35.7
	Nyire	94	31.9	0.14	55.3	36.2
	Foawoman-Banda	91	11	0.15	28.6	19.8
Tain	Tainso	67	22.1	0.54	33.8	16.4
	New Longoro	162	10.5	0.2	19.8	13.4
Kintampo	Kyingakrom	82	20.7	0.51	34.1	25.6
Bole	Agbelekeme-I	63	44.4	1.1	65.1	42.9
	Jagbenbendo	107	39.3	0.97	61.7	41.1
	Takumdo	108	46.3	1.6	60.2	37
	Wiae	164	15.9	0.36	40.5	24.4
	Chabon	94	31.9	0.58	55.3	36.2
	Kojobone	218	8.7	0.16	19.3	12.4
Kpandae	Dalado	66	39.4	1.28	50	33.3
Krachi	Magyimagyi	91	8.8	0.15	22	17.6

Analysis of mf densities at pre-treatment amongs the 15 communities showed significant differences ($p < 0.02$) in geometric mean mf densities (mf/s) ranging from 0.06 mf/s to 6.57 mf/s. Ten out of the 15 communities had relatively higher geometric mean mf density of more than 2 mf/s, with the highest mf density of 6.57 mf/s occurring at Takumdo in the Kpandae District. Analyses of parasitological response profiles of *O. volvulus* at days 180, 270 and 362 after the first study IVM treatment showed that populations of *O. volvulus* were responding differently to the drug. Microfilaria assessment at day 180 after the first study IVM treatment (here called first day 180) showed significantly higher ($p<0.005$) skin mf

repopulations and mf recovery rates ranging from 39.5 % to 77.7 % of the pre-treatment mf densities. Takumdo community recorded the highest mean mf densities of 3.76 mf/s, showing mf recovery rate of 57.2 % while Baaya recorded the lowest mean mf density of 0.03 mf/s with mf recovery rate of 50 %. The highest skin mf recovery rates of 77.7 % and 66.4 % were recorded at Kyingakrom and Agblorkeme no.1, respectively. The fast skin mf recovery observed at day 180 post-treatment in some of the study communities might be as a result of the adult female worms resuming mf production much earlier than expected. This comfirms earlier reports that there were some populations of *O. volvulus* in some communities responding sub-optimally to IVM treatment. Skin mf assessment at day 270 after the first study IVM treatment (i.e. day 90 after the second study IVM treatment) showed no skin mf repopulation in six communities while seven other communities had low levels of skin mf repopulation rates of 1.1 % to 5.9 %. However, two communities: New Longoro and Kyingakrom, recorded a significantly higher ($p<0.02$) skin mf repopulation rates of 12.2 % and 18.5 %, respectively. This early skin mf repopulation at day 90 after IVM treatment makes mf available for vector transmission, resulting into sustained transmission throughout the year. Further skin mf assessment at day 362 after the first study IVM treatment (i.e. day 180 after the second study IVM treatment here called "second day-180") showed low to high skin mf recovery rates ranging from 10.1 % to 97.3 % of the pre-treatment count. It was noted that at the second day-180 mf asseement, the geometric mean mf densities in 12 communities had reduced significantly ($p< 0.001$) to between 10.1 % and 38 %, except for three communities: Kyingakrom, New Longoro and Asubende which had mf recovery rates of 54.1 - 97.3 % of the previous six month mf densities (Table 4).

A comparism of skin mf recovery rates at first day-180 and second day-180 was conducted to evaluate the possible contribution of semi-annual IVM treatment to the goal of onchocerciasis elimination in Ghana. At first day-180 mf assessment, 12 out of 15 communities showed moderately high mf recovery rate of 39.5 - 66.4 % of pre-treatment mf densities. However, the second day-180 mf assessment showed a much lower mf recovery rate of 10 - 38 % in the same 12 communities. This demonstrated that the semi-annual IVM treatment strategy showed a significant reduction in skin mf recovery rates over the past one year when compared with annual IVM treatment (Osei-Atweneboana *et al*. 2011). However, three other communities: Kyingakrom, New-Longoro and Asubende, showed significantly higher skin mf recovery rate between 51 % and 97.3 % at both first day-180 and second day-180 mf assessment (Table 4).

Comparing this current semi-annual IVM treatment study with a previous study on annual IVM treatment (Osei-Atweneboana *et al*. 2011) revealed that the semi-annual IVM treatment strategy had a significant impact on prevalence and intensity of the infection, suggesting that the semi-annual IVM treatment strategy could possibly drive onchocerciasis towards elimination in Ghana. However for areas where sub-optimal response had been documented, the impact of semi-annual treatment was not as great as expected. Therefore to faciliate the process of onchocerciais elimination in Ghana will require that the individuals showing high levels of mf repopulation and recovery rates must be monitored and where necessary complementary strategy like doxycycline treatment should be adopted.

Embryogramme analysis revealed the reproductive status of female worms used to assess IVM response profile of female worms (Figure 2). Out of 419 female worms analysed 63.9 % were actively producing various embryonic stages and stretch mf. About 37 % of total female worms had almost all (i.e > 95 %) intra-uterine stretch mf degenerated, indicating that these worms were responding well (good responders) to IVM treatment. On the other hand, it was

found that only about 4 % of the worms had almost all (> 95 %) normal intra-uterine stretch mf (ie intra-uterine stretch mf alive at the time of nodulectomies), indicating that these worms were responding sub-optimally to IVM treatment. Also about 36 % of the adult female worms had empty uteri or contained only oocytes at the time of nodulectomy, suggesting possible normal response. The high proportion of non-producing female worms was not observed in the previous embryogramme analysis for annual IVM treatments (Awadzi *et al.* 2004; Osei-Atweneboana *et al*. 2011) and could be attributed to the semi-annual IVM treatment. Thus, about 73 % of the female worms were showing good response to IVM.

Table 4: Geometric mean mf density of *O. volvulus* at pre-treatment, days 180, 270 and 362 after the first study IVM treatment and mf repopulation/mf recovery rates in 15 onchocerciasis-endemic communities

Districts	Communities	No. of subjects follow-up	No. of subject used for the analysis	Geometric mean mf density (mf/s) at Pre-treatment	Geometric mean mf density (mf/s) at day 180 (mf recovery rate)	Geometric mean mf density (mf/s) at day 270 (mf recovery rate)	Geometric mean mf density (mf/s) at day 362 (mf recovery rate)
	Ohiampe	24	6	1.25	0.7 (56%)*	0	0.22 (31.4%)*
	Seyase	20	8	1.08	0.5 (46.3%) *	0	0.19 (38%)*
	Asubende	15	11	1.37	0.74 (54%)*	0	0.72 (97.3%)
Pru	Baaya	17	17	0.06	0.03 (50%)*	0	0.01 (33.3%)*
	Agbelekeme-II	25	14	2.83	1.64 (57.9%)*	0.05 (3%)	0.2 (12.2%)*
	Nyire	31	15	1.42	0.67 (47.2%) *	0.04 (5.9%)	0.22 (32.8%)*
Tain	Foawoman-B	27	11	2.71	1.09 (40.2%)*	0	0.11 (10.1%)*
Kintampo	New Longoro	32	19	2.03	1.07 (52.7%)*	0.13 (12.2%)	0.55 (51.4.5%)
	Kyingakrom	28	17	2.78	2.16 (77.7%)	0.4 (18.5%)	1.62 (75.%)
Bole	Agbelekeme-I	41	29	3.9	2.59 (66.4%)*	0.09 (3.5%)	0.61 (23.6%)*
	Jagbenbendo	67	48	3.61	1.88 (52.1%) *	0.02 (1.1%)	0.39 (20.7%)*
	Takumdo	65	51	6.57	3.76 (57.2%) *	0.18 (4.8%)	0.72 (19.2.%)*
	Wiae	52	27	5.02	2.29 (45.6%) *	0	0.24 (10.5%)**
	Chabon	52	32	3.0	1.49 (49.7%) *	0.08 (5.5%)	0.36 (24.2%)*
Kpandae	Kojobone	42	19	4.43	1.75 (39.5%)*	0.04 (2.3%)	0.37 (21.2%) *

* Significant difference ($p < 0.04$) in mf recovery rates between pre-treatment and post-IVM

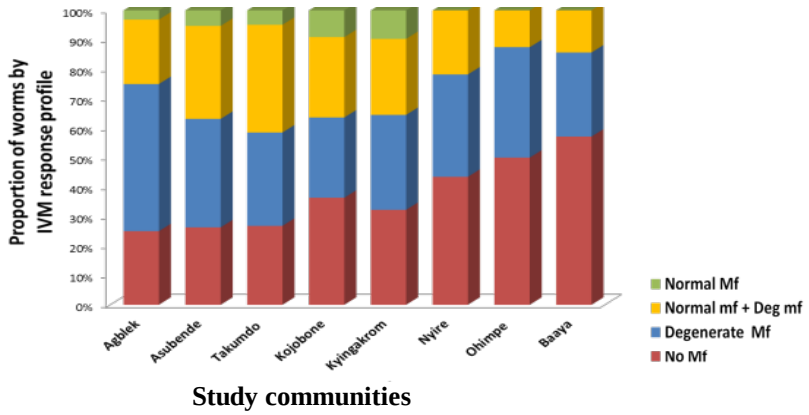


Figure 2: Reproductive status of adult female worms showing proportions of live (normal) or dead (degenerate) intra-uterine mf at the time of nodulectomy to assess phenotypic response profile of adult females

The genetic analysis carried out on 312 worms from 10 communities indicated that 5 % were genotypically poor responders. DNA sequence analysis of 720bp of β-tubulin gene showed

significant SNPs at four positions: 1183 T/G, 1188 T/C, 1308 C/T and 1545 A/G (Figure 3) About 80 % of the female worms characterized as poor responder had the genotype configuration GG/CC/TT/GG occurring at four SNP sites. This genotype was found to be strongly associated with poor IVM response phenotype worms ($p < 0.01$). These four SNPs form a single PCR amplicon of 362 bp, and have been selected as potential genetic marker for beta-tubulin gene. These SNPs will be validated using *O. volvulus* larvae from black flies and mfs from skin snip. In addition, three other SNPs occurring at three consecutive nucleotides positions at 1268 T/A, 1269 A/T and 1270 T/A have been identified. These three SNPs showed much stronger association ($p < 0.001$) with poor response phenotype. Using SNPs identified in β-tubulin genes, the best markers showing the highest consistent pattern of SNP-selection associated with poor IVM response phenotype worms would be used to develop a small panel of markers as a diagnostic tool for early detection and monitoring of IVM resistance.

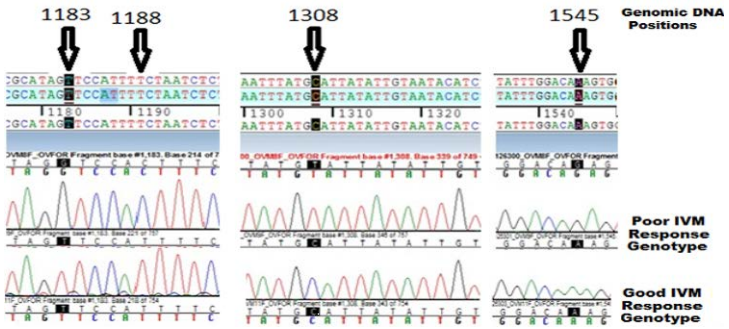


Figure 3: Chromatogram of DNA sequence of Beta-tubulin gene in *O. volvulus* showing SNPs associated with Good and Poor IVM response phenotype worms. SNPs occurred at positions 1183 (T/G), 1188 (T/C), 1308 (C/T), 1545 (A/G) indicated by arrows.

3.1.3 Characterisation of Industrial Wastewater for Ecotechnology Optimization

(Project Staff: E. D. O. Ansa – Research Scientist, M. A. Acheampong, J. H. Adiyiah, F. K. Nkrumah)

The study was carried out in collaboration with the Environmental Protection Agency, Ghana, UNESCO-IHE Institute for Water Education, Accra, and Department of Chemical Engineering, Kumasi Polytechnic, Kumasi. The objective was to characterize the wastewater from major industries in Ghana with the aim to develop appropriate technologies for the removal of key pollutants.

During the reporting period, wastewater samples were collected daily from the tailings dam and analysed for heavy metals and nutrients. Analysis of the constituents of the wastewater depicted high levels of iron which cannot be removed via use of waste stabilization ponds or constructed wetland treatment systems, unlike the other parameters such as suspended solids, COD (chemical oxygen demand), etc. (Table 5). Subsequent experiments would explore the use of biosorbents for the removal of iron from wastewater.

Table 5: Analysis of industrial wastewater

PARAMETERS	RANGE	MEAN(±SD)	GH EPA standards
Temperature (˚C)	26.0-28.5	26.7(± 1.46)	40.0
DO (mg ·l^{-1})	0.9-7.1	2.9(± 0.75)	5.0
pH	8.1-8.3	-	6.0-9.0
EC (µS·cm^{-1})	2,160-2,650	2,334(± 125)	750
TSS (mg ·l^{-1})	41-96	71(± 12)	1,000
Fe (mg ·l^{-1})	22.6-29.2	25.2(± 3.0)	2.0
SO_4^{2-} (mg ·l^{-1})	320-560	450(± 30.0)	250
NH_4^+ (mg ·l^{-1})	60.0-88	74(± 9.5)	1.5
NO_3^- (mg ·l^{-1})	1.5-3.6	2.6(± 0.5)	11.5
PO_4^{3-} (mg ·l^{-1})	2.1-7.8	4.8(± 1.5)	2.0
COD (mg ·l^{-1})	92-150	130(± 8.5)	250

3.1.4 Ecological Study of the Water Storage Facility (WSF) and its Impacts on the Awonsu Stream and the Tano River

(Project Staff: Mr. Mark O. Akrong – Research Scientist, Mrs. Regina Banu – Research Scientist, Mr. Mohammed Bello – Technical Officer, Mrs. Wilhelmina Tetteh – Technical Officer and Ms. Hawa Ahmed – Technical Officer)

The study was undertaken to assess the ecological status of the Water Storage Facility (WSF) of Newmont Ghana Gold Limited at Ahafoano and to determine how release from the facility may impact the ecology of the Awonsu stream and the Tano river. The specific objective was to assess the microbiological water quality of the WSF, Environmental Control Dam 2 (ECD 2), streams of Amoma, Ntrotro, Asuapre, Tano, Subri, Awonsu, Awonsu Pristine and Subika.

Activities carried out included water samples collection from selected sampling points of the various water bodies, laboratory analysis of the water samples, data analysis and report writing. The water samples were collected during the major dry and wet seasons, and the minor dry and wet seasons over a period of one (1) year.

The results clearly showed that the total coliform levels recorded in the WSF during the study period were lower than in ECD 2 and the other surrounding water bodies. This indicated that the effect of releases or spilling from the WSF on the ECD 2 and the other water bodies was minimal. Comparatively, the study showed that lower faecal coliform levels were recorded in the WSF than in all the other sampling points during the study period (Figure 4). With the exception of faecal coliform counts recorded in the WSF in the minor dry (1 cfu/100ml), major dry (9 cfu/100ml) and minor wet season (9 cfu/100ml), all the sampling points including the WSF during the major wet season had bacteria counts above the EPA recommended limit of 10 cfu/100ml. The high faecal coliform counts could be as a result of runoff carring faecal matter from catchments areas especially during the major wet season. Generally, the *E. coli* counts recorded in the WSF and WSF discharge during the study period was below the EPA recommended limit for discharge of wastewater (10 cfu/100ml) (Figure 4) and the minimum *Enterococcus sp.* counts recorded throughout the study was recorded in the WSF. Helminth (*Ascaris lubricoides*) eggs were common in the Awonsu stream and WSF. However, no helminth egg was found in samples from ECD 2, WSF Discharge, Amoma, Ntrotro, Asuapre, Tano, Subri, Awonsu Pristine and Subika. The helminth egg counts recorded were mostly below the WHO recommended level of <1 helminth egg/liter. This therefore implied that Helminth egg contamination was not of much concern at the time of the study. It was therefore concluded from the study that potential impacts of water releases from the WSF and ECD 2 on the receiving water bodies may be minimal, if any.

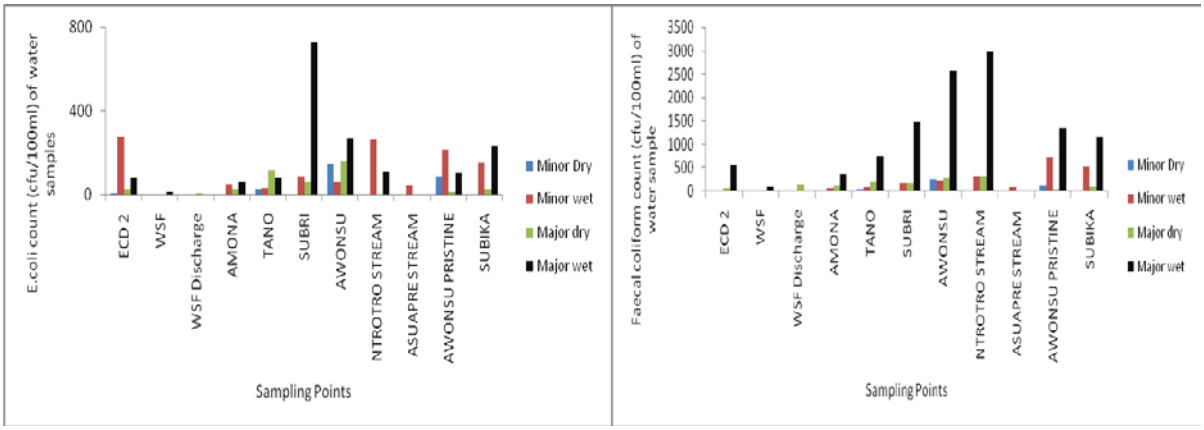


Figure 4: Seasonal *E. coli* and feacal coliform count during the study period in the various water bodies at the Ahafoano mines

3.1.5 Investigations into Periodic Fish Kills in the Environmental Control Dams of the Newmont Ghana Gold Limited at Ahafoano

(Project Staff: Mr. Mark O. Akrong – Research Scientist, Mrs. Regina Banu – Research Scientist, Mr. Mohammed Bello, Mrs. Wilhelmina Tetteh, Ms. Hawa Ahmed and Mr. Borbor Selorm)

This study was conducted to investigate into the periodic fish kills in the Environmental Control Dams (ECDs) of Newmont Ghana Gold Limited at Ahafoano. The specific objective was to assess the bacteriological quality of fish in the ECDs. Activities carried out included collection of fish samples from the different ECDs (2, 3, 4 and 6) within a period of one (1) year for bacteriological laboratory analysis, data analysis and report writing.

The results from the analysis generally showed higher total coliform counts in the skin, gills and intestines of fishes in the ECDs. The coliform counts recorded ranged from 0 – 74400 cfu cm^{-2}. High coliform counts of 74400 cfu cm^{-2} and 37200 cfu cm^{-2} were recorded in the intestine and on the skin of tilapia fish sampled from ECD 2 during the major wet season sampling period. These values were above the 10000 cfu cm^{-2} recommended levels for raw fish consumption of the Ghana Standard Authority (GSA) and International Commission on Microbiological Specifications for Food (ICMSF). All other samples from ECDs 3, 4 and 6 had faecal coliform counts below the recommended limit, ranging from 0 – 4900 cfu cm^{-2} with a mean bacteria count of 519 cfu cm^{-2}. The *Pseudomonas sp* counts ranged from 4 – 18600 cfu cm^{-2} while *Vibrio sp* counts ranged from 0 – 11200 cfu cm^{-2} on the skin, gills and intestine of fishes sampled. It was recommended from the study that fishes from the selected sites be adequately cooked before consumption.

3.1.6 Assessment of Water Sources Used as Drinking Water in Crèches in Selected Communities in Accra

(Project Staff: Mrs. Regina Ama Banu – Research Scientist, Dr. Joseph A. Ampofo – Principal Research Scientist, Mr. Mark Akrong – Research Scientist, Mr. Mohammed Bello, Ms. Lady Boamah Adomako, Ms. Hawa Ahmed)

Most parents now patronize the services of crèches till they return late in the day for their children. Affected children mostly carry packed water from home in water bottles. Poor handling of these water bottles before school by parents and while in school by children could introduce contamination into the water, the cause of most bacterial infections resulting in gastro intestinal diseases such as diahorria, pneumonia, cholera, typhoid fever, etc. among children. This nonetheless, could contribute significantly to the escalating levels of infant mortality in Sub-Saharan Africa. The study therefore seeked to survey the microbial load of

water used by children in crèches to help meet the millennium development goal 'to reduce by two thirds, between 1990 and 2015, the under-five mortality rate'. The specific objective was to investigate the total microbial load of water in water bottles and swab samples from bottles of pupil in crèches - target group children under age 5.

The scope of work included questionnaire administration to parents of pupils and water sampling from crèch pupils water bottles at the start of school day and immediately at the end of school day (Figure 5). Swap samples from the inner covers of the selected water bottles and samples of water supplied by the school to the pupil when child does not bring water were also considered in the study. These samples were bacteriologically analysed and results compiled. In all, four crèch schools in a middle income area were considered.

Out of 83 parents reached through questionnaire, 67.5 % claimed they sanitized their wards water bottles daily and 78 % preferred to bring water from the home for purposes of hygiene. About 56 % of parents sampled washed their wards water bottles daily. However, results of bacteriological analysis revealed that out of the 40 samples analysed (20 morning samples and 20 evening samples), only 5 out of the 20 morning samples collected at the start of school day and just one sample out of 20 evening samples collected at the close of school day were potable and conformed to the GS 175-1(2013) and WHO guidelines of zero total coliform counts per 100ml. Their total heterothrophic bacteria counts were also below the 500 limit. Therefore, only one sample out of the lot remained potable from the start of school day till close of school day. Average cumulative total bacteria load encountered for both morning and afternoon samples in log cycles (Figure 6) showed that levels of total coliform encountered were more than 3.5 per 100 ml of water tested, *E. coli* was between 0.5 and 1.0 per 100 ml of water tested, *Pseudomonas aeruginosa* was above 4.5 per 100 ml of water tested and total heterotrophic bacteria was above 3.5 per 1 ml of water tested.

It was concluded from the study that though most pupil brought their own water from home, the quality of water was not good. It was therefore recommended that schools should provide water to pupils instead of parents. Also, quality checks must be periodically performed on such water.

Figure 5: Collection of water samples from water bottles of crèch pupils

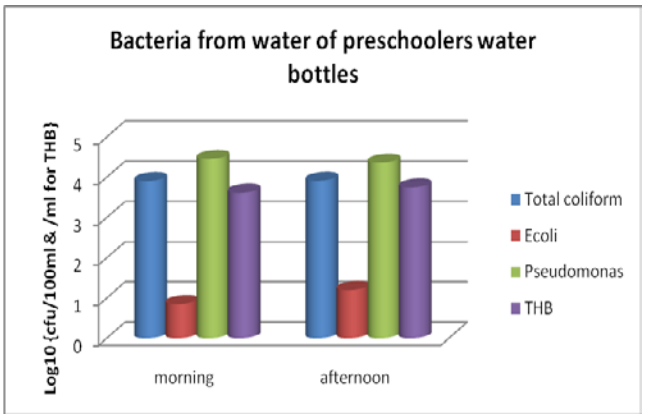


Figure 6: Overall mean bacteriological counts of water samples

3.1.7 Qualitative Survey of Mosquito Breeding in some Parts of the Accra Metropolis

(Project Staff: Mrs. Victoria Afutu-Vanderpuye – Research Scientist and Mr. Sena Niampoma)

Malaria remains one of the most important diseases in both urban and rural areas of Ghana partly because the prevailing temperatures and humidity favour malaria transmission, especially *Anopheles gambiae*, *Anopheles funestus* and *Anopheles arabiensis*. The disease is not just commonly associated with poverty but also a cause of poverty and has a devastating effect on the development potential of the country. It was against this background that the preliminary study was conducted to examine the relative importance and availability of different larval habitats in an area of perennial malaria transmission. The objective was to examine the spatial distribution of aquatic stages of malaria vectors within the Accra Metropolis and to assess the feasibility of targeting mosquito larval control.

During the reporting year, potential mosquito breeding habitats were monitored in some parts of the western portion of Accra. Weekly visits were made to the sites to assess the presence or absence of mosquito larvae in the habitats with water. Mosquito larvae were sampled from such habitats using the dipper method to score the absence or presence of mosquito larvae. Habitats with water that could last between a week to two weeks were classified as semi-permanent and beyond two weeks as permanent. Larvae was identified as anopheline or culicine based on body position to the water surface.

The preliminary results of the study showed that about 80 % of the available habitats were man-made (Table 6). Variety of mosquito species breeding sites catalogued such as tyres, tyre tracks, ditches, water storage receptacles and network of drains were mostly related to human activities (Figure 7). It was observed that human behavior and attitude were the prime causes of mosquito breeding in the study area though pools and ponds which were rainfed were natural contributors.

It was concluded from the preliminary results that human behavioral and attitudinal change was needed to control malaria in the study area. It was recommended that vector control programs must be rather linked with sanitation services than disease control and community participation is relevant for sustainable intervention of the malaria menace.

Table 6: Habitat type and mosquito larvae prevalence in habitats in the western half of Accra Metropolis

Habitat type	Habitats +ve for anopheline larvae only	Habitats +ve for culicine larvae only	Habitats +ve for culicine & anopheline larvae	Habitats –ve for larvae	Total habitats	Total %
Burrow pits	14	9	25	2	50	8.8
Concrete drains	6	4	30	10	50	8.8
Earthen drains	0	1	11	21	33	5.8
Storm drains	0	2	0	0	2	0.4
Pools (rain fed)	26	0	3	4	33	5.8
Ponds	4	1	0	6	11	1.9
Tires	2	12	0	8	22	3.7
Tire tracks	1	0	0	0	1	0.2
Streambed pools	4	0	0	0	4	0.7
Water storage containers	40	9	0	61	110	19.3
Septic tanks	0	0	5	≥50	≥55	≥9.7
Coconut shells	7	0	16	0	23	4.0
Wells	0	0	0	4	4	0.7
Agriculture related	8	0	0	2	10	1.6
Abandon concrete structures	29	17	2	23	71	12.5
Water storage for construction	15	21	1	12	49	8.6
Concrete curing	1	0	0	4	5	0.9
Horticulture	31	14	6	6	57	10.0
Animal water containers	0	4	0	0	4	0.7
Miscellaneous	13	2	0	15	30	5.3
TOTAL					569	100

Figure 7: Some breeding sites of mosquitoes within Accra Metropolis

3.2 ENVIRONMENTAL CHEMISTRY DIVISION

The long-term general objective of the Environmental Chemistry Division is to generate, process and disseminate water and wastewater quality information to end-users. Specific objectives are to:

- perform quality and quantity assessments of industrial, agricultural and domestic discharges in both urban and rural areas and identify their impact on aquatic ecosystems;
- collect, process and disseminate comprehensive high quality and reliable environmental data on surface and groundwater with regard to their chemical constituents; and
- monitor pollution in coastal waters and lagoons in Ghana.
- Currently, the major research programmes of the Division are:
- Water quality monitoring;
- Industrial wastewater studies;
- Environmental impact studies; and
- Development of strategies for water pollution control.

3.2.1 Water Quality Monitoring and Capacity Building Program

(Project Staff: Mr. Humphrey F. Darko – Research Scientist, Dr. O. D. Ansa-Asare – Principal Research Scientist, Mr. Victor Mantey, Mrs. Adwoa Painstsil – WRC)

The study was initiated in the reporting year in collaboration with the Water Resources Commission (WRC) to ensure sustainable water quality monitoring by engaging and building the capacities of the Assistant Basin Officers of WRC within the 5 basin offices established within the country. It is expected to end in 2015

During the reporting year, 41 monitoring stations (Table 7) were visited to sample water for physico-chemical and metals analysis. The sampling frequency was twice in the year (July/August and November 2013) to capture data during the rainy and dry seasons.

Table 7: Monitoring stations at the various zones of the study area

Zone 1	Zone 2	Zone 3
A Brenase-R.Pra	Lake Bosomtwe	Bamboi - Black Volta
Akim Oda-R Birim	Adiembra - R. Offin	Buipe - Black Volta
Ampansie	Aframso - R. Afram	Daboya - White Volta
Baafikrom Reservoir	Dadieso R. Bia	Damanko - Oti
Bonsaso - R. Bonsa	Dunkwa-On-Offin -R. Offin	Nabogo - White Volta
Daboase - R. Pra	Lake Barekese - R. Offin	Pwalugu -White Volta
Dominase - R. Ankobra	Sefwi-Wiawso - R. Tano	Sabari - R. Oti
E Ekosi-R.Ochi-Nakwa	Tanoso - R. Tano	Saboba -R. Oti
Elubo - R. Tano		Lawra – Black Volta
Ewusijo-R. Butre		Ajena - Main Volta
Lake Brimso-R. Kakum		Kpong - Main Volta
Mangoase - R. Densu		Sogakope - Lower Volta
Mankesim-R.Ochi-Amisa		Hohoe - R. Dayi
Mankrong J-R.Ayensu		
Nsawam - R. Densu		
Osino - R. Birim		
Potroase - R. Densu		
Prestea - R. Ankobra		
Twifo-Praso - R. Pra		
Weija Lake		

The results of the study indicated that the data of most water samples were within the stipulated Target Water Quality Range (TWQR) values. Only Brimso (R. Kakum) had a pH value of 6.39 units which was a little lower than the lower limit of the TWQR of 6.5 in July 2013. Two stations, Dominase and Ampansie, all on River Ankobra had pH values of 6.39 and 6.41, respectively, in November 2013. It was observed that 77.5 % of the stations (31 out of 40) had DO values greater than 5 mg/l in July 2013, and 90.0 % of the stations (37 out of 41) had DO concentration greater than 5.0 mg/l in November 2013. This was an indication of high DO concentrations in the water samples (Figure 8). The Biochemical Oxygen Demand (BOD) values were, however, slightly high in the water samples and this could be due to increased organic content in the water samples. For instance, only 20 % of the stations had values below the threshold value of 2.0 mg/l in July 2013 while only 27.0 % of the stations had values below the threshold value of 2.0 mg/l in November 2013. The DO levels and BOD values are indicative of healthy waters.

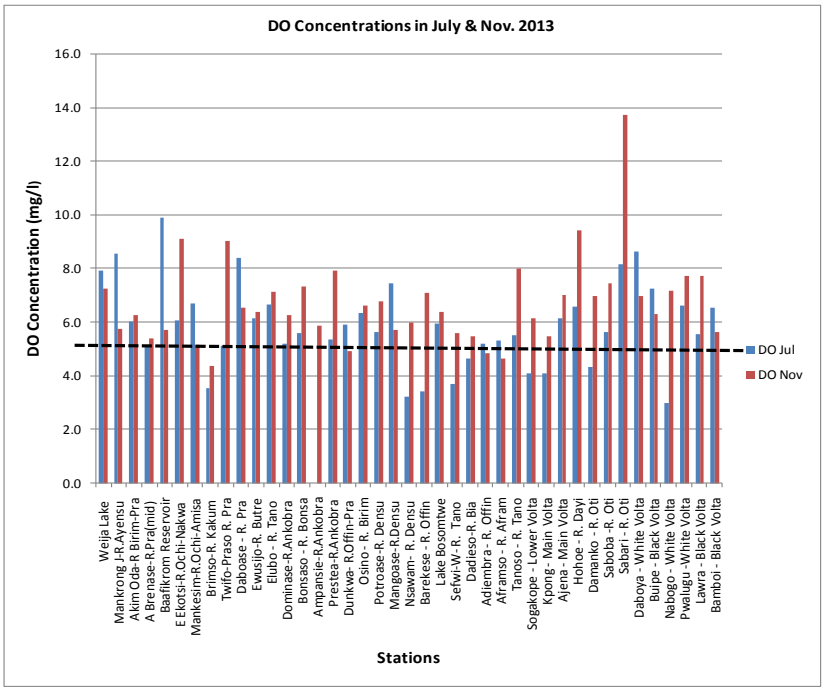


Figure 8: DO levels in July and November 2013 (Dotted line is threshold level)

3.2.2 PURC Water Analysis

(Project Staff: Mr. Humphrey F. Darko – Research Scientist, Dr. O. D. Ansa-Asare – Principal Research Scientist, Mr. Mark O. Akrong – Research Scientist, Mrs. Regina Banu – Research Scientist, Mr. Jude Quansah, Ms. Murjanatu Abdul-Hamid, Mr. Mohammed Bello, Ms. Hawa Ahmed and Mr. Borbor Selorm)

Consumption of tap water may be associated with health risks due to deterioration of its quality in the distribution system by contaminants that may be chemical, microbiological, or both. To ensure the health and safety of the public who are the consumers of tap water, it is important to carry out regular physico-chemical and bacteriological water quality analyses of water produced and supplied by Ghana Water Company Limited (GWCL) in their distribution systems to consumers to assess its suitability for potable use. It was against this background that the study was conducted to independently investigate the quality of drinking water supplied by the GWCL to consumers in selected communities within New Juabeng and Koforidua districts in the Eastern Region to determine whether its physico-chemical and bacteriological quality meets the required standards for potable use.

The scope of work included collection of water samples, laboratory analysis, data interpretation, preparation and submission of reports. In April 2013, 70 selected stations in the Eastern Region were visited and samples of water collected for analysis. However, only 43 stations had water flowing in their taps. Water samples were collected from public standpipes and other selected sampling points within the communities pre-designated by Public Utilities Regulatory Commission (PURC) for physico-chemical and bacteriological analysis.

Almost all the physico-chemical parameters of water samples were satisfactory except pH. Low pH was the main problem observed in the physico-chemical parameters. About 37 % of the water samples had pH values below the lower limit of 6.5 accepted for drinking water. The low pH values of the water samples are unsatisfactory because of health effects associated with low pH. However, the 37 % indicated an improvement in the quality of the water samples compared to a similar study conducted in December 2012 where 49 % of the water samples were observed to have pH lower than 6.5 units. Free chlorine residual was also low in the water samples, except in Effiduase and Koforidua townships. The low chlorine residual concentrations could enhance microbial re-growth in the distribution systems. Some selected stations and their corresponding physical parameters are shown in Table 8.

Table 8: Results of physical parameters in water samples from selected locations in the Eastern Region sampled in April 2013

Sampling Town	Accessible Sampling points	pH (pH units)	Conductivity (µS/cm)	Turbidity (NTU)	Colour (Hz)
Nsawam	Anglican School PSP	7.70	360	2.91	5.00
Nsawam	Djankrom Zongo mosque PSP	7.26	365	3.51	5.00
Nsawam	Djankrom PSP (close to presby sch)	7.14	360	6.19	5.00
Nsawam	Essikafoambantem Hse No. K 98	6.71	366	3.64	5.00
Nsawam	Adoagyire Market PSP	6.83	361	5.42	5.00
Akim Oda	Swedru Methodist School PSP	5.84	349	1.91	5.00
Akim Oda	Akim Oda GUWL Office PSP	5.63	446	3.24	5.00
Akim Oda	Oda Secondary School Kitchen	5.76	165	1.41	2.50
Akim Oda	Aboabo Presby School PSP	5.26	167	1.29	2.50
Kade	Kade Secondary School	5.67	46.9	1.40	2.50
Kade	GUWL District Office PSP	5.23	260	1.25	2.50
Asoum	Hse No. A451	5.07	74.3	1.65	5.00
Kwahu Tafo	Kwahu Tafo Sec. Sch. (Kitchen)	6.60	105	1.92	5.00
Kwahu Tafo	Kwahu Tafo booster station	6.15	106	2.29	5.00
Kotoso	Kotoso Market PSP	6.57	101	3.11	5.00
Kotoso	Asempa na ye PSP 3	6.47	116	2.36	5.00
Kwahu Tafo	Methodist mission House	6.65	107	1.70	2.50
Nkawkaw	Hse. No NF 168	6.88	494	2.40	5.00
Nkawkaw	Nkawkaw central PSP	6.75	523	1.60	2.50
Anyinam	Africa faith Church PSP	6.26	167	1.60	2.50
Bunsu	Cocoa college (Kitchen)	6.60	142	1.50	2.50
Bunsu	Etukrom PSP	6.71	138	10.9	7.50
WHO Guideline		**6.5 – 8.5**	**-**	**5.0**	**15.0**

Thirty one (31) samples out of a total of forty three (43) were found to be contaminated with total coliform (Table 12). Twenty five (25) of the samples had faecal coliform ranged from 1 - 279 cfu/100ml. *E. coli* counts were recorded in seven (7) samples out of a total of 43. The total heterotrophic bacteria counts recorded in the water samples showed that 19 out of 43 were above the Ghana Standards GS 175-1 of 500cfu/1ml of water tested. In general, the bacteriological water quality of 23.3 % conformed to the Ghana Standards GS 175-1 (2013) and WHO guideline of zero total and faecal coliform, and *E. coli* counts per 100ml of water

tested, hence safe for potable use. However, 76.7 % sampling points were bacteriologically unsafe to be used as drinking water sources (Table 9).

Table 9 Bacteriological analysis of water samples from Eastern Region

Acessible Sampling points	**TC/100ml**	**FC/100ml**	***E.coli*/100ml**	**THB/1ml**
Anglican School PSP	372	7	2	1196
Djankrom PSP	276	19	7	300
Adoagyire Market PSP	316	7	0	1092
Essikafoambantem Hse No. K 98	320	8	2	728
Djankrom Zongo mosque PSP	192	10	3	312
Swedru Methodist School PSP	1	0	0	676
Akim Oda GUWL Office PSP	0	0	0	728
Oda Secondary School Kitchen	156	36	32	1404
Aboabo Presby School PSP	4	2	0	1872
Kade Secondary School	5	3	0	1248
GUWL District Office PSP	0	0	0	340
Hse No. A367	11	6	0	2340
Kwahu Tafo Sec. Sch. (Kitchen)	1302	15	0	2028
Kwahu Tafo booster station	279	32	0	1040
Methodist mission House	112	5	1	884
Kotoso Market PSP	465	26	0	728
Asempa na ye PSP 4	744	29	5	3276
Nkawkaw central PSP	212	56	0	2340
Hse. No NF 100	3	7	0	3744
Africa faith Church PSP	0	0	0	248
Aburi borehole	0	0	0	2
Aburi GWCL staff quarters	0	0	0	1
Roman School PSP	0	0	0	49
PSP, Upper Manya Krobo Rural Bank	3	0	0	12
Police Barracks PSP	5	3	0	54
Abusco PSP (Kitchen)	6	0	0	27
Cocoa college (Kitchen)	0	0	0	<1
Etukrom PSP	1488	144	0	5148
Old Tafo Presby PSP	396	279	0	2808
Hs. No. TD 125	33	13	0	9
Hs. No. SUR/D 30	14	9	0	6
Marekt PSP	0	0	0	637
Central Hospital (Kitchen)	8	5	0	23
Residency (Kitchen)	0	0	0	5
Hs. No. KNT/C 23 (New Zongo)	0	0	0	216
Hs. No. KNT/B 29 (New Zongo)	4	3	0	1
Effiduase PSP 1 (Market)	3	1	0	108
Effiduase Airport PSP	21	0	0	11
Hs. No. D 29 (Old estate)	244	0	0	51
OY A 26	465	92	0	296
PSP in front of Ghana Post	0	0	0	3
Jumapo PSP opp. The Chief's Palace	0	0	0	416
Hs. No. JU B 91	7	4	0	24
Ghana Standards GS 175-1 (2009)	**0**	**0**	**0**	**500**
WHO Guidelines	**0**	**0**	**0**	**-**

3.2.3 Water Quality Studies in Relation to Cage Fish Culture in Busa and Sing Reservoirs in the Upper West Region

(Research Staff: Mr. Michael Kumi – Research Scientist, Dr. K. Kwarfo-Apegyah – Senior Research Scientist, Mr. Gerard Quarcoo – Research Scientist, Mr. Etornyo Agbeko – Research Scientist, Mr. Abdul-Latif Salifu – Principal Technical Officer and Ms. Ewurama Adu-Boakye – Principal Technical Officer)

The Institute, in collaboration with Zoomlion Ghana Limited, Wa, Ministry of local Government and Rural Development, Foreign Affairs, and Trade and Development Canada (DFATD) started the study in 2011 and ended in the reporting year. The objectives were to:

- monitor the physical, chemical and biological water quality parameters to assess impact of cage fish culture on the reservoir;
- identify the sources of pollutants that are hazardous to fish production in the reservoirs; and
- make recommendations to control pollution of the reservoir to ensure sustainable and profitable caged fish production.

During the reporting period, water samples were collected from the Sing and Busa reservoirs and physico-chemical, microbial and phytoplankton concentrations analysed. The water samples were collected from selected sites within the up-, mid- and down-stream of each reservoir.

The Busa Reservoir showed an overall ionic dominance pattern of $Ca^{+2} > Mg^{+2} > K^{+} > Na^{+}$, and $HCO_3^{-} > Cl^{-} > SO_4^{-2}$ while Sing Reservoir showed an overall ionic dominance pattern of $Ca^{+2} > Na^{+} > Mg^{+2} > K^{+}$, and $HCO_3^{-} > SO_4^{-2} > Cl^{-}$ (Figures 9 and 10).

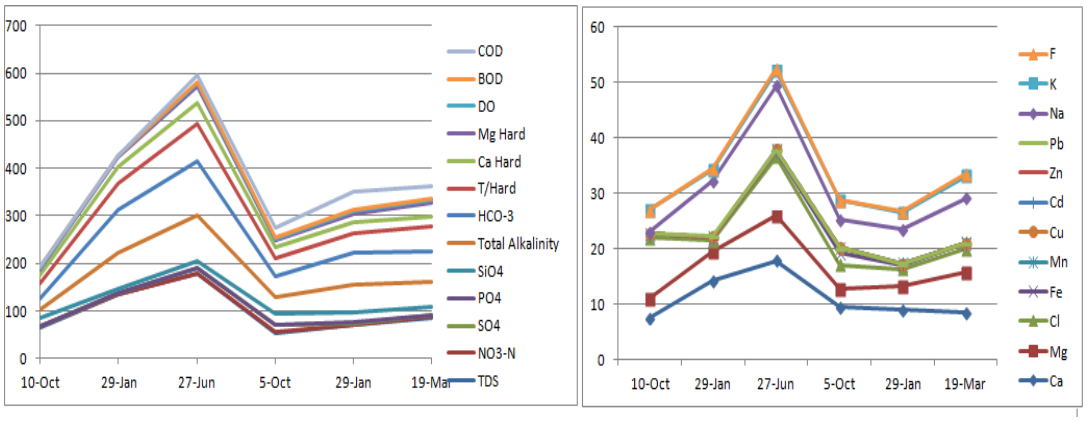


Figure 9: Results of nutrients, trace metals and major ions in the Sing Reservoir

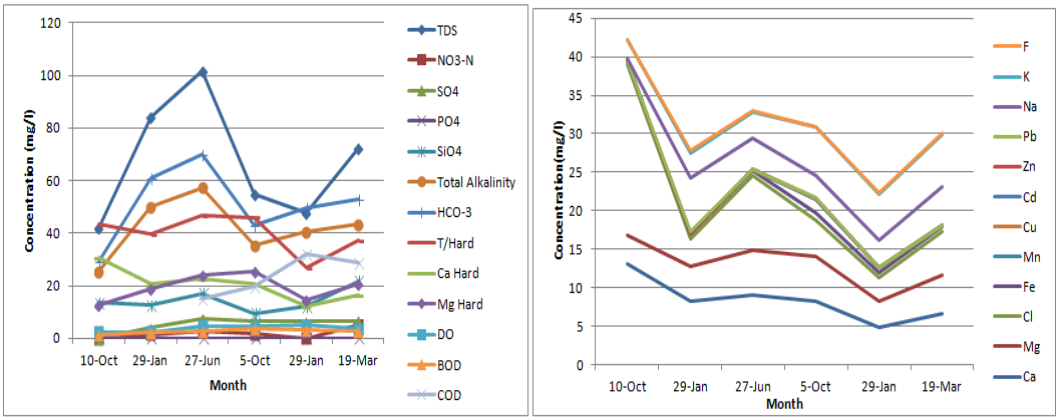


Figure 10: Results of nutrients, trace metals and major ions in the Busa Reservoir

The dominance of Cl^- over SO_4^{-2} in the Busa Reservoir could be attributed to domestic wastes being discharged into it. The dominance of Ca^{+2} over Na^+ and Mg^{+2} in the two reservoirs could be due to the fish feed or geology of the surrounding land of the reservoirs. Bacterial counts for the whole sampling period were below the WHO and EPA Ghana recommended levels of 10^3 cfu/100ml and 10000 cfu/100ml, respectively, for freshwater aquaculture except coliform bacteria counts in Busa Reservoir which exceeded EPA Ghana standard for freshwater aquaculture (10000 CFU/100ml) in January 2013 (Figures 11 and 12). The Busa reservoir was of poor quality and in class III while Sing reservoir was of fairly good quality and in Class II when compared to the Water Quality Index (WQI) (WRC, 2003). However, fish cage production in Busa and Sing reservoirs in relation to phytoplankton composition and abundance did not pose ecological effects. Busa and Sing reservoirs were relatively safe for tilapia production due to its richness in chlorophyta.

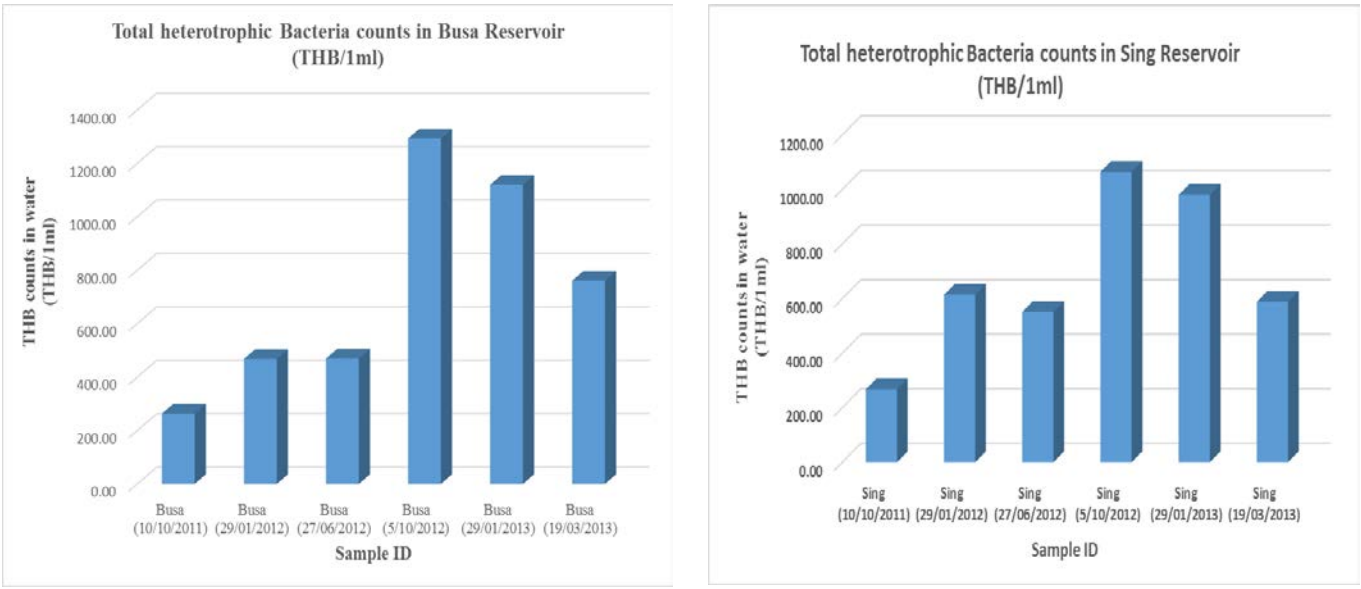


Figure 11: Levels of Total Heterotrophic Bacteria counts in Busa and Sing reservoirs

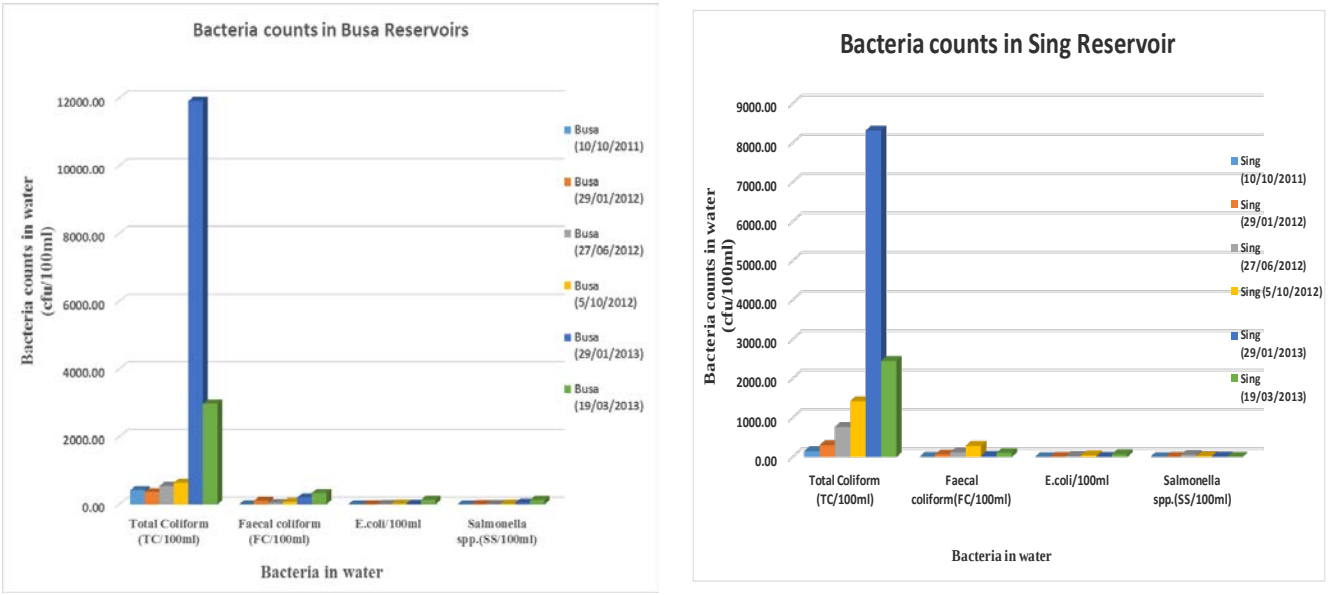


Figure 12: Levels of bacteria count in Busa and Sing reservoirs

It was concluded from the study that the water quality of the two reservoirs were suitable for fish production. Cage fish culture practices in the reservoirs did not adversely affect the water quality of the reservoirs and residual pesticides levels in the two reservoirs were below detection limit. It was however recommended that:

- continuous water quality monitoring should be ensured;
- measures should be put in place to control water weeds and poaching;
- farmers should be educated to take records of fish mortality; and
- number of cages on the reserviors, particularly Busa reservior, should be controlled to avoid complete eutrophication.

3.2.4 Water Quality Studies in Relation to Cage Fish Culture in Baleofiri, Yeliyiri, Nandoguo and Kokoligu Reservoirs in Upper West Region of Ghana

(Research Staff: Mr. Michael Kumi – Research Scientist, Mr. Gerard Quarcoo – Research Scientist, Mr. Etornyo Agbeko – Research Scientist, Mr. Abdul-Latif Salifu – Principal Technical Officer, Ms. Ewurama Adu-Boakye – Principal Technical Officer and Mr. Emmanuel Bekoe – Senior Technical Officer)

In collaboration with Zoomlion Ghana Limited, Wa, and Ministry of local Government and Rural Development, with funding from Foreign Affairs, Trade and Development Canada (DFATD), the study was initiated in the reporting year to:

- monitor the physical, chemical and biological water quality parameters that influence fish production;
- identify the source of pollutants that are hazardous to fish production in the reservoirs; and
- make recommendation to control the pollution of the reservoir to ensure sustainable and profitable caged fish production.

It is expected to end in 2016.

Activities undertaken in the reporting year included sampling of water from selected locations within the up- and down-streams of the reservoirs for physical, chemical and biological analysis.

The pH of the reservoirs ranged from 6.9 - 8.7 pH units while the average water temperature ranged from 27.3 - 34.2 ^{0}C and that of ambient temperature ranged from 28.1 - 31.7 ^{0}C, with most falling slightly above the WRC-Ghana permissible level of 28.0 - 30.0 ^{0}C for raw water for fish growth but not in the upper lethal range of 40 – 43 ^{0}C. Dissolved Oxygen (DO) ranged from 4.0 - 6.6 mg/l, except that of Kokoligu Reservoir which was within the optimal DO concentration stipulated by WRC-Ghana (5 – 8 mg/l) for fish growth. The biological analysis showed higher levels of coliform bacteria, especially in the Kokoligu Reservoir (Figure 13), and this could be attributed to run-offs carrying faecal matter of animals such as goats, sheep and cattle into the reservoir as these animals were observed grazing at the bank of the reservoir during sampling periods. The detailed results obtained are presented in Tables 10 – 13.

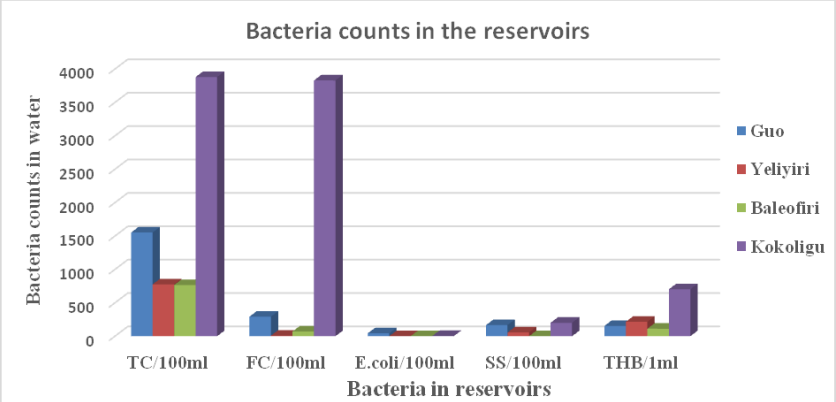


Figure 13: Variation of bacteria in the reservoirs

Table 10: Physico-chemical analysis

	Kokoligu Reservoir			**Nandom Guo Reservoir**				
Parameter	upstream	Down stream	**Ave**	Upstream	Down stream	**Ave**	**WRC TWQR**	**WHO Guideline**
EC(µS/cm)	47.5	45.4	**46.5**	218	221	**219**		-
TDS(NTU)	29.5	28.4	**29.0**	136	200	**168**		1000
p H(pH-units)	7.10	6.90	**7.00**	8.70	8.60	**8.70**	6.5-9.0	6.5-8.5
Turbidity(NTU)	345	305	**325**	41.0	37.0	**39.0**		5
NO_3-N	0.580	0.470	**0.530**	3.01	1.41	**2.21**	< 300	10
PO_4	0.213	0.214	**0.214**	0.022	0.041	**0.032**	0.1	-
SiO_4	42.6	46.9	**44.7**	6.40	8.10	**7.30**		-
F	0.240	<0.010	**0.240**	0.430	0.400	**0.420**		1.5
Total Alkalinity	40.0	44.0	**42.0**	138	84.0	**111.0**	20-100	1000
T/Hard	52.0	44.0	**48.0**	50.0	50.0	**50.0**		500
Ca Hard	20.0	16.0	**18.0**	28.0	24.0	**26.0**		-
Mg Hard	32.0	28.0	**30.0**	22.0	26.0	**24.0**		-
TSS	74,000	102,000	**88,000**	45,000	44,000	**44,500**		-
DO	3.00	4.90	**4.00**	4.50	5.30	**4.90**		-
BOD	1.10	3.00	**2.10**	0.50	1.10	**0.80**		
COD	56.0	112	**84.0**	100	44.8	**72.6**		
Temp of H_2O (℃)	27.1	27.4	**27.3**	30.0	30.3	**30.2**	28-30	
Temp of Air (℃)	27.4	28.4	**28.1**	31.1	31.4	**31.3**		

All units are in mg/l unless otherwise stated

Table 11: Major Ions and Trace Metal Analysis

	Kokoligu Reservoir			**Nandom Guo Reservoir**				
Parameter	Upstream	Down stream	**Ave**	Upstream	Down stream	**Ave**	**WRC TWQR**	**WHO Guideline**
SO_4	4.10	4.90	**4.50**	13.0	9.90	**11.5**		400
Na	3.90	3.90	**3.90**	35.5	37.5	**36.5**		200
K	4.20	4.10	**4.20**	2.80	2.80	**2.80**		30
HCO_3	48.8	53.7	**51.3**	168	103	**136**		-
Ca	8.00	6.40	**7.20**	11.2	9.60	**10.4**		200
Mg	7.80	6.80	**7.30**	5.30	6.30	**5.80**		150
Cl	11.9	11.9	**11.9**	3.00	4.00	**3.50**		250
Fe	0.618	0.795	**0.707**	0.060	1.423	**0.742**		0.3
Mn	8.39	9.04	**8.71**	0.576	0.381	**0.479**		0.4

All units are in mg/l unless otherwise stated

Table 12: Physico-chemical Analysis

	Baleofiri Reservoir			**Yeliyiri Reservoir**				
Parameter	upstream	Down stream	**Ave**	Upstream	Down stream	**Ave**	**WRC TWQR**	**WHO Guideline**
EC(μS/cm)	97.0		97.0	57.9		57.9		-
TDS(NTU)	60.5		60.5	35.9		35.9	< 2	1000
p H(pH-units)	8.30		8.30	8.00		8.00	6.5-9.0	6.5-8.5
Turbidity(NTU)	12.0		12.0	9.00		9.00		5
NO_3-N	0.63		0.63	0.59		0.59	< 300	10
PO_4	0.023		0.023	0.013		0.013	0.1	-
SiO_4	22.3		22.3	24.1		24.1		-
F	0.160		0.160	0.320		0.320		1.5
Total Alkalinity	40.0		40.0	68.0		68.0	20-100	1000
T/Hard	38.0		38.0	48.0		48.0		500
Ca Hard	10.0		10.0	18.0		18.0		-
Mg Hard	28.0		28.0	30.0		30.0		-
TSS	38,000		38,000	23,000		23,000		-
DO	5.90		5.90	6.60		6.60		-
BOD	2.80		2.80	4.10		4.10		
COD	100		100	123		123		
Temp of H_2O (℃)	32.0		32.0	34.2		34.2	28-30	
Temp of Air (℃)	30.7		30.7	31.7		31.7		

All units are in mg/l unless otherwise stated

Table 13: Major Ions and Trace Metal Analysis

	Baleofiri Reservoir			**Yeliyiri Reservoir**				
Parameter	Upstream		**Ave**	Upstream		**Ave**	WRC TWQR	WHO Guideline
SO_4	6.40		**6.40**	7.90		**7.90**		400
Na	3.10		**3.10**	5.10		**5.10**		200
K	5.80		**5.80**	6.40		**6.40**		30
HCO_3	48.8		**48.8**	83.0		**83.0**		-
Ca	4.00		**4.00**	7.20		**7.20**		200
Mg	6.80		**6.80**	7.30		**7.30**		150
Cl	4.00		**4.00**	3.00		**3.00**		250
Fe	0.809		**0.809**	0.173		**0.173**		0.3
Mn	1.244		**1.244**	0.151		**0.151**		0.4

All units are in mg/l unless otherwise stated

3.2.5 Cancer and Non – Cancer Human Health Risk Assessment from Exposure to Toxic Chemicals in Bottom Ash and Soil Samples from E-Waste Recycling Points in Agbogbloshie Scrap Yard, Ghana

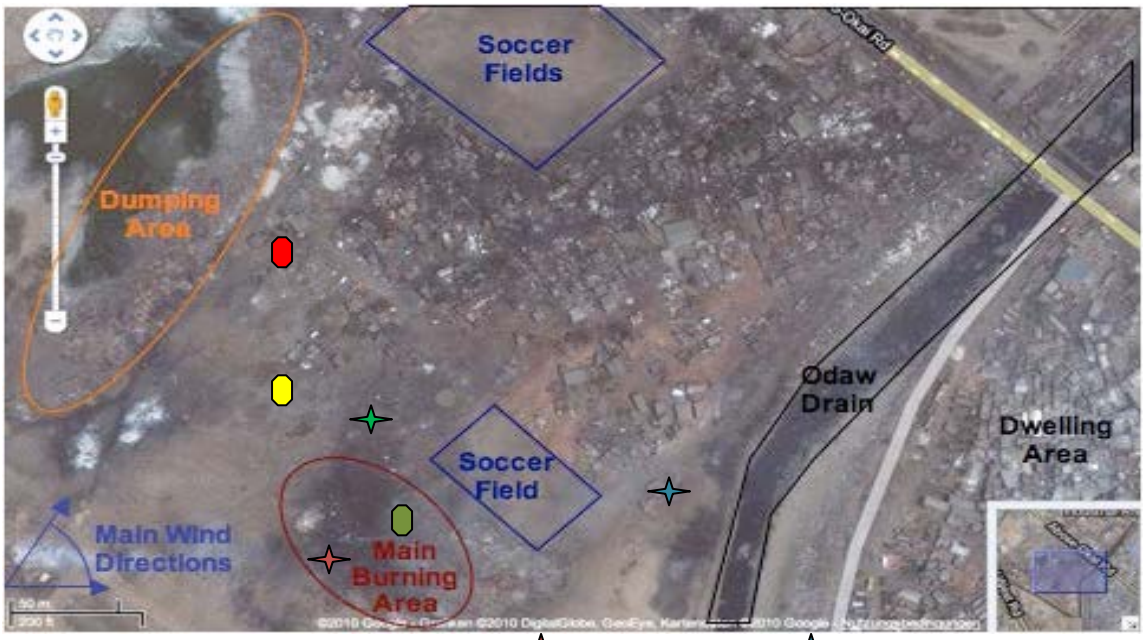
(Project Staff: Mr. Samuel Obiri – Research Scientist, Ms. Mohammed Saada – Research Scientist and Dr. Osmund Ansa-Asare – Principal Research Scientist)

The global market for electronic equipment and products continue to expand while the lifespan of the product is very short. The wastes stream from the use of these obsolete electrical and electronic products, commonly called "e-waste", is growing fast with an estimated amount of 28 million metric tonnes produced each year (Bi *et al*., 2007). E-waste contains numerous toxic or hazardous chemicals that pose significant health hazard to human beings. In Ghana, the main centre for the recovery of materials from e-wastes is within the Agbogbloshie scrap market in Accra, the capital city of Ghana. Primitive methods used for e-waste recycling included mechanical shredding of electronic equipment and exposure to toxic chemicals such as antimony (Sb), arsenic (As), cadmium (Cd), chromium (Cr), cobalt (Co),

copper (Cu) and lead (Pb) via oral and dermal contact could pose significant health hazard (Asante *et al.*, 2012). It was against this background that the study was conducted to:

- determine levels of heavy metals such as antimony (Sb), arsenic (As), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), silver (Ag), tin (Sn) and zinc (Zn) in bottom ash and soil samples at the Agblogbloshie e – waste market;
- evaluate cancer and non-cancer health risks from exposure to the aforementioned toxic chemicals using the laboratory results obtained; and
- recommend to government and other relevant stakeholders to put in appropriate policies to safeguard the environment and human beings.

In the reporting year, 20g of 20 samples were randomly collected from three places (AGH1, AGH2 and AGH3) (Figure 14) where open burning of e-waste (Figure 15) takes place at Agbogbloshie scrap yard on bi-weekly basis. Samples collected for each sampling time was analyzed separately for heavy metals. The mean results from the analysis were used as input parameters for the assessment of the human health risk. The study showed high levels of Pb, Cu, Sn, Zn and Co in the bottom ash and soil samples from areas where e-waste were burnt at Agbogbloshie scrap yard (Table 14 and 15).



Key: ASH1 ; ASH2 ; ASH3 ; ASG1 ; ASG2 ; ASG3

Figure 14: Sampling locations at Agbogbloshie metal scrap yard

Figure 15: Open burning of e-waste as well as selling of other food items and sachet water at Agbogbloshie metal scrap yard

Table 14: Mean concentration of Pb, Cd, Cr, Cu, As, Sn, Zn and Co in the bottom ash samples

Sample Location	Concentrations in mg/kg							
	Pb	Cd	Cr	Cu	As	Sn	Zn	Co
ASH1	5,388	2.39	42	7,940	20	225	276	123
ASH2	3,257	4.58	35	1,190	15	195	274	68
ASH3	4,654	5.37	45	2,457	25	323	124	96

Table 15: Mean concentration of Pb, Cd, Cr, Cu, As, Sn, Zn and Co in the soil samples

Sample Location	Concentrations in mg/kg							
	Pb	Cd	Cr	Cu	As	Sn	Zn	Co
ASG1	1,685	26.89	36.86	1,427	1,622	234	783	135
ASG2	12,492	67.16	351.82	15,761	1,348	171.6	387	86.98
ASG3	699.18	112.7	1,378	1,839	4,142	563	618	563.9

The cancer health risk from accidental ingestion of bottom ash from spot AGH1 was 4.3×10^{-3} and 6.5×10^{-2} via CTE and RME parameters, respectively (Table 16). This indicated that approximately 4 out of 1,000 and 7 out of every 100 e-waste workers who scavenge for metals such as copper wires from the burnt area AGH1 were likely to suffer from cancer related diseases.

Table 16: Cancer health risk faced e-waste workers from accidental oral ingestion and dermal contact of As and Cd in soil samples

Sample Location	Exposure route	Cancer health risk			
		adults e – waste workers (Arsenic)		Adult e – waste workers (Cadmium)	
		CTE	RME	CTE	RME
ASH1	Oral Dermal	0.0043 0.0080	0.065 0.060	0.063 0.0034	0.092 0.0017
ASH2	Oral Dermal	0.0012 0.0052	0.0099 0.0040	0.076 0.014	0.0019 0.0021
ASH3	Oral Dermal	0.12 0.0026	0.010 0.0076	0.080 0.0086	0.0020 0.0025

The non – cancer health risk in most cases exceeded the acceptable hazard quotient value of 1.0 and this suggested that the tendency of the workers to exhibit symptoms of diseases associated with exposure to non-cancerous diseases like skin rashes, upper respiratory tract infections, nausea, low IQ, etc. was very high (Tables 17 and 18).

Table 17: Non – cancer health risk from exposure to Pb, Cd, Cr and Cu in bottom ash by e-waste workers

Sample Location	Exposure route	Non – cancer health risk							
		Pb		Cd		Cr		Cu	
		CTE	RME	CTE	RME	CTE	RME	CTE	RME
ASH1	Oral	24	36	2.2	2.9	4.3	5.7	78	89
	Dermal	56	65	4.5	6.2	4.6	4.5	112	245
ASH2	Oral	33	91	1.3	5.6	2.0	4.5	45	73
	Dermal	82	97	7.3	9.1	2.2	3.7	52	78
ASH3	Oral	15	21	2.4	7.5	0.19	0.37	22	44
	Dermal	24	98	3.1	2.6	0.56	0.67	12	23

Table 18: Non – cancer health risk from exposure to As, Sn, Zn and Co in bottom by e-waste workers

Sampling Location	Exposure route	Non – cancer health risk							
		As		Sn		Zn		Co	
		CTE	RME	CTE	RME	CTE	RME	CTE	RME
ASH1	Oral	0.37	0.11	1.7	4.4	6.3	5.7	1.5	1.3
	Dermal	0.67	0.50	1.2	6.4	1.2	2.6	27	6.2
AGH2	Oral	1.3	3.8	5.9	1.5	2.2	2.0	1.9	1.9
	Dermal	2.3	1.7	4.0	2.2	4.0	3.0	3.5	3.5
AGH3	Oral	2.2	6.5	1.0	2.0	3.7	3.4	2.5	2.3
	Dermal	4.0	3.0	6.9	3.8	6.8	9.0	4.6	10

It was concluded from the study that exposure to carcinogenic chemicals and non-carcinogenic chemical via informal recycling of e-waste at Agbogbloshie scrap yard poses significant health hazard to the workers. However, this conclusion would have to be linked to other aspect of the broader project "Assessment of human health risk from exposure to toxic chemicals via recycling of e-waste at Agbogbloshie market – Accra, Ghana" which is yet to be completed.

3.2.6 Suitabily of the Nima Creek for Urban Agriculture

(Project Staff: Ms. Mohammed Saada – Research Scientist and Dr. Isaac Hodgson – Principal Research Scientist)

Many people eat exotic vegetables daily on the streets of Accra and in canteens and restaurants. Irrigated urban vegetable production covers about 47 ha. However, poor farmers rely solely on the open drain gutters, wastewater or polluted water for irrigation. Most of the farmers grow vegetables around these waste or polluted water sites (IWMI, 2006). These waters may contain heavy metal and pesticide which accumulates in the soil over a period of time and enter into the food chain. It was against this background that the study was carried out to determine the physico-chemical quality of the creek; the heavy metal levels in the water, water sediment and irrigated soil; and the pesticide residue levels in the water, soil and the vegetables.

Activities undertaken during the year under review included monthly sampling of water from the Nima Creek at six selected sites (NC1 - NC6) from January to December 2013. These samples were analysed for parameters such as conductivity, pH, biochemical oxygen demand (BOD), nutrients, heavy metals and coliform bacteria

Results obtained from the study indicated that the range of parameters such as pH (7.31 - 7.53 units) electrical conductivity (1105 -11267 µS/cm), total dissolved solids (568 - 701 mg/l), chloride (145 - 173 mg/l), iron (0.170 - 0.221 mg/l), ammonia (2.96 - 3.48 mg/l) and phosphate (0.410 - 0.623 mg/l) were within the recommended levels for irrigation purposes. The heavy metals values were generally low. The range of SAR (4.29 to 5.43 units) was

satisfactory compared to the recommended value of 3 - 6. Thus there will be no infiltration problems when the water is used for irrigation. However, the range of sodium (126 - 141) was above the recommended value of < 70 (mg/l). Hence, the water has to be restricted when used for surface and sprinkler irrigation. Moreover, the Nima Creek was polluted with high levels of total suspended solids (96 - 300 mg/l), turbidity (43.7 - 65.8 NTU), conductivity (1149 - 1267 µS/cm), BOD (22.1 - 52.4 mg/l), ammonia (2.96 - 3.48 mg/l) and coliform bacteria (285 - 465x10^4 cfu/100ml) (Table 19). The high levels of ammonia and nitrate could lead to eutrophication. The high faecal coliform count (286-465x10^4) could be attributed to runoff containing solid waste and faecal matter from the catchments of the creek. The high coliform counts could negatively impact on the public health of the people who come into contact with the water or eat raw vegetables irrigated with the Nima Creek.

Table 19: Mean concentrations of physico-chemical and bacteriological parameters of the Nima Creek

Parameters	**NC 1**	**NC 2**	**NC 3**	**NC 4**	**NC 5**	**NC 6**	**Guideline values**
pH	7.31	7.33	7.37	7.46	7.49	7.53	6.5-9.4
Conductivity (µS/cm)	1149	1105	1153	1239	1206	1267	700-3000
Total dissolved solids (mg/l)	701	568	607	660	639	667	450-2000
Chloride (mg/l)	157	145	156	173	170	157	140-350
SAR	5.43	4.56	4.79	4.75	4.29	4.52	3-9
Nitrate (mg/l)	0.590	0.431	0.166	0.272	0.253	1.15	5
Ammonia (mg/l)	3.16	3.35	3.48	2.96	3.12	3.15	5
Iron (mg/l)	0.194	0.215	0.221	0.208	0.170	0.180	5
Copper (mg/l)	0.022	0.043	0.019	0.012	0.014	0.011	0.20
Chromium (mg/l)	0.011	0.015	0.010	0.010	0.012	0.021	0.10
Cobalt (mg/l)	0.011	0.009	0.008	0.010	0.011	0.011	0.050
Aluminium (mg/l)	1.81	2.25	2.54	2.75	1.82	2.26	5
Manganese (mg/l)	0.043	0.107	0.070	0.552	0.048	0.087	0.20
Lead (mg/L)	0.012	0.009	0.001	0.011	0.006	0.011	-
Faecal coliform/100ml	-	285x10^4	-	465x10^4	-	372x10^4	0
E-coli/100ml	-	186x10^4	-	279x10^4	-	196x10^4	-

3.3 FISHERY DIVISION

The mandate of the Fishery Division is to engage in research to generate scientific information whose application would enhance sustainable management and development of Ghana's fish, fisheries and aquaculture resources. The Division's goal is to increase local fish production to support livelihoods through increasing yield from existing fisheries and development of sustainable aquaculture and culture-based fisheries practices.
Currently, the Division's major research and development programmes are aquaculture development, environmental impact assessment and monitoring of fish populations in relation to socio-economic development activities, fisheries enhancement and culture-based fisheries.
Some research activities undertaken during the year under review are presented below.

3.3.1 Renaturation and Restoration of the Fosu Lagoon

(Project Staff: Dr. H. R. Dankwa – Principal Research Scientist, Mr. Theodore Quarcoopome – Research Scientist, Mr. Mark Osa Akrong – Research Scientist, Mrs. Regina Banu – Research Scientist, Dr K. Kankam-Yeboah – Principal Research Scientist, Dr J. A. Ampofo – Chief Research Scientist, Dr R. Asmah – Senior Research Scientist, Dr F. Akpabey – Senior Research Scientist, Ms D. Ofori – Research Scientist, Mr F. Logah – Research Scientist, Mr. Edem Amerdome – Technologist, Mr. Mohammed Bello, Ms. Lady Adomako Frimpong, Ms. Hawa Ahmed, Mr. Borbor Selorm and Mr. Bright Awunor – Fisherman)

The Fosu Lagoon is a major source of livelihood for a lot of people in the Cape Coast Metropolis. It serves as a recipient of both liquid and solid wastes from various activities dotted along its catchments. The lagoon is also being threatened by climate change resulting in wild fluctuations in water level sometimes to near desiccation during the dry season. These factors lead to physiological or morphological changes, decreased species diversity and alteration in the fish community structure which ultimately can impact negatively on the fisheries of the Lagoon. In collaboration with Parks and Gardens, University of Cape Coast and Lands Commission, this study was undertaken to provide information to establish sustainable and economically sound management plan for the lagoon and thus preserve its natural state as a source of livelihoods for the inhabitants and as a habitat for rare flora and fauna. The objectives were to:

- undertake a site analysis from a hydrological perspective;
- identify the major water contributions (streams, drains, catchment, etc.) to the lagoon;
- determine the suspended sediment concentrations and particle size of the bed-material to determine ecosystem implications;
- perform bathymetric surveys to measure the depths of water column at different sections of the lagoon;
- investigate the current status of the fisheries;
- assess the level of productivity and fish biodiversity of the lagoon;
- make appropriate recommendations for its restoration and management;
- determine the current water quality status of the Fosu Lagoon;
- identify the sources of pollution to the lagoon; and
- assess the quality status of fish from the lagoon for human consumption.

In the year under review, the lagoon was divided into 3 sections – northern, middle and southern – for the purposes of sampling to ensure that samples were taken from all sections of the lagoon. Fishing was done on daily basis for 5 days using cast net, gill net and 2-man drag net at various sites within each section by local fishers. Fishing effort was calculated as the man-hours used in fishing and the total catch computed for a day for the different gears. The annual production from the lagoon was estimated from the number of fishers, their average

daily catch and the number of fishing days in a year. Based on the catch per annum and the total surface area of the Lagoon, the yield per ha^{-1} yr^{-1} was computed. Based on length and weight measurements and the total number of each species caught, the following were estimated:

- Species composition – to determine the fish population structure.
- Relative abundance – to determine the importance of each species in the population.
- Size distribution of major species – to compare same species from other lagoons to assess how well fishes are doing in the Lagoon
- The condition factor – to assess the physiological 'well-being' of the fish or how suitable the lagoon is for the growth of each species of fish.

The biodiversity of fish species was also calculated by three diversity indices: the Shannon-Wiener diversity index (H'), Species richness (D) and Evenness (J).

Additional activities carried out included collection of water samples from the upstream, midstream and downstream sections of the lagoon and wastewater samples from ten (10) drains that discharge wastewater from various anthropogenic activities into the lagoon. Dominant fish species, Tilapia and *H. biodorsalis*, were also sampled from the three sections of the lagoon. Microbiological analyses were conductetd on the water and fish samples and data obtained analysed. Sources of water inputs to the lagoon as well as the hydrological connections to the lagoon were assessed. Hydrometeorological analyses were also performed for the Cape Coast Municipality. Suspended sediments and bed-material samples were taken from pre-determined sections of the lagoon to determine probable activities in the watershed which contributed to sedimentation of the lagoon. Depth profiles across transects were also taken to determine the capacity of the lagoon. Digital mapping including locations of the profile transects and sampling points were collected. Water available to the lagoon was estimated through a water balance estimation of the lagoon. In addition, floating, submerged and emergent aquatic macrophytes at the selected sites were randomly sampled with a 0.25 m^2 wooden quadrat and plants enclosed in the quadrat were removed, mopped, identified and weighed to determine the wet weight from which the biomass (g/m^2) was estimated. The mangrove strands were also visited and the species and their relative numbers recorded.

A total of 6,197 individuals were sampled during the study period comprising five species and four families. These were *Sarotherodon melanotheron* (Fm. Cichlidae), *Heterobranchus bidorsalis* (Fm. Clariidae), *Clarias gariepinus* (Fm. Clariidae) (observed in a fishers' catch), *Pellonula leonensis* (Fm. Clupeidae) and *Liza falcipinnis* (Fm. Mugilidae). *S melanotheron* constituted 99.5 % and 92 % of the total number and weight, respectively, of fishes caught (Figure 16).

The total length of *S. melanotheron* caught from all the gears combined ranged from 4.1 - 14.0 cm with a modal class of 7.0 - 7.9 cm while the weight ranged from 0.8 - 47.3 g with a mean weight of 6.5 g. With the exception of gill net where the modal length of fish caught was 8.0 - 8.9 cm, the modal length of fish from each of the other gears was 7.0 - 7.9 cm. The proportion of smaller-sized fish i.e., individuals with length below 7.0 cm was, however, much higher in drag net than in cast net and gill net samples. From the size range and modal size class recorded, *S. melanotheron* populations in the Fosu Lagoon could be described as stunted.

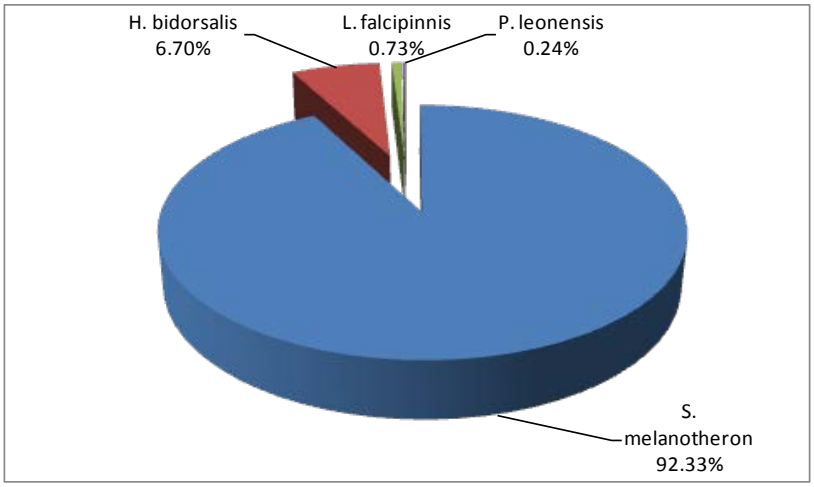


Figure 16: Percentage composition in terms of weight of fish caught from Fosu Lagoon

The length-weight relationship of *S. melanotheron* from the Fosu Lagoon which was described by the equation $W = 0.025\ TL^{2.78}$ indicated that the growth pattern of *S. melanotheron* was allometric (i.e., increases in length and weight of the species were not equal during growth), which was typical of cichlids. The condition factor was calculated to be 3.9, which was also typical of cichlids. Thus, the *S. melanotheron* were not emaciated and indicated that the aquatic environment or the water quality of the lagoon was favourable for the growth of *S. melanotheron*. The length at first maturity for both males and females which was estimated at about 6.0 cm was small but was similar to what was reported in a previous study in the same lagoon and could be a strategy in response to the high fishing pressure.

The biodiversity index of Shannon-Wiener (H') was calculated to be 0.02 whiles those for species richness (D) and evenness (J) were 0.93 and 0.03, respectively. Species richness measures the number of species in a community, the more species the richer the sample whiles evenness is the individuals' distribution among species in a community, greater evenness indicating greater ecological stability. The low diversity indices were true reflections of the situation in the lagoon where there were just five species with distribution of individuals skewed towards only one species. This suggested that the diversity of the lagoon community was poor and ecologically imbalanced.

Catch rates of 0.94274 kg/man h^{-1}, 6.300 kg/man h^{-1} and 0.255 kg/man h^{-1} were calculated for cast net, drag net and gill net, respectively, and an annual catch of 199 tonnes was estimated for the lagoon. Though the lagoon fisheries were major source of livelihood for over 1000 direct users, it was not being exploited on a sustainable basis.

The total coliform (TC) count recorded in the lagoon, stream and drain ranged from 1320 – 4650 cfu/100 ml. The highest coliform count (4650 cfu/100 ml) was recorded at the mechanic shop area while the lowest coliform count (1320 cfu/100ml) was recorded at the midstream of the lagoon. The upstream and downstream coliform counts were 3255 cfu/100ml and 3952 cfu/100ml, respectively. The highest faecal coliform count was recorded from Drain 2 (930cfu/100ml) while the least (40 cfu/100ml) was recorded at the Upstream of the lagoon. Comparatively, high *E. coli* counts were recorded at St. Augustines, Drain 2 and Antem stream than counts recorded in the various sections of the lagoon. The highest *Enterococcus spp* count of 1395 cfu/100ml was recorded from Drain 1. Generally, the total coliform counts (Figure 17) in the samples were above the EPA Ghana maximum limit for wastewater discharge of 400 cfu/100ml. The faecal coliform, *E.coli* and *Enterococcus spp* counts (Figure

18) were also above the recommended level for aquaculture and recreational purpose. The results showed that bacterial contaminations in fishes sampled from the middle of the lagoon were slightly lower than those from upstream and downstream. In general, high total coliform and *Vibrio spp* counts were recorded in the intestines of fishes from the upstream and downstream of the lagoon, respectively. These counts were above the 10000 cfu/cm^2 and 1000 cfu/cm^2 recommended level for total coliform and *Vibrio spp* count, respectively.

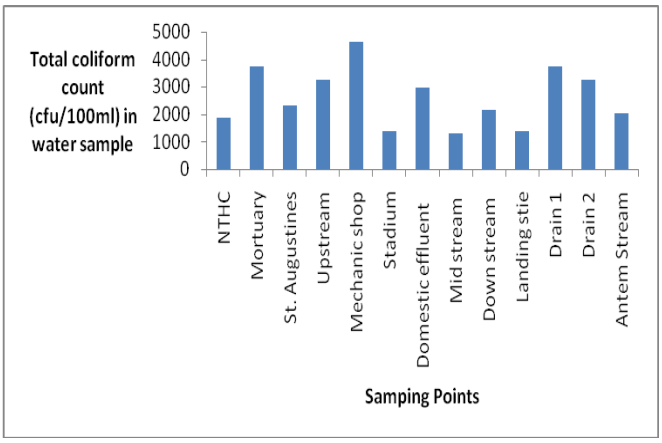


Figure 17: Total coliform count in the Fosu Lagoon during the study period

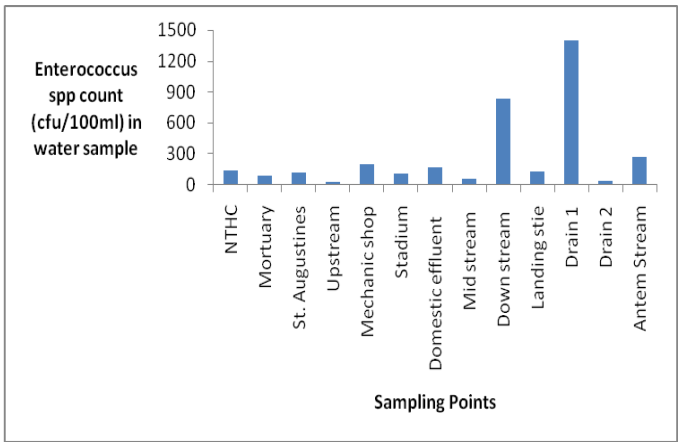


Figure 18: *Enterococcus sp.* count in the Fosu Lagoon during the study period

Results from the hydrometeorological assessment suggested that the buffer zone of the lagoon have been destroyed due to developments and human activities in the zone in addition to activities in the catchments which may have accelerated physical processes such as sediment deposition and other materials (particularly organic and inorganic materials). Thus, marshes/ wetland habitats have been altered and as a result, the natural evolution of the lagoon may have been hindered. Hydrometeorological analyses and bathymetry survey also indicated that about 40 % of the lagoon's capacity has been lost to siltation or encroachment or both. Thus, the lagoon may be breached during the peak months of the rainy seasons and therefore not able to store all available water.

Aquatic macrophytes present included *Pistiastratiotes*, *Nymphaea* sp., *Eleocharis*, *Ipomoea aquatica* and duckweeds with *Paspalumvaginatum* and *Typhadomingensis* dominating around the banks, shallow sections and parts of the landing sites of the lagoon. The weeds contribute to health problems by providing suitable habitats, refuge and food for vectors of water-borne and water related diseases (snails, *Biomphalaria* sp. and *Bulinus* sp. for intestinal and urinary schistosomiasis; and mosquitoes for malaria). The amounts of fresh weight of plant matter estimated for the Fosu Lagoon pose a great threat to the life of the lagoon (Table 20). The death and decay of the plant matter will lead to the rapid silting up of the lagoon and therefore a reduction in the volume of water to be stored. The massive presence of plant matter also affects the quality of water from the reservoir since the decaying weeds add taste and odour to the water, decrease the oxygen content and inadvertently affect the fauna through oxygen demand reduction.

Table 20: Wet weight of plant samples harvested from the 0.25 m^2 quadrat at the sampling sites

Site	Sample 1 (kg)	Sample 2 (kg)	Sample 3 (kg)	Mean value (kg)	Weight of samples in kg/m^2
1	3.30	3.35	3.50	3.38	13.52
2	4.20	4.50	4.85	4.52	18.08
3	3.45	3.80	3.80	3.68	14.72
4	3.20	3.40	3.15	3.25	13.00

The mangrove community showed that it has been extensively degraded due to changes in the sedimentary environments, except for a strand of *Avicenniagerminans* around the Fosu shrine and near St. Augustines College area.The degradation of the mangrove community has also resulted in the loss of roosting sites of some migratory birds. The impact of this loss of mangrove cover reduces ecosystem services such as fish breeding and nursery as well as erosion control.

It was concluded from the study that the lagoon was unsuitable for domestic, recreational and aquaculture use and should the current trend continue, the fisheries of the lagoon could collapse in the near future. To improve upon the bacteriological quality of the lagoon, there should be adequate infrastructure to properly treat domestic waste before discharging into the lagoon. Also, dumping of refuse indiscriminately at the banks and within catchments of the lagoon should be prohibited and the bacteriologically unsafe fishes caught from the lagoon should be adequately cooked before consumption.

To restore the fisheries of the lagoon and ensure sustainable exploitation, the following recommendations were proposed taking into consideration the concerns of fishers:

- Enforce non-fishing days - This could ease the fishing pressure and give the fish some respite.
- Ban the use of 2-man drag net - The mesh size of these nets is too small and virtually scooped all sizes of fish from the lagoon. Additionally, their catch rates were too high and unsustainable.
- Control the spread of weeds - Gradually the size of the lagoon was being reduced due to the spread of aquatic vegetation.
- Re-open old bridges - The new bridge now in place, unlike the two old ones, had its bottom raised above that of the lagoon so does not allow easy flow of sediments from the lagoon into the sea whenever the sand bar is breached leading to siltation of the lagoon.
- An association of fishers should be formed and the executive given full legislative backing by the Cape Coast Municipal Assembly (CCMA), the District Assembly and the Traditional Authority to enable them manage the Lagoon resources by enforcing existing regulations and enacting new ones and also sanction deviants.
- Cape Coast Municipality Assembly should prevent human-induced impacts in the buffer zone, marshes/wetlands and floodplains of the lagoon to ensure the reduction in direct and waste leachates from draining into the lagoon.
- Existing bye-laws on buffer zone and catchment measures that will reduce sediment availability and pollutant thus, attenuate deposition via various channels to the lagoon should be enforced.
- Restoration of sediment traps (floodplains, marshes/wetlands) at the confluence of the drains or streams should be considered.
- Graduated metal/wire bars and meshes should be installed near the end of the artificial drains to prevent coarse and fine plastics and other solids from being deposited in the lagoon.
- Dredging at this time is not advised but may be considered after extensive investigations have been conducted to determine the hydrogeological stratification of the lagoon bottom.
- Installation of hydrometeorological station near the lagoon to provide environmental data for the management of the lagoon.

3.3.2 Impacts of Mining Operations on the Ecology of River Ankobra in Ghana

(Project Staff: Dr. H. R. Dankwa – Principal Research Scientist, Mr. Francis Amevenku – Senior Research Scientist, Mr. Solomon Owiredu – Research Scientist, Mr. Edem Amerdome – Technologist and Mr. Bright Awunor – Fisherman)

Mining and its associated activities could, among others, be responsible for considerable environmental damage, especially the ecology of riverine ecosystems. Pollution of water, damage to land and habitat destruction are some of the impacts that have been recorded in the past (UNEP, 1991). Changes in water quality and quantity and the structure of the environment have been found to have major modifying effects on fish population structure. In Ghana, gold is one of the main export commodities and mining occurs within the catchment of such rivers as Birim, Pra, Ankobra and Offin. Alluvial dredging practiced in these rivers result in the release of residual chemicals, not only in the dredging area but also further downstream. For example, studies conducted by the Center for Environmental Impact Analysis (CEIA) and Wassa Association of Communities Affected by Mining (WECAM) in 2008 and 2009, respectively, on the water bodies in the mining communities in Tarkwa Nsuem Municipality and Prestea Huni Valley District, revealed that out of 400 water bodies in the two districts, 250 of them had high levels of heavy metals such as arsenic, cadmium and lead, among others (Boateng, 2013). These rivers do not only serve as a source of drinking water for several communities but also serve as a source of livelihood, with respect to fishing and its related activities. Unfortunately, they have been gravely affected by small-scale mining activities. Chemicals used in mining operations may, consequently, affect man through the food chain. There is therefore the need to control the activities of these miners to ensure that the aquatic ecosystems are not unduly degraded. It was against this background that this study was initiated in 2012 and ended in the reporting year to assess the impacts of mining operations on:

- the water quality along the course of the river;
- primary productivity of the river; and
- the distribution of fish species, their diversity and community structure along the course of the river.

Three sites; one upstream which was outside the influence of mining operation and considered as control site, one within the mining area and the third site situated downstream of the mining area were sampled during the dry and rainy seasons to assess the quality of both water and sediment, and the distribution of algae and fish species along the course of the river. Gill nets of various mesh sizes were used to sample fish for two nights at each site. Species distribution and composition were assessed and a number of ecological indices calculated.

Turbidity, which was the most visible physical parameter of the water ranged from 43 NTU at Asawinso, the pristine area, to 342.3 NTU at Prestea, the mining area. The highest conductivity, total dissolved solids (TDS), total iron and sulphate levels were recorded at Dominase downstream of the mining area. However, the highest concentrations of nitrite and nitrate were recorded at Prestea and reduced considerably at Dominase. The pH ranged from 6.28 at Dominase to 6.76 at Asawinso and were within the recommended range for fish growth. The highest concentration of chloride was recorded at Dominase. Sediments from Asawinso and Prestea were mainly sandy while that from Dominase was muddy. Concentrations of trace metals in sediments, except iron (Fe) at Dominase, were below the WHO limits. The algae found were grouped into three; Chlorophyta (green algae), Cyanophyta (blue-green) and Bacillariophyta (diatoms). All three groups were found at Prestea, only Cyanophyta was found at Dominase while Chlorophyta and Cyanophyta were

found at Asawinso. Eight genera were identified at Asawinso while the least number of genera (five) was recorded at Dominase.

The fish fauna comprised 33 species belonging to 24 genera and 14 families. The highest number of species was recorded at Asawinso, the pristine area and the lowest at Dominase just like the distribution of phytoplankton. Of all the species caught, *Brycinus nurse* (Characidae) and *Heptus odoe* (Hepsetidae) occurred at all three sites. Twelve out of the twenty-two species caught were found only at Asawinso. *Parachana obscura*, *Brycinus longipinis* and *Mastacembelus sp.* formed 64 % of the total catch. *Pseudotholitus elongatus, Caranx hippos* and *Polydactilus quadrifilis* occurred at Dominase only, an area which had relatively high concentrations of sodium and chloride ions due to salt water intrusion from the marine environment. Asawinso recorded the highest catch per unit effort (CPUE) both in terms of number and weight followed by Prestea, while Dominase recorded the lowest for both weight and number. The low diversity indices at Prestea and Dominase confirm the poor water quality at these sites.

It can be concluded from this study that mining activities have adversely affected the abundance, distribution and community structure of fish and algal species as well as the quality of water along the river's course. Hence, it was recommended that efforts should be made to stop illegal mining activities due to the devastating effects not only on the quality of water but also on the biodiversity of aquatic ecosystems and the environment as a whole. Areas already devastated should be restored by reclaiming the land and embarking on forestation.

3.3.3 Sustainable Land and Water Management Project

(Project Staff: Dr. H. R. Dankwa – Principal Research Scientist, Mr. Edem Amedorme – Technologist and Mr. Bright Awunor – Field Assistant)

The study, in collaboration with the Environmental Protection Agency, started in 2012 to address issues pertaining to biodiversity and conservation of fish in the streams and rivers of the three Northern regions. The specific objective was to assess the conservation significance (national and international) of the aquatic species present in these streams/rivers and determine how possible changes in water quality and/or quantity due to climate change could affect such species. It is expected to end in 2016.

Fish samples were collected from thirteen sampling sites over a fourteen-day period using a battery of gillnets (monofilament and multifilament) with various mesh sizes. The nets were set overnight and retrieved the following morning at each sampling site. Cast net was also used in places where difficulties were encountered in deploying gill nets. Fishes caught from all the sampling sites were identified, weighed using an electronic balance and the total and standard lengths measured using a measuring board to the nearest 0.1 gram and 1.0 millimeter, respectively. The catch per unit effort (CPUE) was determined as the number and weight of fish caught per night at each site for the set of nets used. The Shannon-Weaver diversity (H') index, Margalef's species richness (D) and Pielou's Index (J) were used to describe and compare the diversity and structure of the fish communities at the sampling sites.

Results from the study showed that the fish fauna comprised of 23 species belonging to 15 genera and 10 families. The highest catch (2,572 g) of species was sampled from the White Volta at Naga and Buliko in the Builsa District and Pwalugu in the Talensi-Nabdam District.

The lowest catch (116 g) of species, however, was sampled from the Red Volta at Nangode and River Nakulaa at Zebila in the Talensi-Nabdam and Bwaku West Districts.

The White Volta River recorded the highest CPUE by number and weight while the Red Volta River recorded the lowest CPUE by weight. The fish caught during the study period weighed 4,741 g. The highest species diversity and evenness indices were recorded from the White Volta River. However, the species richness index was almost the same for fish communities in all the rivers sampled (Table 21). The high diversity index for fish community in the White Volta River indicates a highly complex community for a greater variety of species which allows for more species interactions. This is expected because the White Volta is the biggest amongst the rest of the rivers and is likely to offer more ecological niches. None of the species caught has been listed as endangered or threatened by the International Union for the Conservation of Nature (IUCN).

Table 21: Species diversity, richness and evenness of fish communities at the sampling sites

River/ Index	Kulpawn	Vrikpala	Sissili	Nakulaa	Red Volta	White Volta	Nasia
Diversity(H')	0.71	0.69	0.72	0.45	0.41	1.00	0.65
Evenness(J)	0.40	0.39	0.37	0.41	0.37	0.36	0.40
Richness (D)	2.17	1.33	2.04	1.44	1.24	3.85	1.92

3.3.4 Enhancing Food Security through Cage Fish Culture and Water Conservation by Reforestation of Reservoirs in Northern Ghana

(Project Staff: Mr. Etornyo Agbeko – Research Scientist, Dr. Felix Akpabey – Senior Research Scientist, Mr. Michael Kumi – Research Scientist, Mr. Gerard Quarcoo – Research Scientist, Mr. Salifu Abdul Latif – Principal Technical Officer, Ms. Millicent Adu-Boakye – Principal Technical Officer, Ms. Asabea Agadzi – Senior Technical officer, Mr. Emmanuel Bekoe – Senior Technical Officer, Mr. Michael Adu-Worae – Technical Officer, Mr. Richard Sevato – Fisherman)

In collaboration with the Ministry of Fisheries and Aquaculture Development, Forest Services Division of Forestry Commission, CSIR Forestry Research Institute of Ghana, Ministry of Local Government and Rural Development (MLGRD) and Foreign Affairs, Trade and Development, Canada (DFATD), started in the reporting year to establish the physical, chemical and biological water quality of the reservoirs and determine the suitability of the reservoirs for cage fish culture. The objectives were to:

- increase fish production through cage fish culture with fast growing 'Akosombo strain' of *Oreochromis niloticus* to ensure food security and alleviate poverty;
- create green belts through the planting of *Cassia sp.* for water conservation in the reservoirs for sustainable fish production;
- monitor reservoir water quality and identify any spatial or temporal variations in relation to cage fish culture to ensure reservoir ecosystem health; and
- make recommendations in respect of water quality for sustainable cage fish culture and fish production in reservoirs in Northern Ghana.

In the year under review, samples of water from the Vea and Bontanga reservoirs were analysed physically, chemically and biologically to assess their current quality. The water samples were taken from the up-, mid- and down-stream of the reservoirs. Bacteriological parameters: total coliform, faecal coliform, *E. coli*, *Salmonella spp* and total heterotrophic bacteria were considered. In addition, baseline studies were carried out to assess fish catch from Bontanga and Vea reservoirs before the introduction of fish cage culture system. Eight sites were selected for fish cage culture. Sixteen cages measuring 5x5x2 m each were constructed and mounted at the sites. Some of the cages were stocked with fingerlings in

November and December. In addition 2000 seedlings of cassia were planted around the reservoir as green belt for water conservation.

The pH ranged from 7.31-7.58 pH units, making them slightly alkaline. The electrical conductivity of the samples from Bontanga and Vea reservoirs averaged 66.1µS/cm and 102µS/cm respectively. The total alkalinity levels of the reservoirs were within the WRC permissible limits for raw water (20 - 100 mg/l). High alkalinity could cause ammonia toxicity and algal blooms, hardens drinking water, cause pipe scaling, exacerbates the salinization of fresh water, alter water quality and harm aquatic life. The detailed physico-chemical results are presented in Tables 22 and 23.

Comparatively, lower bacterial levels were recorded in the Bontanga reservoir than the Vea reservoir (Figures 19 and 20). This could be attributed to the fact that household settlements were far away from the Bontanga reservoir as compared to the Vea reservoir. Hence, waste water from households could easily be washed into the Vea reservoir by runoff, thus contributing to the levels of bacteria. However bacterial levels (FC and TC) in both reservoirs were below WHO and USEPA permissible levels of 1000 FC/100ml and 10000 CFU/100ml for freshwater aquaculture.

Table 22: Physico-chemical analysis of water samples from Bontanga and Vea reservoirs

	Bontanga Reservoir				**Vea Reservoir**				
Parameter	upstream	Mid stream	Down stream	**Ave**	Upstream	Mid stream	Down stream	**Ave**	WRC TWQR
EC(µS/cm)	66.2	65.7	66.5	**66.1**	102.0	103.0	101.0	**102.0**	
TDS(NTU)	40.9	40.6	41.3	**40.9**	63.0	64.0	63.0	**63.3**	< 2
p H(pH-units)	7.34	7.33	7.31	**7.33**	7.58	7.45	7.51	**7.51**	6.5-9.0
Turbidity(NTU)	63.0	59.0	64.0	**62.0**	21,0	15.0	23.0	**19.7**	
Colour (Hz)									
NO_3-N	0.29	0.35	0.38	**0.34**	0.34	0.16	0.47	**0.32**	< 300
PO_4	0.150	0.065	0.085	**0.100**	0.028	0.058	0.030	**0.039**	0.1
SiO_4	27.9	32.5	28.8	**29.7**	21.4	19.8	21.7	**20.97**	
F	<0.01	<0.01	0.03	**0.03**	0.44	0.44	0.50	**0.46**	
Total Alkalinity	40.3	40.0	36.0	**38,8**	56.0	60.0	56.0	**57.3**	20-100
T/Hard	18.0	20.0	20.0	**19.3**	36.0	40.0	36.0	**37.3**	
Ca Hard	12.0	10.0	14.0	**12.0**	16.0	16.0	20.0	**17.3**	
Mg Hard	6.0	10.0	6.0	**7.3**	20.0	24.0	16.0	**20.0**	
TSS	31,000	34,000	38,000	**34,333**	26,000	29,000	20,000	**25,000**	
DO	5.5	5.0	4.8	**5.1**	4.2	4.5	4.8	**4.5**	
BOD	1.9	2.4	2.6	**2.3**	1.4	2.9	2.0	**2.1**	
Temp of H_2O (℃)					28.7	28.7	28.7	**28.7**	28-30
Temp of Air (℃)					27.8	27.6	28.6	**28.0**	

All units are in mg/l unless otherwise stated

Table 23: Major ions and trace metal analysis of water samples from Bontanga and Vea reservoirs

	Bontanga Reservoir				Vea Reservoir				
Parameter	Upstream	Mid-stream	Down stream	**Ave**	Upstream	Mid-stream	Down stream	**Ave**	WRC TWQR
SO_4	14.6	14.4	12.4	**13.8**	6.4	6.7	7.0	**6.7**	
Na	6.4	6.4	6.4	**6.4**	8.1	8.3	8.3	**8.2**	
K	3.3	3.3	3.3	**3.3**	3.6	3.6	3.6	**3.6**	
HCO_3	48.8	48.8	43.9	**47.2**	68.3	73.2	68.3	**69.9**	-
Ca	4.8	4.00	5.6	**4.8**	6.4	6.4	8.0	**6.9**	
Mg	1.5	2.4	1.5	**1.8**	4.9	5.8	3.9	**4.9**	
Cl	7.9	8.9	8.9	**8.6**	6.0	7.9	7.9	**7.3**	-
Fe	0.276	0.287	0.296	**0.286**	0.976	0.805	1.098	**0.960**	<0.01
Mn	0.103	0.104	0.107	**0.105**	0.714	0.595	0.437	**0.582**	<0.1-0.5

All units are in mg/l unless otherwise stated

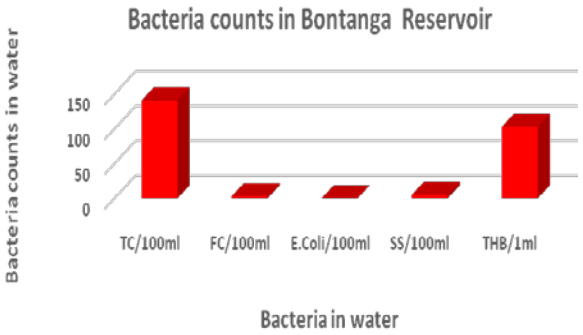


Figure 19: Variation of bacteria in the Bontanga reservoir

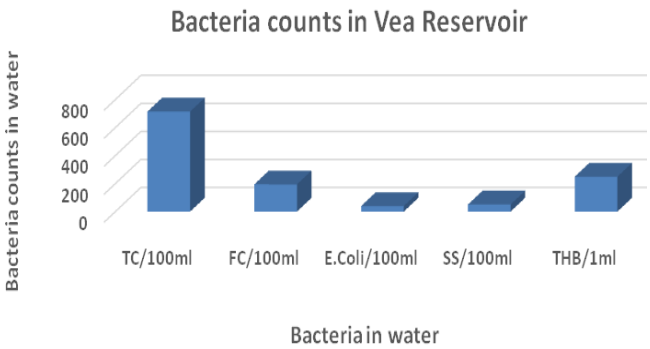


Figure 20: Variation of bacteria in the Vea reservoir

The baseline studies showed that 10 fish species from eight (8) families were recorded in the Bontanga reservoir. The family Cichlidae had the highest species diversity which included *Oreochromis niloticus, Tilapia zillii* and *Sarotherodon galilaeus.* In the Vea Reservoir, 8 species belonging to 5 families were recorded with Cichlidae dominating in species diversity (Table 24).

Table 24: Fish species composition in Bontanga and Vea Reservoirs

Family	**Species**		**Common name**
	Bontanga Reservoir	**Vea Reservoir**	
Claroteidae	*Auchenoglanis occidentalis*		Claroteids
Characidae	*Brycinus nurse*		Characins
Clariidae	*Clarias gariepinus*		Mudfish
Malapteruridae	*Malapterurus electricus*	-	Electric fish
Osteoglossidae	*Heterotis niloticus*	-	Bony tongue
Mormyridae	*Marcusenius senegalensis*		Elephant nose fish
Cichlidae	*Oreochromis niloticus* *Tilapia zillii* *Sarotherodon galilaeus*		Nile tilapia Red belly tilapia White tilapia
	-	*Hemichromis fasciatus*	*
Cyprinidae	*Raiamas senegalensis*	-	*

Note: - Not encountered, * unknown

In Bontanga Reservoir, catches were dominated by *A. occidentalis* (27 %) in terms of numbers and *M. electricus* (23 %) in terms of weight. In Vea Reservoir, *S. galilaeus* was the highest in terms of numbers (34 %) while 57 % of the catch constituted *C. gariepinus* by weight. From length measurements shown in Table 25, there were no remarkable differences in the mean size of fish that occurred in both reservoirs.

Table 25: Length distribution of fish species in Bontanga and Vea reservoirs

Species	Bontanga Reservoir				Vea Reservoir		
	Lower Total Length (cm)	Upper Total Length (cm)	Mean Total Length (cm)		Lower Total Length (cm)	Upper Total Length (cm)	Mean Total Length (cm)
Auchenoglanis occidentalis	15.0	31.2	24.0		15.4	28.2	22.3
Brycinus nurse	7.8	17.0	13.2		7.3	18.1	13.0
Clarias garipienus	15.0	35.0	20.0		22.0	53.2	39.5
Electricus malapterurus	30.0	30.0	30.0		-	-	-
Heterotis niloticus	34.0	34.0	34.0		-	-	-
Marcusenius senegalensis	29.4	35.6	31.7		14.8	38.4	31.7
Oreochromis niloticus	13.3	22.4	19.5		13.5	24.2	19.5
Raianas senegalensis	12.2	16.5	14.4		-	-	-
Sarotherodon galileaus	9.5	25.2	17.7		8.2	28.1	20.4
Tilapia zillii	11.5	20.1	17.0		11.0	22.0	17.0
Hemichromis fasciatus	-	-	-		6.2	18.3	15.4

Daily fish catches per canoe ranged from 1.0 - 34.5 kg at Bontanga Reservoir and 0.25 - 17 kg at Vea Reservoir. The major fishing gears at Bontanga and Vea reservoirs included gillnets, cast net, hook-and-line and traps. Gillnets constituted 98.7 %, cast net 1.0 % and traps 0.3 %. Bontanga Reservoir had an average depth of 6 m upstream, 7.5 m for midstream and 3 m for downstream zones, while Vea Reservoir had average depth of 5.5 m upstream, 5.9 m midstream and 2.9 m for downstream zones during the study period. Thus, the midstream zone was selected along each fish landing site of the reservoir for mounting of cages. Out of 16 cages mounted, 10 cages in the year under review had been stocked with 53,000 fingerlings of improved Akosombo strain of 'generation 7' *O. niloticus.* Fingerlings had grown from an initial mean weight of 1g to 11.8g over a 14 day period. It was however concluded from the preliminary results that Vea and Bontanga reservoirs were ideal for fish cage culture of tilapia, *Oreochromis niloticus.*

3.3.5 African Catfish, *Clarias gariepinus*, Hatchery Seed Production for Supply to Farmers and Research for Increased Farmed Fish Production in Ghana

(Project Staff: Dr. Joseph N. Padi – Research Scientist, Mr. Emmanuel Tetteh-Doku Mensah – Research Scientist, Mr. Justus Teye – Technical Officer, Mrs. Patience Atsakpo – Chief Technologist, and Ms. Mercy Johnson-Ashun – Principal Technical Officer)

The African catfish, *Clarias gariepinus*, is one of the promising local freshwater fishes that have potential to boost aquaculture production to address the staggering annual national fish supply deficit estimated at approximately 500,000 metric tons in 2013. The African catfish is environmentally tolerant of low dissolved oxygen due to unique adaptations of this species which allows it to breathe atmospheric oxygen just as land animals. Thus, the African catfish can be stocked at very high densities in fish culture facilities to produce yields in excess of 300,000 kg/ha (300 metric tons/ha). However, one of the challenges facing African catfish aquaculture as compared to other traditionally farmed fish species including the popular Nile tilapia, *Oreochromis niloticus*, is low fry and fingerling survival (< 60 %). This stems mainly from cannibalism and predation from aquatic insects and frogs when fry are stocked in earthen ponds. Therefore, research to identify production systems that could reduce mortality of catfish during hatchery and fingerling production is critical for year-round aquaculture. It was against this background that the study was initiated in 2010 and was completed in the reporting year to:

- evaluate hatchery and pond management systems for enhanced African catfish fry survival for efficient fingerling production; and
- develop new genetic types (genotypes) of African catfish which exhibit superior survival for maximization of fingerling output in catfish hatcheries.

In the reporting year, the feasibility of using hapas to nurse African catfish fry to fingerling stage in commercial quantities (several thousands) instead of nursing fry directly in earthen ponds was assessed. Eleven (11) female catfish brood stock were injected with Ovaprim, a commercial hormone, and fish were hand-stripped under hatchery conditions for production of purebred and crossbred catfish fry for survival assessment. The catfish fry used in the study were derived from four (4) genetic groups comprising two (2) purebreds (AXA; TXT) and two crossbreds (AXT; TXA). Fries were maintained on brine shrimp (*Artemia* spp.) for 16 - 19 days post-hatch in nine (9) rectangular and circular indoor concrete tanks. Fries were subsequently stocked in thirty (30) 3x1m^2 hapas mounted in two earthen ponds. An estimated 40,000 fries were produced and stocked in the hapas. Eighteen (18) out of thirty (30) 3x1x1m^3 hapas were used as experimental hapas for assessment of fry survival. The experimental hapas were stocked randomly with varied number of fry to assess fish survival. Mean fry stocking rate was 406 $\pm$ 245fry/hapa (range=13 -754fry/hapa) in the experimental hapas. Fries and fingerlings were maintained on commercial fish feeds.

At the end of the study, mean fry survival during 35 - 58 days post-hatch was high (84 $\pm$ 13 %; range = 57 - 100 %) in fine mesh net enclosures (hapas). This observed survival was the highest registered for catfish fry under pond nursery conditions at ARDEC. The high survival of catfish fry could be attributed to the use of hapas to nurse fry. The hapas apparently protected catfish fry from natural predators which included aquatic insects and frogs.

The study showed that survival of fry in hapas correlated negatively with stocking rates (r = -0.6353, R^2 = 0.403) and this observed inverse relationship was statistically significant (P< 0.05). Generally, fry survival was higher (81 - 84%) at intermediate stocking rates (400 – 500 fry/hapa, 133-167 fry/m^2) compared to survival (< 80%) at higher stocking rates (> 500 fry/hapa) (Figure 21). Therefore, practically, catfish fingerling production could be maximized per unit area of hapa space at intermediate stocking rates (400 - 500 fry/hapa) compared to lower or higher stocking rates based on the regression analysis. The smallest catfish fry that could be retained by hapas (mesh size = 1.7 mm) had a body weight of 0.01g.

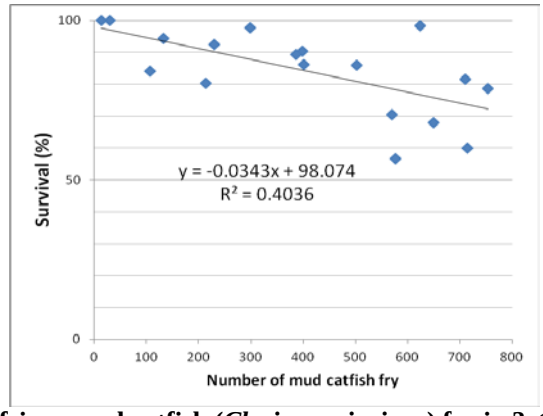


Figure 21: Survival of the African mud catfish (*Clarias gariepinus*) fry in 3x1x1m^3 fine mesh hapa nets at varied stocking rates in earthen ponds.

It was concluded from the study that catfish fry (< 21 days post-hatch) could be nursed in outdoor hapas inside ponds to enhance survival as compared to stocking them directly in open ponds. Recommendations proposed at the end of the study were:

- Catfish fry survival under commercial hatchery fingerling production settings could be maximized by using stocking rates of 400 – 500 fry/hapa.
- Research should explore the possibility of using hapa material with finer mesh size (< 1.7 mm) to allow fry to be transferred at younger ages to enhance fingerling turn-over and also ensure 100 % fry retention inside hapas.
- Conduct experiment to determine which of the four (4) genetic groups of catfish developed at ARDEC can optimize fingerling production and grow-out performance. This is critical for determination of whether genotype- environment interaction exists for the various genetic groups. It would enable adoption of all or selected genetic groups (genotypes) for efficient aquaculture production.

3.3.6 Improving Reproductive Performance of the African Bonytongue Fish, *Heterotis niloticus*, for Increased Fingerling Production in Aquaculture

(Project Staff: Dr. Joseph N. Padi – Research Scientist, Mr. Emmanuel Tetteh-Doku Mensah – Research Scientist, Mr. Justus Teye – Technician, Mrs. Patience Atsakpo – Chief Technologist and Ms Mercy Johnson-Ashun – Principal Technical Officer)

The African bonytongue, *Heterotis niloticus*, is freshwater fish that growths to relatively large size (> 1 kg) under one (1) year in farm ponds. The species is in high demand by fish farmers because of the potential of the species to attract high market price due to its relatively large size at harvest. The bonytongue also has above average consumer acceptability. One of the challenges facing bonytongue aquaculture is inadequate supply of fingerlings to farmers due to their decline in Ghana's water bodies emanating from over-exploitation. In response to the high demand for bonytongue fingerlings, research was initiated in 1998 at ARDEC to domesticate the species. The species however, does not tolerate other species in ponds during its reproductive period and fingerling survival in open ponds is low (< 50 %) in spite of their high fry output estimated at 2500 - 4000 fry per nest. It was against this background that the study was conducted to:

- assess the effects of increased African bonytongue brood stock density (stocking rate) on reproductive performance in earthen ponds;
- determine whether multiple use of the same nest occurs in the bonytongue to enable maximization of brood stock densities in reproduction ponds; and
- evaluate fry and fingerling performance in protective systems: concrete tanks and fine-mesh net enclosures (hapas), to enable artificial nursing of fry for enhanced fingerling production.

Activities undertaken in the reporting year included:

1. Assessment of effects of increased bonytongue stocking rate on reproductive performance

Three (3) experimental trials were carried out to assess reproductive performance of male and female bonytongue broodstock in two 0.2 ha ponds during the year at varied durations. In one of the ponds (Pond 24) bonytongue reproduction was studied from February 2013 to June 2013 and again from September 2013 to November 2013 in the same pond. Bonytongue reproductive performance was assessed in a second pond (Pond 23) from October 2013 to December 2013. Average broodstock weight was 1.5 kg. Stocking rates of broodstock were 560 fish/ha and 775 fish/ha in Ponds 23 and 24, respectively. Fishes were fed two (2) times

daily on a 33 % crude protein commercial diet at a rate of 2 % of fish body weight. Ponds were examined daily for reproduction evidenced by presence of fry in nests.

2. Evaluation of multiple use of same nest by bonytongue for reproduction.
Fourteen (14) bonytongue nests on the periphery of one of the ponds (Pond 23) were used from October 2013 to December 2013 for assessment of multiple nest use by fish. Nests were pegged randomly with stakes to aid identification of individual nests. Daily examination of all the 14 nests was conducted for presence of swim-up fry for the duration of the experiment.

3. Fry and fingerling survival in a protective system
Fry and fingerlings produced in the ponds stocked with broodstock were harvested from nest or open ponds using scoop and seine nets, respectively, and subsequently held in 3x1x1 m^3 hapas inside 0.2 ha ponds. Body weights of fry ranged from 0.012 – 0.015 g and 4-8 g, respectively. Stocking rates were 600 – 1500/hapa (200 -500 fish/m^2) for fry and 20 -100 fish/hapa (6 -33 fish/ m^2) for fingerlings. Duration of the experiment ranged from 14 – 30 days.

At the end of the study, bonytongue reproductive performance was improved by 88% to 150% compared to previous studies in 2011, apparently in response to increased broodstock density (575 fish/ha and 775 fish/ha) compared to the 2011 study (150 fish/ha). Thirty five (35) bonytongue reproductions were observed in the two (2) experimental ponds from February 2013 to December 2013. However, reproductive performance was marginal from February 2013 to June 2013 compared to the remainder of the months in which the trial were conducted. Only one (1) bonytongue reproduction was observed in the February 2013 to June 2013 trial. This was due to accidental introduction of tilapia fingerlings into the broodstock ponds. This once again demonstrated the sensitivity of bonytongue to other fish species during its reproductive period. Differences were observed between the numbers of fry harvested in nests as against number of fry harvested in open ponds. Mean number of fry harvested from nests was three (3) times higher than those harvested from open pond (2,063 $\pm$ 752 fry and 650 $\pm$ 265 fry, respectively).

Multiple use of same nest was observed by three (3) out of fourteen (14) nests used in the present study. The proportion (21%) of multiple nest use observed in the study was higher (14 %) than that observed in 2012. This suggested that increased broodstock density within the range of 130 – 560 fish/ha did not negatively impact multiple nest use by bonytongue.

Open pond harvested fry (< 1g) which were held in hapas at 100 - 200 fry/hapa had mean survival which was approximately eight 8 times (800 %) higher than fry harvested directly from nests (nets fry) [16.5 $\pm$ 8.2 % vs 2.2 %$\pm$ 3.4%]. Fingerlings harvested from open pond had higher survival compared to nest fry or open pond fry (Figure 22). It was observed that fry of 0.013 g held in hapas increased body weight approximately 55 times (5523 %) to attain a mean final weight of 0.718 $\pm$ 0.68 g after 30 days in the hapas.

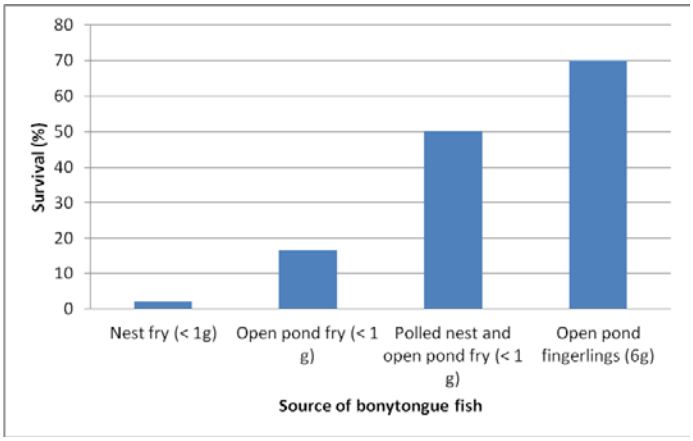


Figure 22: Comparative survival of fry and fingerlings of bonytongue fish, *Heterotis niloticus*, harvested from two different sources: nest and open pond, and held in 3x1x1 m^3 hapas at varied stocking rates (10 - 200 fish/m^2)for 14- 30 days.

It was concluded from the study that:

- bonytongue fry collection from nests maximizes fry output. However, this practice negatively affected fry survival;
- open pond harvested bonytongue fry provides a better alternative for maximizing fingerling output of bonytongue; and
- increasing bonytongue broodstock stocking rate within the range of approximately 600 - 800 fish/ha enhances multiple nest use and improves fingerling output in ponds.

Recommendations outined from the study included:

- Research into artificial fry management systems for increasing bonytongue fry and fingerling survival preferably under protective systems should be explored to ensure efficiency and predictability of bonytongue fingerling production for aquaculture.
- Information on new broodstock management procedures for increasing bonytongue fingerling output by manipulating stocking rates need to be disseminated to farmers.
- Evaluation of growth performance of bonytongue in diferent production systems towards diversification of aquaculture should be considered.

3.3.7 Breeding and Selection of *O. niloticus* for fast Growth

(Project staff: Dr Felix Yao Klenam Attipoe – Research Scientist, Dr Seth Koranteng Agyakwah – Research Scientist, Mrs Lily Ofori Boateng – Principal Technical Officer, Mr. Godfred Yeboah – Senior Technical Officer, Dr Raul W. Ponzoni – WorldFish and Hooi Ling Khaw – WorldFish)

The development of improved Nile tilapia seed for increased culture production has been going on at the CSIR Water Research Institute's (WRI) Aquaculture Research and Development Centre (ARDEC) since 1991. After almost a decade of breeding and selection, eight generations of improved strains of the Akosombo strain of the Nile tilapia have been developed and released to farmers since 2003. The releases of generations of the Akosombo strain coupled with the introduction of fish cage culture technology in early 2000s, both by the Institute, have contributed significantly to the fast growth of national aquaculture production (from 950 mt in 2001 to 15,000 mt in 2012) within the last decade. This new strain of tilapia has a higher survival rate and grows about 30 % faster than other farmed tilapia currently in the West African sub-region. Against this background and in collaboration with WorldFish, Malaysia, the study was undertaken to conduct on-station field work to produce an F_9 generation of the Akosombo line using single pair mating in hapas and estimate the genetic gain and response to selection.

During the reporting year, single pair mating system was used to pair selected males (sires) and females (dams) of the Akosombo line (F_9 generation) and also for the control line in 1x1x1 m^3 hapas. Harvested fry from 85 families comprising both the selected (56) and control (29) lines were nursed for 90 days and tagged with PIT tags after harvesting of fingerlings. Tagged fish were communally stocked in two replicated semi-intensive pond culture system, each of size 2000 m^2, and tested for 120 days. Biodata (Fish ID, age, standard and total lengths, width, weight) of individual fish were recorded and data processed with statistical software packages (SAS, ASReml etc.) to generate breeding values and other genetic parameters, which form the basis for estimating genetic gain and response to selection, leading to the selection of breeders for the next generation.

Part of harvest data generated for the test fish in communal culture of G9 selected breeders are presented in Table 26.

Table 26: Biodata information of G9 selected breeders at harvest

Research Station	Generation	Sire ID	Dam ID	Hapa/ Family No.	Harvest date	Standard length (mm)	Total length (mm)	Width (mm)	Weight (g)	Sex (F=1; M=2)	Hapa No.
ARDEC	9	69E 83D2	6D0 8A9D	44B	3/7/2013	140	183	38	98	2	39
ARDEC	9	69E 83D2	6D0 8A9D	44B	3/7/2013	159	208	45	142.4	2	37
ARDEC	9	69E 83D2	6D0 8A9D	44B	3/7/2013	128	162	36	72.8	1	52
ARDEC	9	69E 83D2	6D0 8A9D	44B	3/7/2013	146	190	40	116.5	2	43
ARDEC	9	69E 76E8	69E 8D47	53B	3/7/2013	126	163	35	64.3	1	64
ARDEC	9	6A2 04B3	6A2 224C	10B	3/7/2013	145	184	40	104.2	1	51
ARDEC	9	6A2 27EB	69E A393	20A	3/7/2013	160	207	45	143.5	2	40
ARDEC	9	69E 76E8	69E 8D47	53B	3/7/2013	133	170	37	73.7	1	62

Fifty five (55) families of selected line and 37 control families were generated and ranked based on their breeding values (Table 27). Selected sires were allocated corresponding dams and stocked in 1x1x1m^3 hapas. A total of 31,550 fry were produced in the first harvest in December 2013. Of the 55 families at spawn, only 12 families failed to spawn. The maximum number of fry per spawn was 1,189. More than 60 % of breeders had spawn size of more than 150. It is expected that there will be much more improvement in the spawning activities of breeders in order to select the required 200 fry per family for nursing and subsequent communal testing to produce G10.

Table 27: Mate Allocation for some individual breeders of Generation 9 Selection Line

No	Choices	Male				Female				Inbreed (F)
		Tag ID	Rank	EBV	Hapa	Tag ID	Rank	EBV	Hapa	
1	1st	6D72C5A (9000128)	1	1.8770	65	69DF232 (9001839)	3	1.9230	29	0.0486
	2nd	69E4319 (9000079)	2	1.8450	14	69DD558 (9001864)	9	1.8480	50	
	3rd	6D7A9E9 (9000097)	3	1.8330	8	69DF010 (9001881)	14	1.8130	47	
2	1st	69DC9EB (9001815)	4	1.8320	3	6A22039 (9000370)	91	1.5760	58	0.0469
	2nd	69DF558 (9001846)	9	1.7800	8	6A20A77 (9000328)	92	1.5750	31	
	3rd	69DDA46 (9001825)	11	1.7650	1	6A231FC (9000380)	96	1.5600	60	
3	1st	69E58D8 (9000845)	16	1.7530	41	66B3D8E (9000105)	1	1.9710	52	0.0486
	2nd	68E82A4 (9000830)	22	1.7190	63	69E6635 (9000121)	2	1.9250	51	
	3rd	69E4C55 (9000806)	24.5	1.7100	15	6D7980E (9000093)	4	1.9130	20	

3.3.8 Performance Comparison of Imported (GIFT) and Local (Akosombo) Strains of Nile tilapia *Oreochromis niloticus*

(Project staff: Dr. Felix Attipoe – Research Scientist, Dr. Seth Koranteng Agyakwah – Research Scientist, Mrs. Lily Ofori Boateng – P rincipal Technical Officer, Mr. Godfred Yeboah – Senior Technical Officer, Dr. Raul W. Ponzoni –WorldFish and Hooi Ling Khaw – WorldFish)

In the mid-2000s, farmers in the sub-region expressed strong desire to use improved tilapia strains, the local "Akosombo" and the imported "GIFT" from Asia for production. "GIFT" strain was developed more than 20 years ago by the Genetic Improvement of Farmed Tilapia (GIFT) Project involving several partner countries in Asia, Norway and WorldFish. GIFT fish has shown a remarkable genetic gain in growth rate and has out-performed other strains being used in a variety of farming systems in Asia. In 2008, a sub-regional project, "the Aquaculture Investments for Poverty Reduction in the Volta Basin: Creating Opportunities for Low-income African Fish Farmers through improved Management of Tilapia genetic Resources" was initiated. This Project with the acronym "TIVO Project" involved Ghana and five other countries of the Volta Basin, *viz;* Benin, Burkina Fasso, Cote d'Ivoire, Mali and Togo. These Volta Basin countries had expressed interest in the use of the new Akosombo strain of Nile tilapia for aquaculture production and development. Hence, the Institute in collaboration with FAO, Worldfish, Volta Basin Authority and the Government of Spain, initiated the study in 2008. The aims included characterization of wild and cultured Nile tilapia populations, continued development, improvement and dissemination of the improved strain, performance comparison of imported (GIFT) and local (Akosombo) improved strains and assessment of potential risks involved in the use of imported improved strains.

In the reporting year, sixty Genetically Improved Farmed Tilapia (GIFT) strain of Nile tilapia breeders were imported into Ghana from Malaysia in 2012 and held at the quarantine unit at

WRI ARDEC for three (3) months. Each of the 60 GIFT families that arrived was stocked in hapas mounted in circular tanks in the quarantine unit (Figure 23).

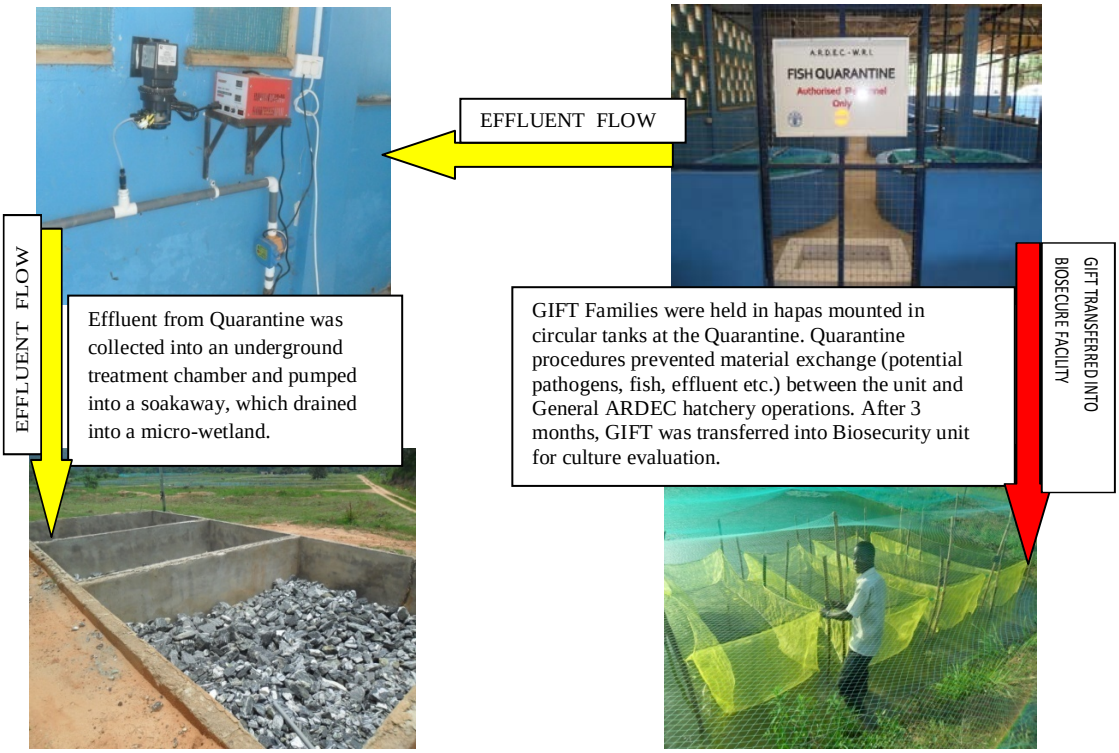


Figure 23: Flow diagram of quarantine procedures for holding and culture of GIFT

Twelve (12) breeders (9♀, 3♂) per strain were stocked in 3x1m^2, 10 replicates per strain. The initial mean fish sizes are presented in Table 28. Spawns of Akosombo and GIFT strains were each produced separately but synchronously from the 10 replicated spawning hapas. Spawn classes (eggs, sac-fry, swim-up) were determined, weighed and counted at each bi-weekly harvest from December 2012 to June 2013. Fertilized eggs were incubated in quarantine. Batches of fries were stocked in three (3) replicates of 1x1m^2 hapas installed in a 0.2 ha earthen pond at a density of 200 fry/m^2. Fries were nursed for 2-weeks and transferred into 3x1m^2 hapas.

Early-life culture was evaluated in hapas while juvenile were tagged with PIT tags and communally stocked in earthen ponds for the evaluation of their growth. Mortalities recorded with respect to fingerlings of GIFT tilapia imported from Malaysia was very high (51.35 %) during the first two weeks after arrival at WRI ARDEC. The cause of death was diagnosed as due to *Saprolegnia* infection. Death of fingerlings was minimized by dipping infected fingerlings in a solution of potassium per manganate ($KMnO_4$) (20 ppm) for 15 seconds. Mean seed produced by Akosombo strain of *O. niloticus* during the six-month monitoring was more than that of GIFT strain. Mean seed production per month was 138.99 ± 33.62 and 112.48 ± 34.10 respectively. Difference in seed production was however not significant ($P>0.05$) (Figure 24).

Table 28: Mean initial standard length (SL), total length (TL) and live body weight (BW) of GIFT and Akosombo strains of Nile tilapia breeders stocked in 3 m^2 spawning hapas

STRAIN	SEX					
	MALES			FEMALES		
	SL (mm)	TL(mm)	BW(g)	SL (mm)	TL(mm)	BW(g)
GIFT	186.8	238.7	252.6	169.7	215.7	188.3
AKOSOMBO	202.0	257.4	278.6	187.0	234.5	220.8

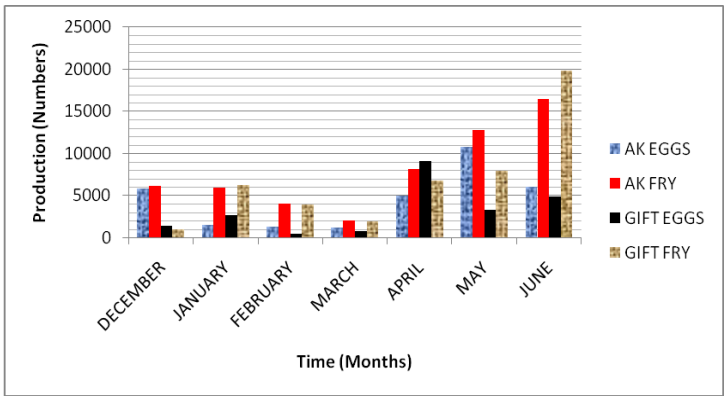


Figure 24: Mean monthly seed production of Akosombo and GIFT Strains of Nile Tilapia, *Oreochromis niloticus*

Fry growth evaluation of all four batches in hapas showed leading trends by GIFT strain over that of Akosombo strain. Mean daily growth rate in terms of standard lengths, total lengths and weights of juveniles of GIFT strain in the communal culture were all higher than those of the Akosombo strain. Differences in the growth rate parameters were however not significant ($P>0.05$) between the strains (Figure 25: Table 29). The relatively fast growth characteristics of the early-life of GIFT could be an attribute of the cumulative gains of genetic improvement over several years, compared to the genetic gains within the Akosombo strain over relatively shorter selection period.

GIFT strain appeared to be socially more aggressive on feed at surface of water, compared to Akosombo strain, as the success rates of capture during sampling (using feed as bait) were significantly higher ($P < 0.05$) in the GIFT. There was also significant linear trend among sampling. This behavior suggest that GIFT might have consumed more feed and converted them efficiently, thereby increasing the rate of growth compared to Akosombo strain. This could partly explain why growth of GIFT was higher than that of Akosombo strain. The comparative evaluation study between Akosombo and GIFT strains is on-going.

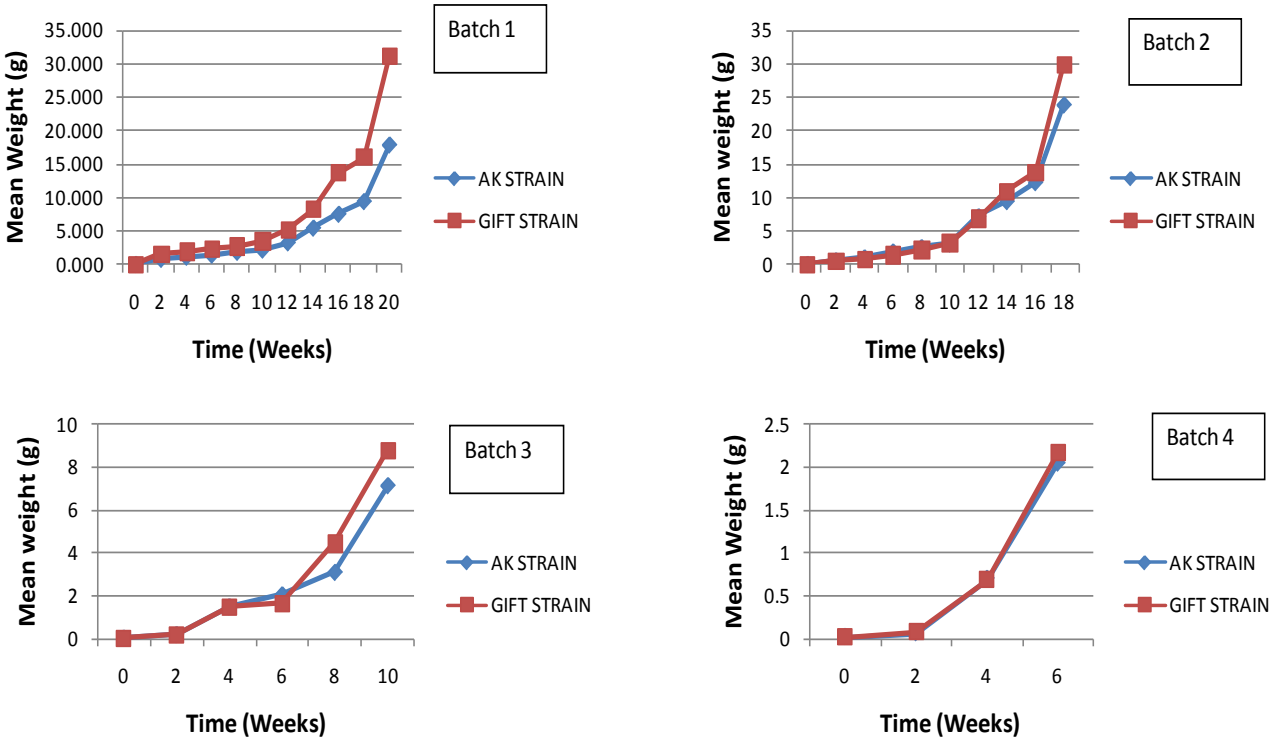


Figure 25: Early-life growth comparison of four batches (1 to 4) of Akosombo (AK) and GIFT strains cultured in separate hapas (3m^3 size), in 0.2ha pond for various numbers of weeks at ARDEC

Table 29: Mean standard lengths (SL), total lengths (TL), weights (Wt) and daily growth rates (MDGR) of juveniles of Akosombo and GIFT strains of *O. niloticus*, communally cultured and monitored in 0.1ha. pond for 64days at WRI-ARDEC

		AT STOCKING		SAMPLING						MDGR* (mm/day or g/day)
	PARAMETER	2013-05-08	(s.e.)†	2013-05-30	(s.e.)	2013-06-20	(s.e.)	2013-07-11	(s.e.)	
AKOSOMBO STRAIN	SL (mm)	49.59	0.246	72.78	3.353	84.05	2.868	93.75	1.677	0.690[1a]
	TL (mm)	65.08	0.323	92.78	4.239	106.26	3.411	119.63	2.143	0.852[2a]
	Wt (g)	**4.65**	**0.071**	**15.50**	**2.937**	**25.80**	**3.961**	**33.10**	**1.892**	**0.445[3a]**
GIFT STRAIN	SL (mm)	47.35	0.275	73.79	0.512	87.23	0.693	106.99	1.073	0.932[1a]
	TL (mm)	62.00	0.365	96.63	2.406	109.32	0.827	135.75	1.338	1.152[2a]
	Wt (mm)	**4.50**	**0.079**	**17.24**	**0.568**	**29.23**	**0.686**	**53.39**	**1.554**	**0.764[3a]**

† s.e. = Standard error

* Mean daily growth rates (MDGRs) with same superscript numbers are for comparison. MDGRs with same superscript letters for comparable pairs are not significant P>0.05.

3.4 GROUNDWATER DIVISION

The long-term objective of the Groundwater Division is to generate, process and disseminate information on the availability of groundwater, quantity of water to be abstracted for various uses as well as the reliability and sustainability of its recharge.

3.4.1 Re-optimization and Re-operation of Akosombo and Kpong Dams

(Project Staff: Dr. H. R. Dankwa – Principal Research Scientist, Dr. J. A. Ampofo – Chief Research Scientist, Dr. F. Akpabey – Senior Research Scientist, Mr. Solomon Owiredu – Research Scientist, Mr. Humphrey F. Darko – Research Scientist, Mr. A. Y. Karikari – Senior Research Scientist, Dr. William A. Agyekum – Senior Research Scientist and Dr. Anthony A. Duah – Research Scientist, Dr. O. D. Ansa-Asare – Principal Research Scientist, Mr. Mark Osa Akrong – Research Scientist, Mrs Regina Banu – Research Scientist,and Mr. Victor Mante, Mr. Godwin Amegbe, Ms. Hawa Ahmed, Mr. Edem Amedorme – Technologist and Mr. Bright Awunor – Fisherman)

The Akosombo dam was completed in 1965 and created the Lake Volta, the largest water storage reservoir in Africa and until recently the whole world whiles the Kpong dam, which operates as a run-of-the-river facility situated 25 km downstream, was completed in 1981. The construction of the two dams have considerably distorted the natural flows by storing and releasing water in rhythm with the patterns of electricity demand rather than the seasonal patterns of rainfall and runoff in the catchment area. The effect on the downstream flow pattern was to reduce the peak flows and increase the base flows, effectively eliminating the dynamic interactions between the river and its flood plains, wetlands, deltas, estuaries, mangrove and beach environments. The livelihoods of the downstream communities and the physical ecosystem processes on which they depend have also been devastated by the two hydropower dams. The results have been a drastic reduction in floodplain agriculture as natural flooding no longer leaves rich alluvial deposits that improve soil fertility in the overlying upland areas, and an explosion in the growth of exotic weeds that have choked off the once lucrative shell fishery, increased the snail vectors for bilharzia, and fostered the formation of a permanent sandbar at the estuary. The overall effects have created intense poverty and have led to a dramatic shift in income-generating activities. Some 80,000 people are directly adversely affected by the change in livelihood. It was against this background that the study was initiated in the reporting year in collaboration with the Center for African Wetlands (CAW), Institute of Environment and Sanitation Studies (IESS), National Heritage Institute (NHI), International Water Management Institute (IWMI), Volta River Authority (VRA), Water Resources Commission and GRIDCO. The overall objective was to produce a technically and economically feasible re-operation plan which will retain existing benefits of Akosombo and Kpong operations while improving livelihoods and ecosystems. The specific objectives were to:

- monitor the water quality of the dams to determine whether the water quality characteristics meet the designed criteria, and to estimate the extent of seawater intrusion from the estuary up the channel;
- improve hydropower generation at the Akosombo and Kpong dams;
- improve livelihoods and ecosystems on the Lower Volta River;
- contribute to a global process of shared learning;
- provide baseline hydrogeological information that would guide the general groundwater availability in the project area; and
- use the output of the analysed hydrogeological baseline data as inputs to determine the groundwater recharge and trends of the study area.

It is expected to end in 2015.

During the reporting year, a reconnaissance survey was undertaken at ten (10) selected sites: Adomi, Kpong, Amedeka, Volivo, Mepe, Adidome, Sokpoe, Agordome, Big Ada and Anyanui (Figure 26). Surface and bottom water samples were collected from the selected stations for physico-chemical and bacteriological analysis. The current status of the fisheries was assessed through experimental sampling with a set of both multi- and mono- filament gill nets. The relative abundance, longitudinal distribution, Catch per Unit of Effort (CPUE), Shannon-Weaver diversity index (H'), evenness index and species richness were determined. Observations of local fishermen's catches and interview of local fishers was also conducted to assess any impacts of re-operation and re-optimization.

Boreholes from 24 communities in seven (7) District Assemblies within the downstream part of the Akosombo and Kpong dams were selected for the study (Table 30). Available geological maps, satellite photos, topographic sheets, hydro-meteorological maps and existing borehole and hand-dug well data of the study area were acquired and analysed to provide information about the geomorphological and structural characteristics of the study area. Reconnaissance survey on the selected 24 boreholes was carried out. This was followed by pumping test (Figure 27) and the results obtained analysed using the classical Cooper-Jacob semi-log straight line method to estimate the aquifer characteristics (transmissivity coefficient and specific capacity) of the underlying basement aquifer. The computed hydrogeological characteristics were used to establish the general groundwater availability of the entire downstream part of the Akosombo and Kpong dams. Water samples from upper, mid and lower sections of the study area were also collected and analysed physico-chemically for parameters such as chloride, sodium, iron and total dissolved solids (TDS). Studies on aquatic weeds and their flow requirements at the ten (10) selected sites were also undertaken.

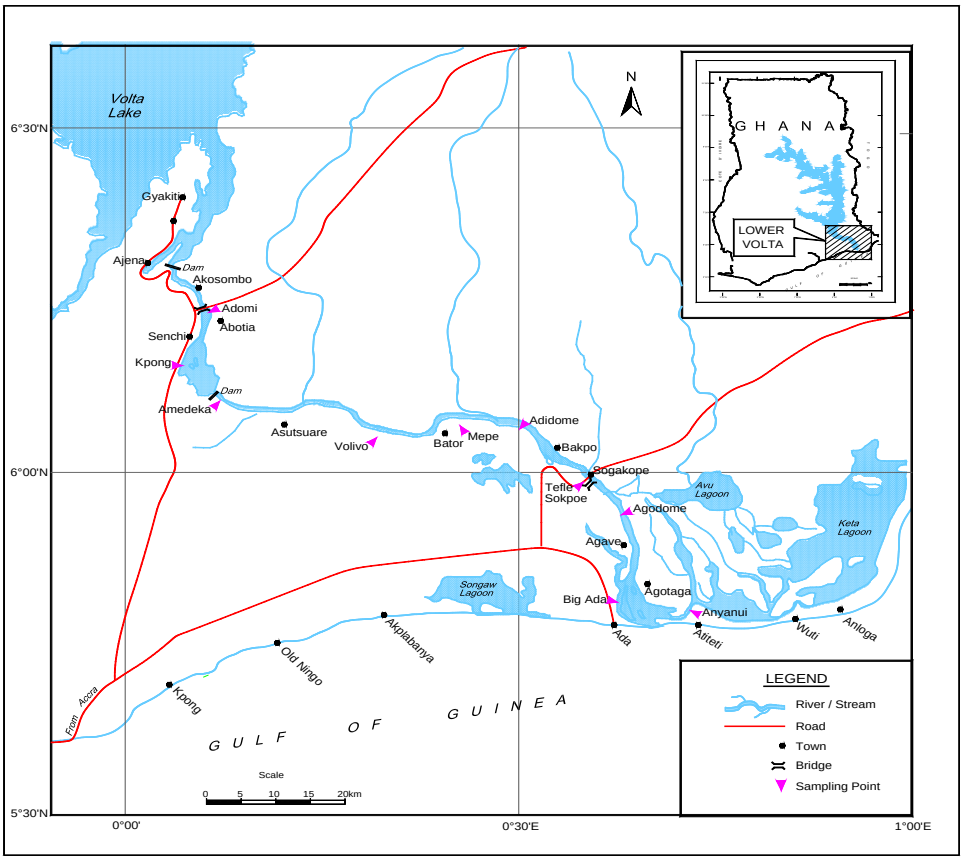


Figure 26: The Lower Volta River Basin showing sampling sites

Table 30: Pump-tested boreholes and their locations

No.	Community/borehole	District Assembly/ Municipality	District Capital	Pumping test Date	GPS location	Elevation (m)
1	Atimpoku District Ass	Asuogyaman	Atimpoku	6/6/'13	N6.24324°, E0.09076°	57
2	Ayermesu			7/6/'13	N6.21745°, E0.03255°	137
3	Tortibo			8/6/'13	N6.24649°, E0.02141°	110
4	Odorkorm			9/6/'13	N6.24703°, E0.04662°	276
5	Old Akrade			10/6/'13	N6.20301°, E0.10209°	27
6	Volivo	Shai-Osidoku	Dodowa	12/6/'13	N6.09977°, E0.25159°	19
7	Atrobinya			13/6/'13	N6.09399°, E0.22680°	18
8	Kewum			14/6/'13	N6.09677°, E0.22648°	25
9	Manya Battor (Nurses qtrs)	North Tongu	Battor	15/6/'13	N6.06318°, E0.40444°	16
10	Manya Battor (Methodist)			16/6/'13	N6.06055°, E0.39775°	14
11	Manya Battor (Atsu's hse)			17/6/'13	N6.05811°, E0.39801°	15
12	Mepe (St Kizito SHS)			18/6/'13	N6.07547°, E0.43070°	16
13	Mepe (Presby Church)			18/6/'13	N6.07869°, E0.43101°	19
14	Afiadenyigba (Adekykope)	Ada-West	Sege	19/6/'13	N5.93199°, E0.49813°	40
15	Afiadenyigba (Dogorbom)			20/6/'13	N5.96312°, E0.50071°	14
16	Sogakope (District Hosp)	South Tongu	Sogakope	21/6/'13	N6.00771°, E0.61621°	28
17	Vume			22/6/'13	N6.00884°, E0.54808°	16
18	Kpotame, (Lumor's hse)			23/6/'13	N5.98375°, E0.52270°	13
19	Kpotame (Vuvor's hse)			25/6/'13	N5.98438°, E0.52881°	15
20	Dabala (Snr High School)			26/6/'13	N5.98833°, E0.67761°	10
21	Anyako (Snr. High School)	Keta	Keta	24/6/'13	N6.00822°, E0.90182°	06
22	Mafi-Agoe	Central Tongu	Adidome	27/6/'13	N6.26365°, E0.52124°	15
23	Mafi-Avedo			28/6/'13	N6.13483°, E0.63956°	80
24	Srekpe			29/6/'13	N6.25850°, E0.66021°	61

Figure 27: Carrying out pumping test on a selected borehole

Generally, the results from the study showed that the lake is contaminated with bacteria (Table 31), making the water unsafe for drinking purposes. The level of bacteria count could be due to effluent discharges and runoffs within the catchments of the lake. However, zero (0 cfu/ml) *E. coli* and/or *Enterococcus sp.* was recorded in water samples from Anyanui, Big Ada and Agordome. Levels of the physico-chemical parameters investigated were all generally low, and characteristic of freshwaters, except at Anyanui, where the water samples exhibited seawater characteristics with high conductivity and chloride values (Tables 32 and 33). This implies that seawater intrusion into the channel at high tide is very minimal and for a short distance. The water samples were clear with high transparency values and this could enhance primary productivity. Although the water samples were low in nutrients, phosphate concentrations were relatively high. The pH values observed were within the TWQR for surface freshwater of 6 – 9 units.

Table 31: Summary of bacteria counts at the sampling sites

Sample ID	TC/100ml	FC/100ml	*E.coli/100ml*	*Entero/100ml*	THB/1ml
Anyanui	360	28	0	2	676
Big Ada	696	30	20	0	58
Agordome	432	14	0	0	124
Tefle/Sokpoe	930	38	10	4	176
Adidome	1256	24	4	4	3744
Mepe	1302	48	28	20	3276
Avakpo/Volivo	800	38	6	26	140
Amedeka	512	62	50	26	204
Kpong	372	160	46	64	2340
Adomi Middle	352	24	2	22	76
Adomi Bank	360	80	10	18	4212
Ghana standards GS 175-1 (Drinking water)	**0**	**0**	**0**	**0**	500
WHO guidelines (Drinking water)	**0**	**0**	**0**	**0**	
WHO guidelines (Bathing /recreation)	**500**	**100**	**100**		
Ghana Raw Water Criteria and Guidelines (Target Water Quality Range) for:					
Recreational Water Uses (Full contact)		**130**	**130**		
Domestic Use	**100**	**0**	**0**		
Aquaculture Use			**10**		

Table 32: Mean concentrations of Major Ions in surface waters sampled in April and May 2013

Place	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Chloride (mg/l)	Sulphate (mg/l)	Bicarbonate (mg/l$CaCO_3$)
Anyanui	496	22.5	22.9	53.6	804	203	26.8
Big Ada	6.33	4.35	4.40	2.00	5.00	12.7	18.5
Agordome	5.85	3.50	4.20	2.00	3.00	14.8	17.2
Tefle	5.75	3.40	3.15	2.20	3.00	15.0	15.9
Adidome	5.80	3.40	3.80	1.65	4.00	13.5	15.7
Mepe	5.20	3.25	3.75	2.60	2.50	14.3	18.3
Volivo	6.21	3.85	4.50	1.50	4.25	8.55	24.8
Amedeka	5.85	3.50	3.80	1.60	4.00	14.0	15.5
Kpong	5.70	3.50	3.85	2.10	4.00	14.2	17.4
Adomi	5.75	3.65	4.05	1.65	4.00	10.5	17.2
TWQR	**0 - 100**	**0 - 50**	**0-32**	**0 - 30**	**0-100**	**0 - 200**	**-**

Table 33: Concentrations of Major Ions in bottom waters sampled in June 2013

Place	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Chloride (mg/l)	Sulphate (mg/l)	Bicarbonate (mg/l$CaCO_3$)
Anyanui	475	22.5	24.7	54.1	745	198	27.6
Big Ada	5.00	3.20	1.60	1.90	4.00	4.35	19.3
Agordome	5.00	3.90	2.60	0.700	4.00	4.80	18.1
Tefle	6.00	3.80	1.30	1.50	4.00	4.38	14.6
Adidome	5.30	3.40	2.20	0.700	4.00	3.68	14.6
Mepe	5.10	3.50	2.20	1.30	3.90	4.00	18.3
Volivo	5.10	3.40	2.20	1.00	4.00	4.13	18.5
Amedeka	5.30	3.30	2.10	1.10	6.00	3.80	15.1
Kpong	5.10	3.30	2.40	1.00	4.00	3.00	18.1
Adomi	5.40	3.20	3.00	0.500	4.00	4.43	18.1
TWQR	**0 - 100**	**0 - 50**	**0-32**	**0 - 30**	**0-100**	**0 - 200**	**-**

Fifty-one (51) fin fishes and 5 shell fishes were recorded from the study area from both experimental and fishers' catches. Out of these, 36 were freshwater species, 8 brackish water species and 7 marine species. The fish species that were of most importance to the fisheries at the Lower Volta area were the tilapias (*Tilapia zillii*, *Sarotherodon galilaeus* and *Oreochromis niloticus*) and the *Chrysichthys* species (*C. nigrodigitatus* and *C. auratus*). The marine species, *Pomadasys jubelini*, *Trachinotus teraia* and *Lutjanus* spp were found as far as Mepe (about 45 km from Ada) whiles marine/brackish water species, *Liza falcipinnis*, *Caranx hippos* and *Eleotris vittata* occurred further up at Amedika (about 85 km from Ada). The West African manatee, *Trichechus senegalensis*, which is listed by the IUCN as endangered species, was reported by fishers to be present in the Adidome area.

The static water level values recorded prior to conducting the pumping test on each of the boreholes ranged from 1.5 - 16.35 m, with a mean value of 7.35 m. The highest static water level range was 3.78 - 7.2 m in the southern section of the study area at Battor and Mepe areas in the North Tongu-District, whilst the lowest static water level range was 1.5 - 16.3 m at Afiadenyigba in Ada-West District (Figure 28).

The pumping yield results showed yield values ranging from 0.6 - 6.6 m^3/hr. The lowest pumping yield values ranged from 0.6 - 4.5m^3/hr and averaged 2.5 m^3/hr at the northern section of the study area in the Asuogyaman District. The highest pumping yield values were recorded in the southern section of the study area at Battor, Mepe, Sogakope, Dabala, Vume, Kpotame, as well as Keta and Anyako areas in the North and South Tongu districts and in the Keta Municipality with pumping yield values ranging from 2.4 - 6.6 m^3/hr with a mean value of 4.5 m^3/hr (Figure 29). Analyses of the pumping test results revealed that borehole yields in the upper section of the study area near Akosombo were relatively low, whilst those close to the coast in the southern section of the study area were relatively high.

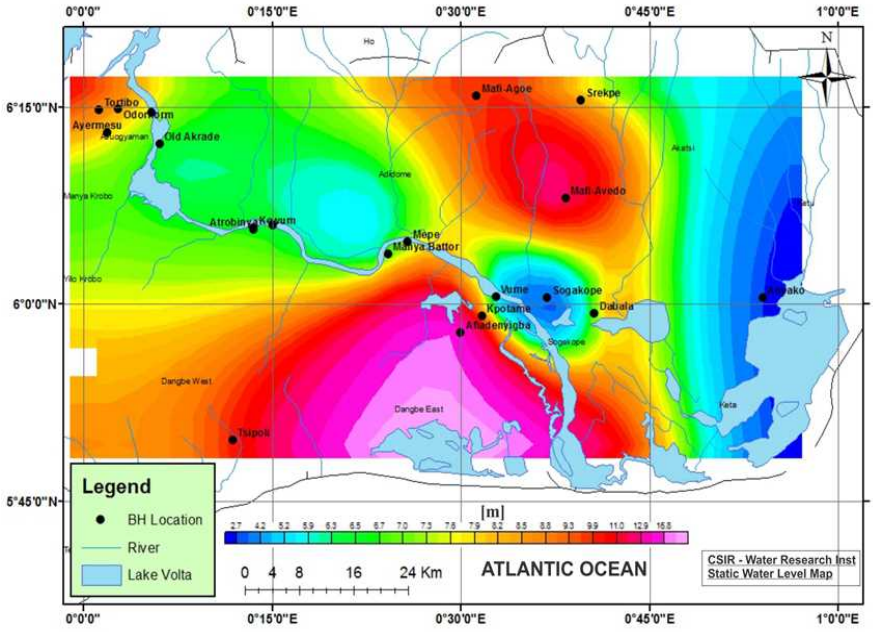


Figure 28: Static water level map of the study area

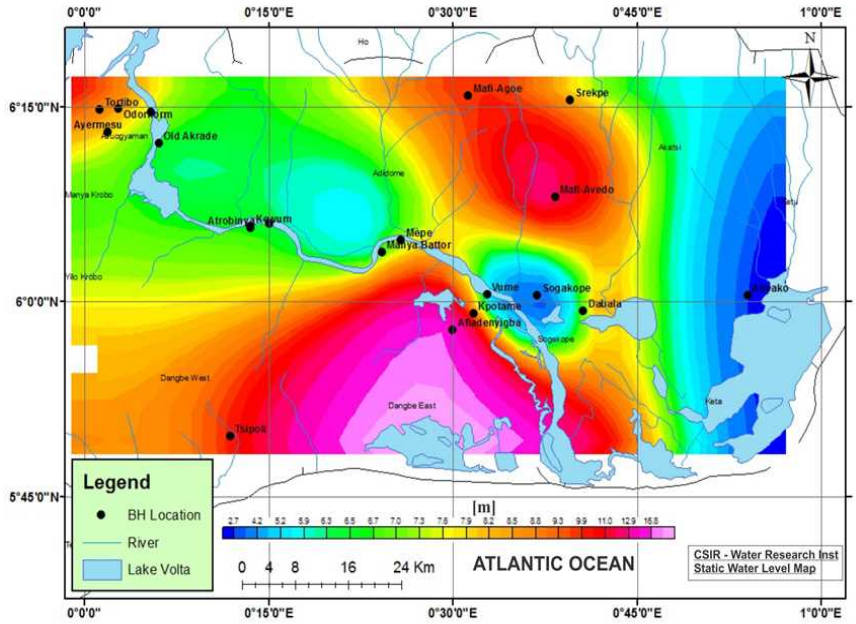


Figure 29: Borehole yield map of the study area

The computed transmissivity values of the underlying aquifer varied widely from 0.116 - 264 m^2/d across the study area, with relatively lower values (0.11 - 8.4 m^2/d) recorded in the northern and south-western sections of the study area near Akosombo and Ada-West districts. On the other hand, transmissivity values ranging from 0.13 - 264 m^2/d with a mean of 12 m^2/d were recorded in the southern section of the North and South Tongu districts and Keta Municipal (Figure 30). This may be due to the high porosity and hydraulic conductivity characteristics of the underlying sandy formation, which allows fast rainwater percolation to recharge the aquifers at the southern section of the study area.

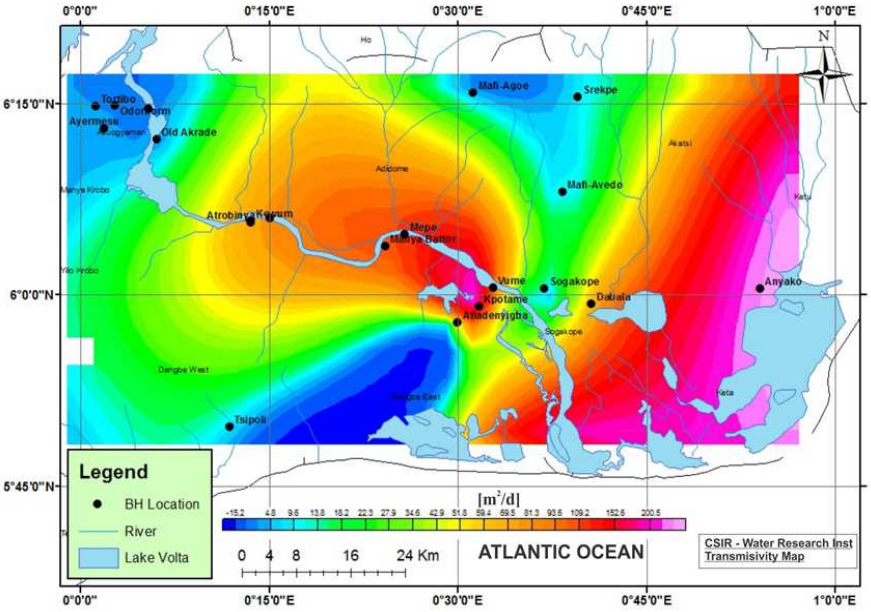


Figure 30: Transmissivity variation map of the study area

The computed specific capacity values of the entire downstream section of both dams ranged from 0.53 - 211.6 $m^3/d/m$. Higher values, which indicated relatively lower stressful nature of the aquifer to pumping were recorded in the mid-sections and the south-eastern sections of

North-Tongu (Mepe and Battor), through Central Tongu to South Tongu areas at Vume, Sogakope and Dabala to the coast around Keta in the south-eastern portion of the study area with values of 1.09 - 211.6 $m^3/d/m$. Lower specific capacity values were obtained in the north-western and south-western portions of the study area near Akosombo, Atimpoku and Old Akrade in the Asuogyaman District and in the Ada-West District. In line with the hydraulic characteristics of the underlying bedrock, the low transmissivity and specific capacity zones were recorded in the sections that were underlained by massive and less fractured acidic and basic Dahomeyan rock formation with low porosity and low water permeability (Figure 31).

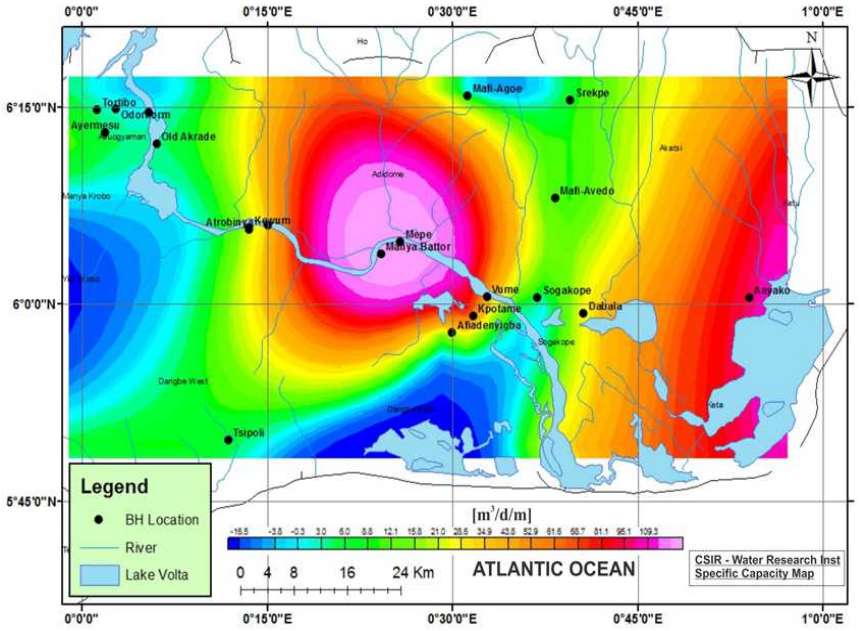


Figure 31: Specific capacity distribution map of the study area

The water quality results showed that the mean chloride concentrations increased from the northern section to the southern section with concentrations of 103.3 mg/l, 121 mg/l and 2,405 mg/l for the northern, middle and southern sections, respectively. In terms of sodium ions, the residual groundwater concentrations ranged from 44.5 mg/l in the north section, 199.5 mg/l in the mid section to 983 mg/l in the southern section. Total dissolved solids (TDS) concentration from the boreholes ranged from 421 mg/l in the north to 4980 mg/l in the south (Figures 32 and 33). The results indicated that the concentrations of sodium, chloride and TDS had significant water quality impact on the hydrogeology of the study area.

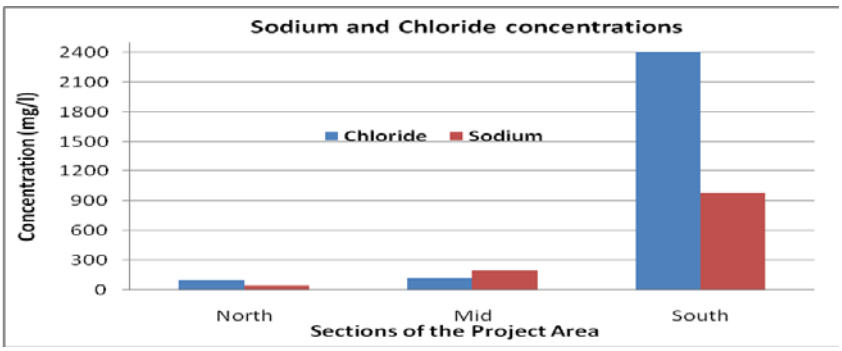


Figure 32: Graphical presentation of Na and Cl concentrations in the North, mid and south portions of the study area

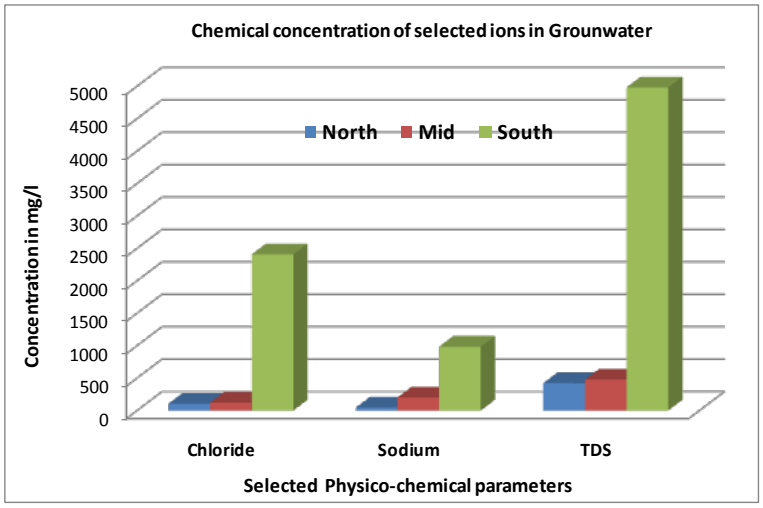


Figure 33: Graphical presentation of Na, Cl and TDS Concentrations in Groundwater samples in the Lower Volta Basin

The study also showed that construction of the two dams have led to the proliferation of emergent, free floating and submerged aquatic weeds (Table 34) in the Lower Volta, especially in the Kpong headpond.

Table 34: Distribution of aquatic weeds at the various sites in the Lower Volta

Plant Species	Sampling sites								
	Anyanui	Agordome	Sokpoe	Adidome	Big Ada	Mepe	Avakpo	Amedeka	Adomi
Emergents									
Aponogetonpectinatus		x	x		x	x			
Commelinadiffusa		x		x		x	x	x	
Cyclosorusstriatus		x							
*Cyperus*sp.		x							x
Echinochloapyramidalis		x							
Eleocharisacutangula		x			x				
Ipomoea aquatica		x		x		x	x		x
Leersiahexandra		x							
*Ludwigia*sp.		x	x	x		x	x	x	x
Marsilea sp.							x		
Neptuniaoleracea		x				x	x		x
Typhadomingensis				x					
Vossiacuspidata		x	x	x	x	x	x	x	x
Free Floating									
*Azolla*sp.		x				x			
Eichhorniacrassipes		x	x	x	x	x	x		
Pistiastratiotes								x	
*Salvinia*sp.		x	x	x	x	x			
Spirodellapolyrrhyiza							x	x	
*Nymphaea*sp.					x	x			
Submerged									
Ceratophyllumdemersum		x	x	x	x	x	x	x	x
Potamogetonoctandrus					x	x			
Vallisneriaaethiopica		x	x	x	x	x	x	x	

The number of species in the headpond has increased from 15 in 1981 to 65 in the current study consisting of 47 emergent, 12 free floating and 4 submerged species. More invasive alien species (*Eichhorniacrassipes*, *Cyperus papyrus* and *Salviniamolesta*) which were hitherto not there, have also invaded the headpond. The presence of the weeds has not only brought along with them various water borne diseases, the vectors of which are associated with the weeds, but also impedes fishing activities. The weeds however cannot survive in fast flowing waters, especially the free-floating ones, and also in saline conditions. The flow rate and regime is likely to change with the reoperation exercise. Since the distribution of aquatic plants is, to a large extent, influenced by environmental factors of which flow and salinity play a major role, increase in flow rate will flush away the weeds and most of them will perish with the intrusion of more saline waters.

3.4.2 Geophysical Investigation to Select Borehole Drilling Points in Some Selected Institutions in Cape Coast Municipality

(Project Staff: Mr. Manu Evans – Research Scientist and Dr. William A. Agyekum – Senior Research Scientist)

Following the recent water crisis that struck various institutions in Cape Coast Municipality and its environs, in collaboration with the National Security of Ghana, the study began and ended in the reporting year to carry out geophysical survey to locate possible drilling points for borehole construction, drill the selected points and fully construct the successful wells to solve the acute water shortage problems of the beneficiary institutions. The beneficiary institutions were University of Cape Coast (Hospital, Science Faculty, SRC Hostel, PSI Hostel, Lecturers Village and the Medical Student's Hostel), Center for National Culture (CNC), OLA Training College, Cape Coast Metropolitan Hospital, Cape Coast Polytechnic, St. Augustine's College, Adissadel College and Aggrey Memorial College.

Activities carried out included desk study, field reconnaissance and geophysical exploration. Vertical Electrical Sounding (VES) survey method was used to determine both the horizontal and vertical variations of rock resistivity with depth and further to delineate bedrock fractures. The VES ranked results for the selected locations of the study area is shown in Table 35 and a typical response curves for the apparent resistivity measurement is shown in Figure 34.

The results of the geophysical investigations indicated that Cape Coast area is generally underlain by three sub-surface geological strata with low apparent resistivity values. Based upon the results obtained, the following conclusion and recommendations were made:

- Test drilling in each institution should be in the order provided in Table 1
- If drilling proves successful with appreciable yield, the test wells should be developed into production boreholes.
- Water from the successfully-constructed boreholes should be sampled for physico-chemical and bacteriological analyses to determine their suitability for domestic and other uses.

Table 35: VES ranked results for the selected points

No.	Beneficiary Institution	Rank List of VES points
1	UCC SRC Hostel	1) SP1, (2) SP2
2	UCC PSI Hostel	1) SP4 (2) SP3
3	UCC Medical Hostel	1) SP6 (2)SP5
4	UCC Lecturers Village	1)SP9, 2)SP8, 3)SP7
5	UCC Science Faculty	1)SP2, 2)SP3, 3)SP1
6	UCC Hospital	1)SP2, 2)SP1
7	CNC Sub Area	1)SP1, 2)SP3, 3)SP2
8	OLA Training College	1)SP2, 2)SP1, 3)SP3, 4)SP4
9	St Augustine's College	1)SP2, 2)SP3, 3)SP1
10	Metropolitan Hospital	1)SP2, 2)SP1, 3)SP3
11	Aggrey Memorial Senior High	1)SP1, 2)SP2
12	Adisadel College	1)SP1, 2)SP2, 3)SP3
13	Cape Coast Polytechnic	1)SP2, 2)SP1

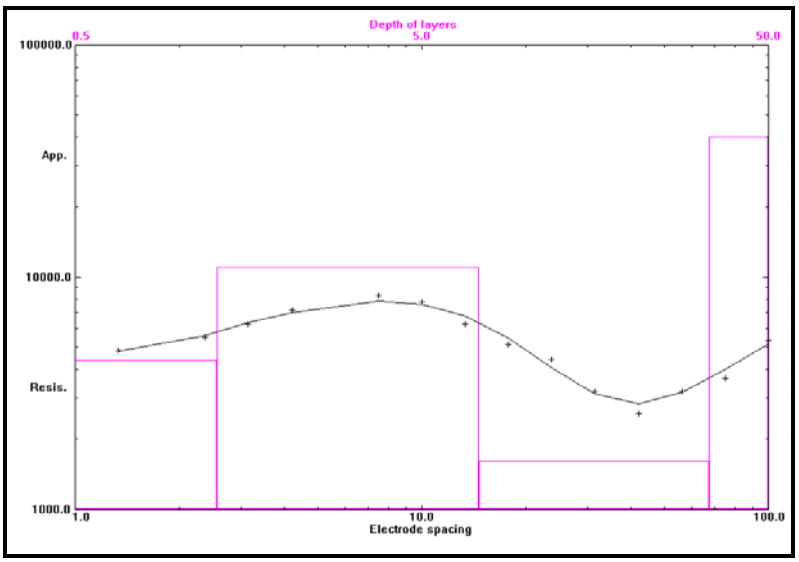


Figure 34: Typical VES Curve in the study area

3.4.3 Borehole Construction at the Premises of SSNIT Property Sites

(Project Staff: Mr. Collins Okrah – Research Scientist and Dr. William A. Agyekum – Senior Research Scientist)

High pressure on the use of water at SSNIT offices and its staff management flats as a result of the large staff strength coupled with extensive clientele service and the fact that dependence on Ghana Water Company Limited for water supply has not proven reliable over the years necessitated the study to construct mechanized boreholes at six (6) SSNIT Property sites within the Greater Accra Region. The beneficiary property sites included Ridge Tower, Premier Tower, Heritage Tower, Trust Tower, Dome Management Flats and Tantra-Hill Management Flats.

At least three points were selected at each site for Vertical Electrical Sounding (VES) in order to obtain the best points for drilling boreholes in the area of study (Figure 35). The drilling results indicated borehole depth ranging between 52 – 108 m with the deepest well at Tantra-Hill Flats. The drilling yield ranged from 25 - 250 *lpm* with an average yield of 117 *lpm*. The aquifer zone within the Accraian Rock Formation ranged from 35 - 59 m whilst the aquifer zone within the Togo Series ranged from 74 - 99 m. The success rate of the drilling program was 83 % indicating five successful wells and one marginal well at the Premier

Tower, which was drilled to 104 m and backfilled. The pumping test results on the five successful boreholes indicated a safe discharge rate in the range of 15 - 144 *lpm* (Table 36).

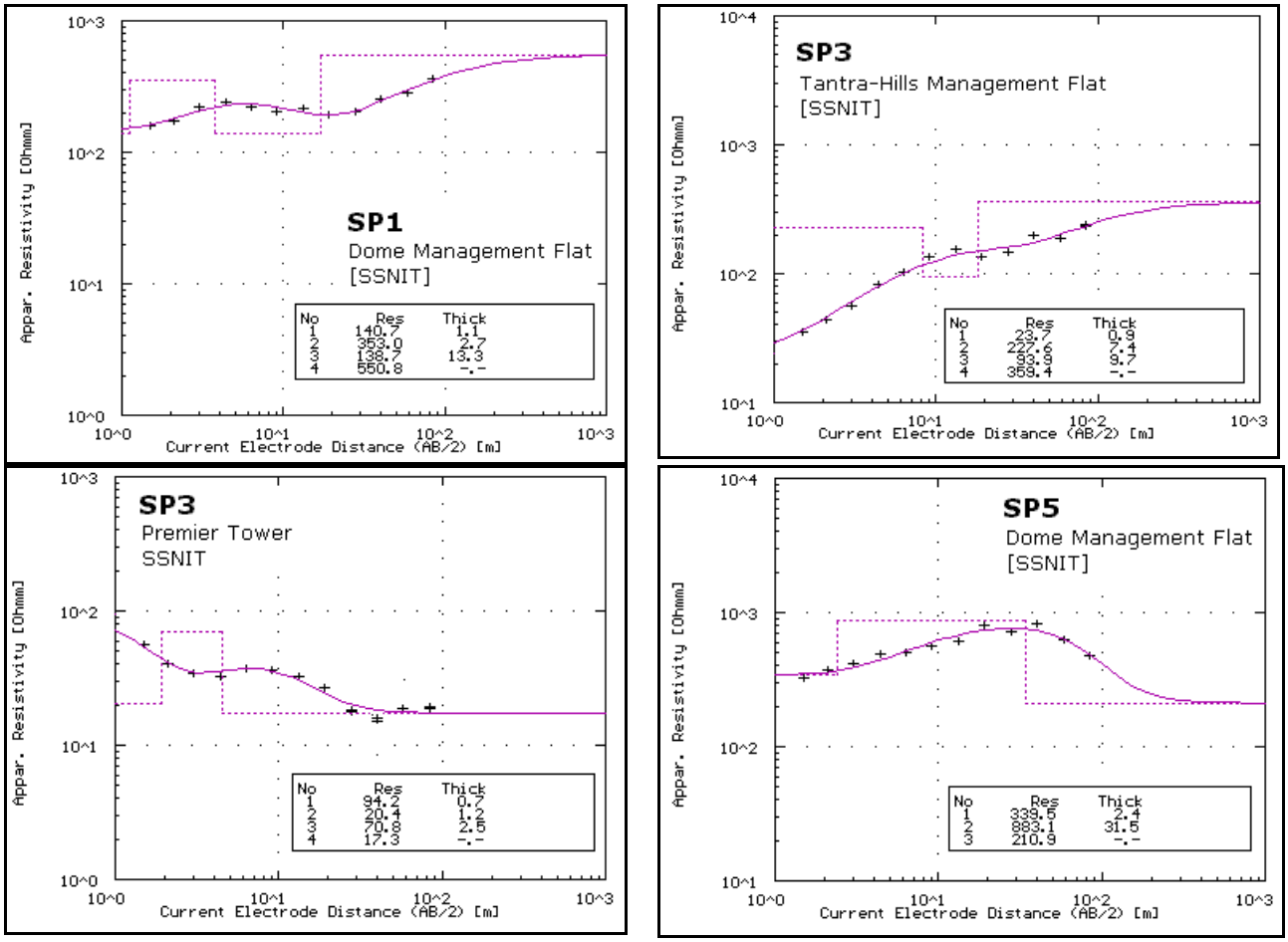


Figure 35: Typical VES Curves in the study area

Table 36: Pump installation and operations at the selected sites

Site	Pump type	Date installed	Borehole depth (m)	Aquifer Zones (m)	Installed depth (m)	Discharged Rate (lpm)	Discharge Period (hrs)	Recovery period (hrs)
Trust Tower	Grundfos -SQ255	February 2013	61	45-57	35	50	6	3
Ridge Tower			61	44-59	55	100	6	3
Heritage Tower			52	35-52	35	144	6	3
Dome Flats			94	74-93	60	15	6	3
Tantra-Hill Flats			108	75-99	75	30	6	3

3.4.4 Hydrogeological Investigations for 16 Boreholes in the Pru District (Point Source)

(Project Staff: Mr. Manu Evans – Research Scientist, Dr. William A. Agyekum – Senior Research Scientist and Dr. Anthony A. Duah – Research Scientist)

The study was undertaken to carry out intensive hydrogeological studies in sixteen selected communities in the Pru District to locate sub-surface aquifers (water-bearing rocks) that are capable of yielding substantial volume of groundwater for hand pump installation. It was initiated and completed in the reporting year in collaboration with TABCON. The beneficiary

communities included Dupordorkura, Labun Nsuano, Seila No. 2, Kadue/Doekura, Tonka, Gboradzikope, Kunkunde/Domeabra, Bassa Chief, Korancha, Gbrenkwanta, Kobre Nsuano, Zabrama West, Anyigbi No.2, Kamanpa Damankwanta and Nakpei Junction (Figure 36).

In the year under review, two (2) geophysical techniques: 2-D resistivity and Vertical Electrical Sounding techniques, were used to determine high groundwater potential zones to drill boreholes that could yield sustainable amount of groundwater for hand pump installation in each of the beneficiary communities. The 2-D Resistivity survey technique, which does both profiling and vertical electrical sounding (VES) concurrently, was used to investigate to a maximum depth range of 75 - 100 m along each traverse. Resistivity anomaly points on the 2-D profiles in each community were selected for further investigation using VES methodology.

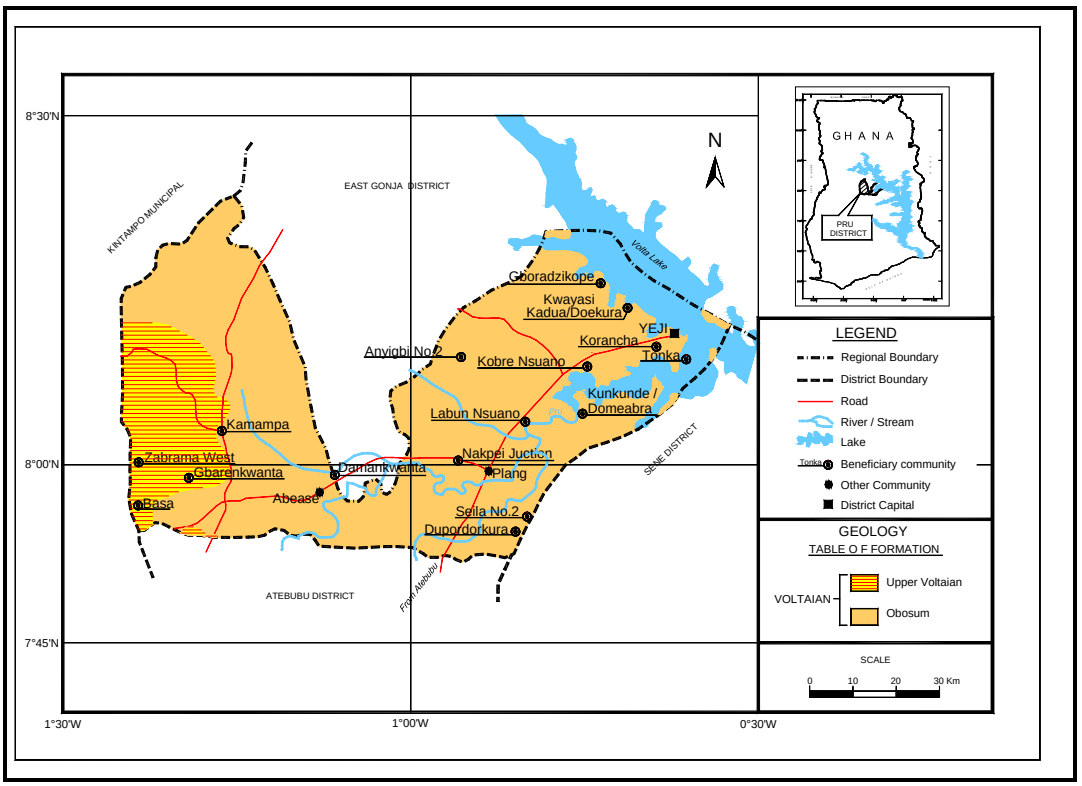


Figure 36: Location map of the beneficiary communities in the Pru District

The results of the 2-D resistivity survey showed the trend of resistivity variations of the sub-surface for a lateral distance of 400 m along each traverse. The analyses of the pseudo-section (Figure 37) provided information about the existence of fracture development within the underlying bedrock. Analytical results of the VES points (Figure 38) in the sixteen (16) beneficiary communities generally indicated that three and four sub-subsurface geological layers underlie the study communities. In each community, the second and third layers had relatively lower resistivity values and probably represented the major aquifer zone. These layers may be fractured to contain the necessary conditions for groundwater storage. The last layer was the slightly-fractured to hard bedrock and had some potential of yielding additional water to the main aquifer of the second and third layers. Based upon the results of the investigations, the groundwater potential at the sixteen communities was expected to be sufficient for hand pump installation. A summary of the rank-list of the VES points for drilling in each community is presented in Table 37. At the end of the study, it was

recommended that drilling must be carried out at the exact selected VES points in selected communities and the drilling should be done according to the ranking provided in Table 37.

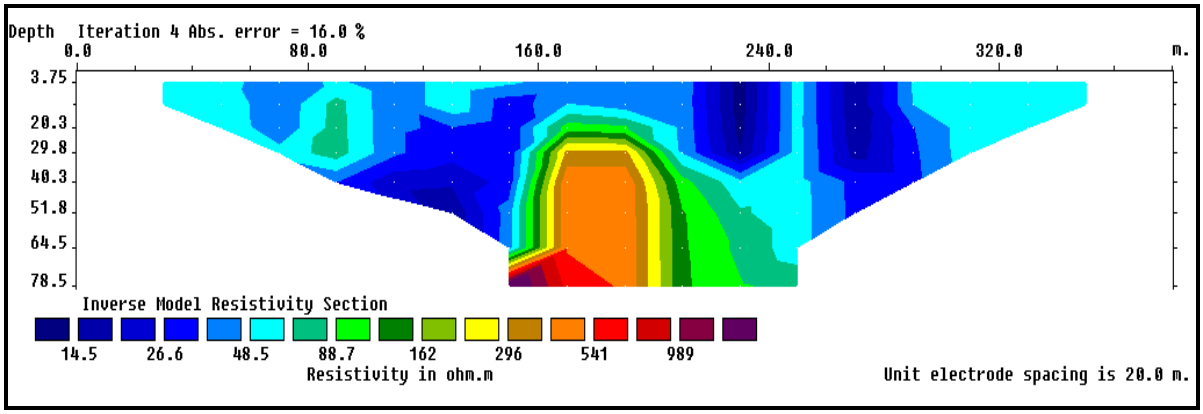


Figure 37: A typical 2D apparent pseudo section at Labun Nsuano

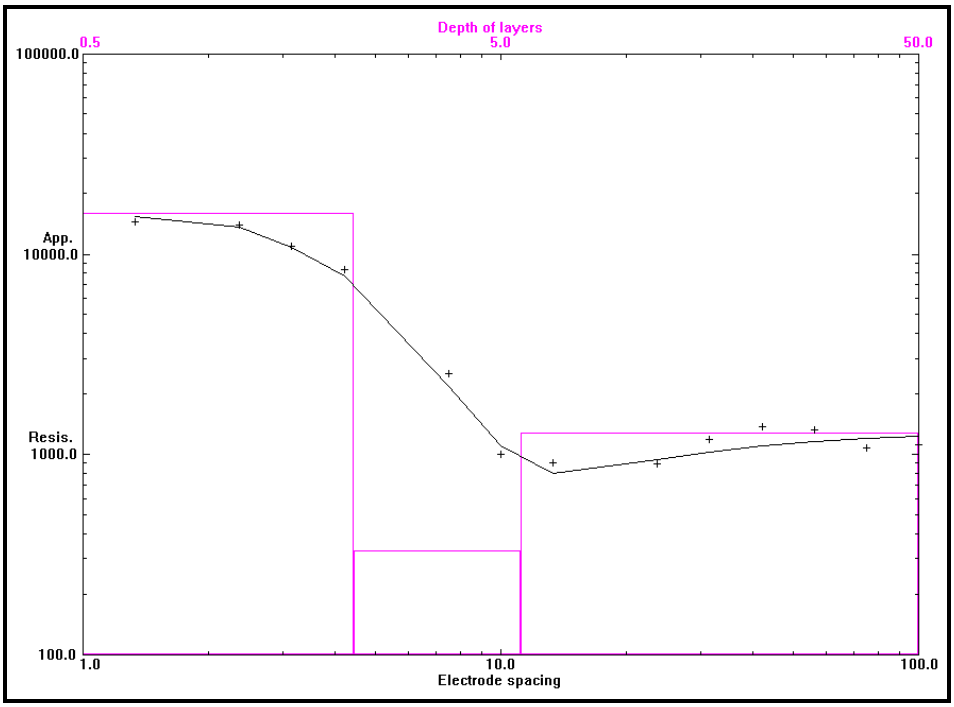


Figure 38: A typical VES modeled curve at Labun Nsuano

Table 37: VES results and their rank list for test drilling

Community	Geology	Rank-list of Drilling points	
		VES	**2-D Resistivity**
Dupordorkura	Voltaian Supergroup, Obosum Group	1) SP1 2) SP3 3) SP2	-
Labun Nsuano	Voltaian Supergroup, Obosum Group	1) SP2 4) SP1 5) SP3	2) A210 6) A140 3) A160
Seila No. 2	Voltaian Supergroup, Obosum Group	-	1) B160 2) B190 3) A120 4) A180
Kadue/Doekura	Voltaian Supergroup, Obosum Group	1) SP2 2) SP3 3) SP4 4) SP1	
Tonka	Voltaian Superproup, Obosum Group	3)SP1 4)SP2	1) A210 2) A240 5) A80
Gboradzikope	Voltaian Supergroup, Obosum Group	1)SP3 4)SP2 5)SP1	2)A160 3)A100
Kunkunde/ Domeabra	Voltaian Supergroup, Obosum Group	4)SP1 5)SP2	1) A160 2) A240 3) A120
Bassa	Voltaian Supergroup, Kwahu-'Morago' Group	2)SP3 4)SP2 5)SP3	1)A160 3)A240
Korancha	Voltaian Supergroup, Obosum Group	3)SP2 4)SP1	1)A220 2)A155
Gbrenkwanta	Voltaian Supergroup, Kwahu-'Morago' Group	2)SP1 4)SP2	1)A240 3)A160 5)A120
Kobre Nsuano	Voltaian Supergroup, Obosum Group	1)SP2 3)SP3 4)SP4	2)A180 5)A260
Zabrama west	Voltaian Supergroup, Kwahu-'Morago' Group	1)SP1 3)SP2	2)A140 4)A260
Anyigbi No. 2	Voltaian Supergroup, Obosum Group	1)SP2 3)SP1 5)SP3	2)A210 4)A90
Kamampa	Voltaian Supergroup, Obosum Group	1)SP3 2)SP2 5)SP1	3)A200 4)A140
Damankwanta	Voltaian Supergroup, Obosum Group	-	1)B230 2)B140 3)A260 4)A320
Nakpei Junction	Voltaian Supergroup, Obosum Group	2)SP1 3)SP3 5)SP2	1)A250 2)A80

3.4.5 Hydrogeological Investigations for 18 Boreholes in the Sene District (Point Source)

(Project Staff: Mr. Manu Evans – Research Scientist, Dr. Anthony A. Duah – Research Scientist and Dr. William A. Agyekum – Senior Research Scientist)

The Institute, in collaboration with TABCON, initiated and finalized the study in the reporting year. The purpose was to determine high groundwater potential zones in each community and the possibility of drilling boreholes that could yield sustainable amount of groundwater for hand pump water supply. The specific objective was to carry out intensive hydro-geological studies in each of the eighteen (18) communities to locate sub-surface aquifers (water-bearing rocks) that are capable of yielding substantial volume of groundwater for hand pump water supply in each of the beneficiary communities. The beneficiary communities were Kalipo, Kajaji, Kenkuase New site, Kyeamekrom, Okai Akuraa, Pantoon Line (Aboagye Addai), Akenten, Amponsah Akuraa, Danger Akuraa, DCE Residential Area, DCD Residential Area, Domeabra, Donkware, Drobe, Frobon, Kaboanya and Chokose (Figure 39).

The 2-D resistivity and Vertical Electrical resistivity techniques were used to site the boreholes in each of the eighteen (18) communities. The 2-D Resistivity survey technique was used to investigate to a maximum depth range of 75 - 100 m along each traverse. Resistivity anomaly points on the 2-D profiles in each community were selected for further investigation using VES methodology.

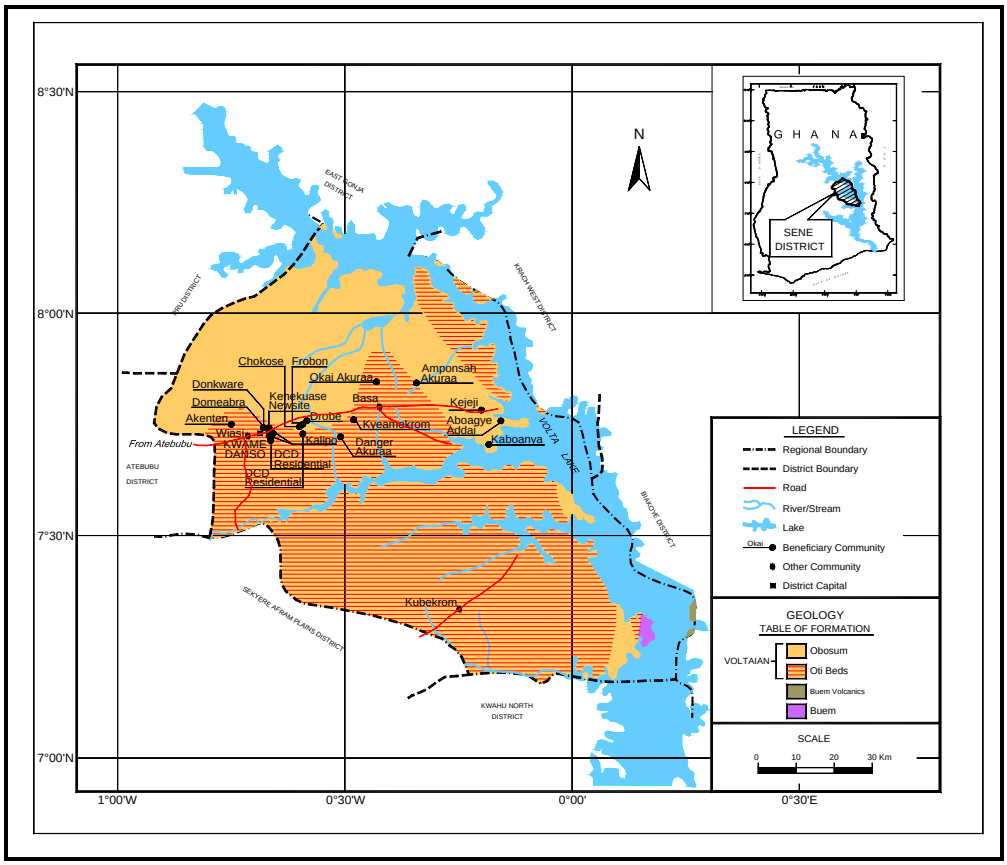


Figure 39: Location map of selected beneficiary communities in the Sene District

The results of the 2-D resistivity survey showed the trend of resistivity variations of the sub-surface for a lateral distance of 400 m along each traverse. The analyses of the pseudo-section (Figure 40) provided information about the existence of fracture development with the

underlying bedrock. The results of the VES points (Figure 41) in the eighteen (18) beneficiary communities generally indicated that three and four sub-subsurface geological layers underlie the study communities. In each community, the second and third layers had relatively lower resistivity values which was an indication of the existence of major aquifer zone. Hence, the layer might be fractured to contain the necessary conditions for groundwater storage. The last layer was the slightly-fractured to hard bedrock and probably had the potential to yield additional water to the main aquifer of the second and third layers. A summary of the rank-list of the VES points for drilling in each community is presented in Table 38.

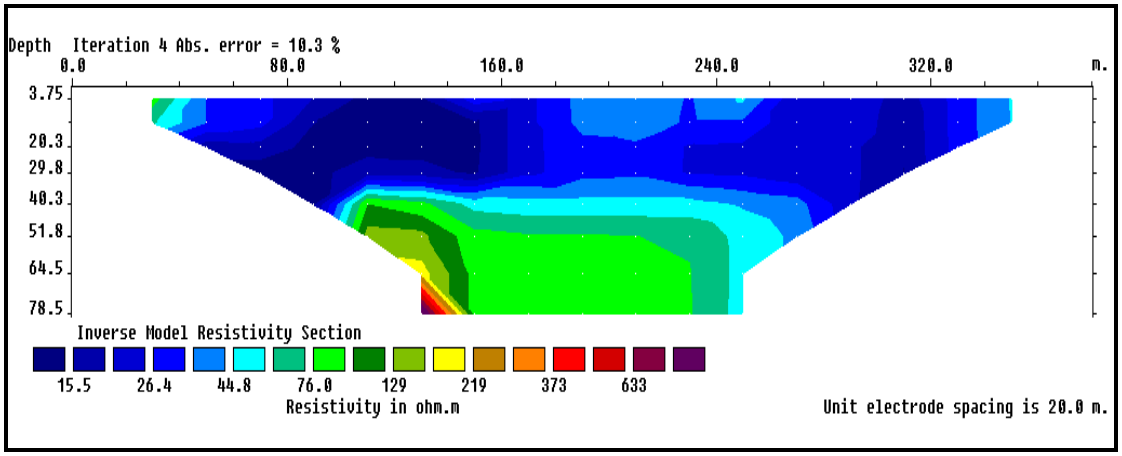


Figure 40: A typical 2D apparent resistivity Pseudo section at Drobe community

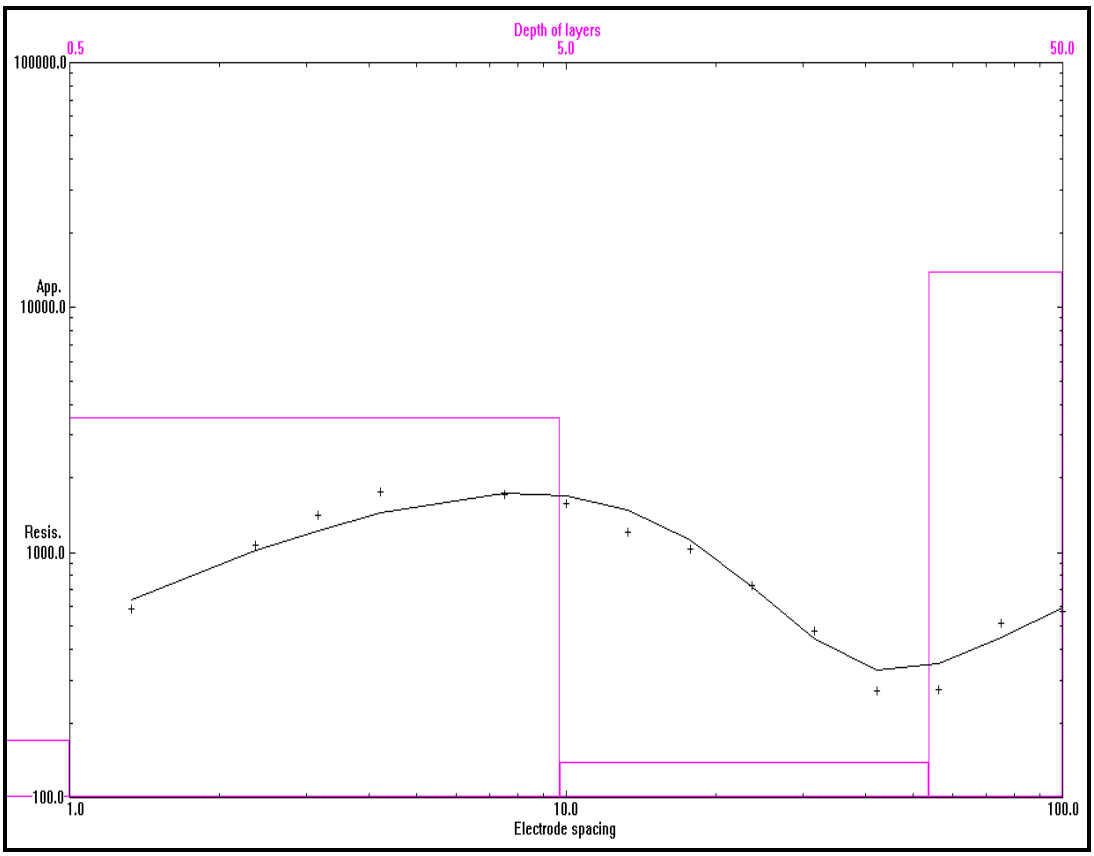


Figure 41: A typical VES modeled curve at Drobe Community

Table 38: VES results and their rank list for test drilling

Community	Geology	Rank-list of Drilling points	
		VES	2-D Resistivity
Aboagye Addai	Voltaian Supergroup, Obosum Group	2)SP2 4)SP4	1)A200 3)A160 5)A240
Akenten	Voltaian Supergroup, Obosum Group	1)SP4 2)SP3 3)SP1 4)SP2	-
Amponsa Akuraa	Voltaian Supergroup, Obosum Group	1)SP1 2)SP2 3)SP3	-
Chokose	Voltaian Supergroup, Obosum Group	1)SP4 2)SP3 3)SP2 4)SP1	-
Danger Akuraa	Voltaian Supergroup, Obosum Group	2)SP2 3)SP1	1)A310
DCD Residential	Obosum Group	1)SP3 2)SP1 3)SP2	-
DCE Residential	Voltaian Supergroup, Obosum Group	1)SP3 2)SP1 3)SP4 4)SP2	-
Domeabra	Voltain Supergroup, Kwahu-'Morago' Group	1)SP1 2)SP3 3)SP2	-
Donkware	Voltain Supergroup, Obosum Group	1)SP3 2)SP4 3)SP2 4)SP1	-
Drobe	Voltaian Supergroup, Kwahu-'Morago' Group	1)SP1 3)SP2	2)A160 4)A240
Frobon	Voltaian Supergroup, Obosum Group	1)SP3 2)SP2 3)SP4 4)SP1	-
Kaboanya	Voltain Supergroup, Kwahu-'Morago' Group	1)SP3 2)SP1 3)SP2	-
Kadipo	Voltain Supergroup, Obosum Group	1)SP2 2)SP4 3)SP3 4)SP1	-
KejejiNewsite	Voltain Supergroup, Obosum Group	1)SP2 2)SP1 3)SP3	-
Kalipo	Voltain Supergroup, Obosum Group	1)SP4 4)SP2 2)SP3 3)SP1	-
KenkuaseNewsite	Voltain Supergroup, Obosumgrp	1)SP3 4)SP1 2)SP4 5)SP2 3)SP5	-
Kyeamekrom	Voltaian Supergroup, Obosum Group	1)SP4 2)SP3 3)SP3 4)SP1	-
OkaiAkuraa	Voltaian Supergroup, Obosum Group	1)SP3 2)SP4 3)SP2 4)SP1	-

3.4.6 Hydrogeological Investigation on 12 Small Towns in the Brong Ahafo Region of Ghana

(Project Staff: Mr. Manu Evans – Research Scientist, Dr. William A. Agyekum – Senior Research Scientist and Dr. Anthony A. Duah – Research Scientist)

The purpose of the study was to determine high groundwater potential zones to drill high-yielding boreholes that could yield sustainable amount of groundwater for the Small Town Water Supply Project. The objective was to carry out hydro-geological studies in twelve (12) beneficiary Small Towns to locate sub-surface aquifers (water-bearing rocks) that are capable of yielding substantial volume of groundwater for mechanization in each of the beneficiary communities through piped water supply systems.

During the reporting period, the 2-D Resistivity and Vertical Electrical Resistivity techniques were employed to site the boreholes in each of the twelve (12) small towns (Figure 42). The 2-D Resistivity geophysical technique was used to investigate to a maximum depth of 149 m along each traverse. Resistivity anomaly points on the 2-D profiles in each community were selected for further investigation using VES methodology. A number of spot Vertical Electrical Soundings were also done in most of the small towns where due to lack of space, the 2-D Resistivity survey could not be done. All the VES points in each small town were pegged and labelled with wooden pegs in the field for easy identification purposes.

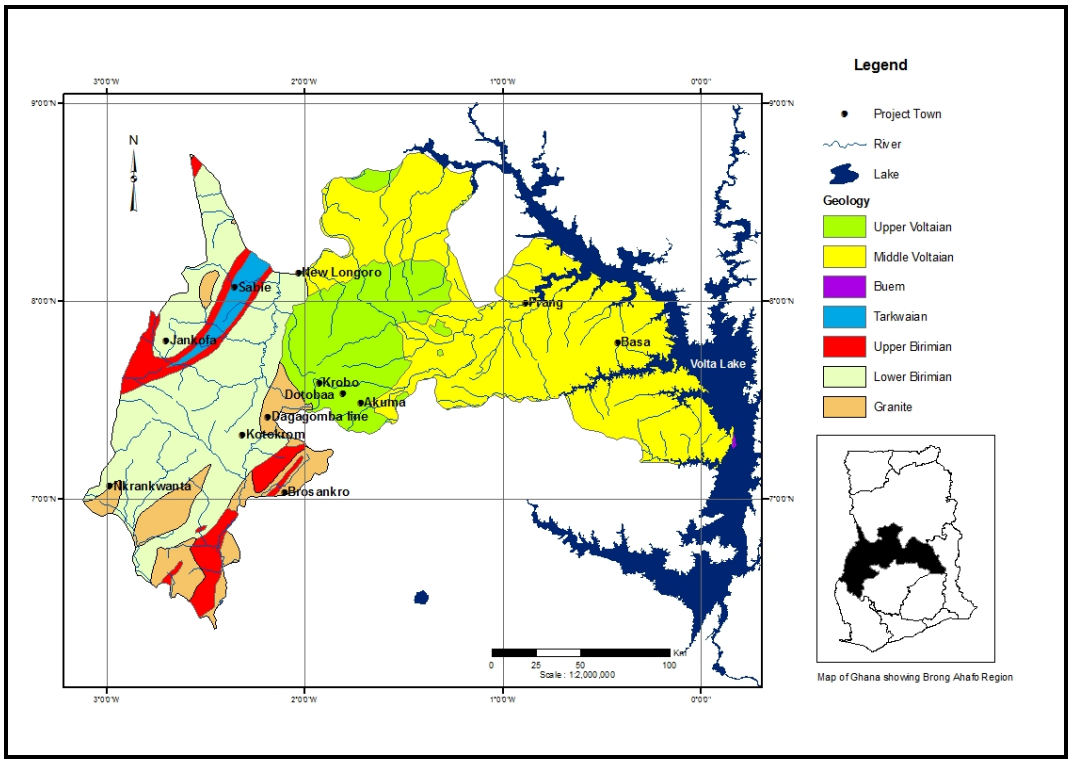


Figure 42: Location map of selected beneficiary communities in the Brong Ahafo Region

The results of the 2-D Resistivity survey showed the trend of resistivity variations of the sub-surface for a lateral distance of 400/800m along each traverse. The analyses of the pseudo-section provided information about the existence of fracture development within the underlying bedrock (Figures 43 and 44). The results of the geophysical investigations indicated that the various communities are generally underlain by either three (3) or four (4) geological strata with varying apparent resistivity values. The four strata are the overburden, the weathered zone, the moderately fractured zone and/or the fresh basement rock. Based upon the results of the investigations, the groundwater potential at Brosankro, Kotokrom and

Asiri-Jankofa was expected to be high, while the potential at Nkrankwanta, Dotobaa, Dagombaline, Krobo-Techiman, Prang and Akuma/Brahoho communities was expected to be medium to low. The potential in Sabie and New Longoro communities was expected to be low. Based upon the results of the studies, it was recommended that drilling must be carried out at the exact selected VES points in each town as shown in Table 39.

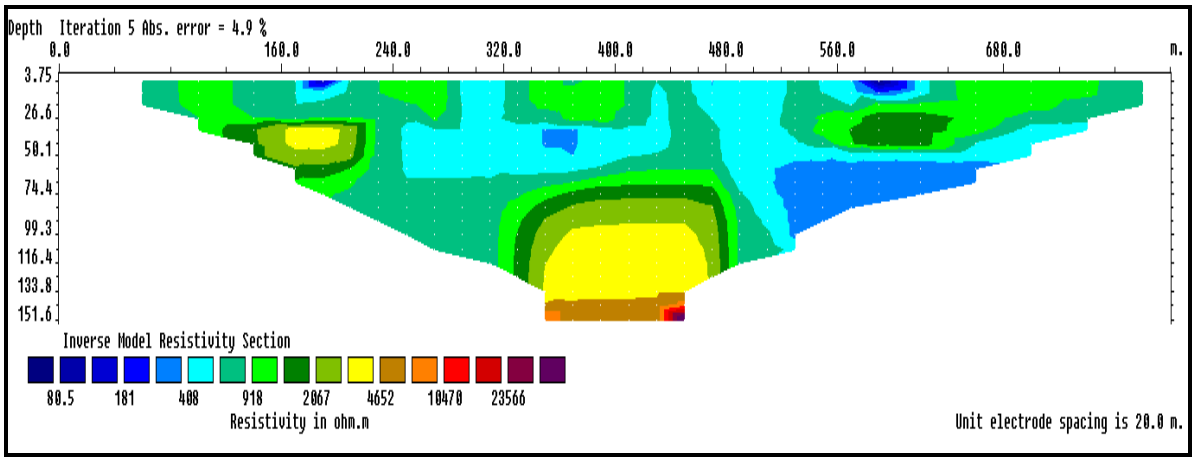


Figure 43: A typical 2D resistivity pseudo section at Nkrankwanta

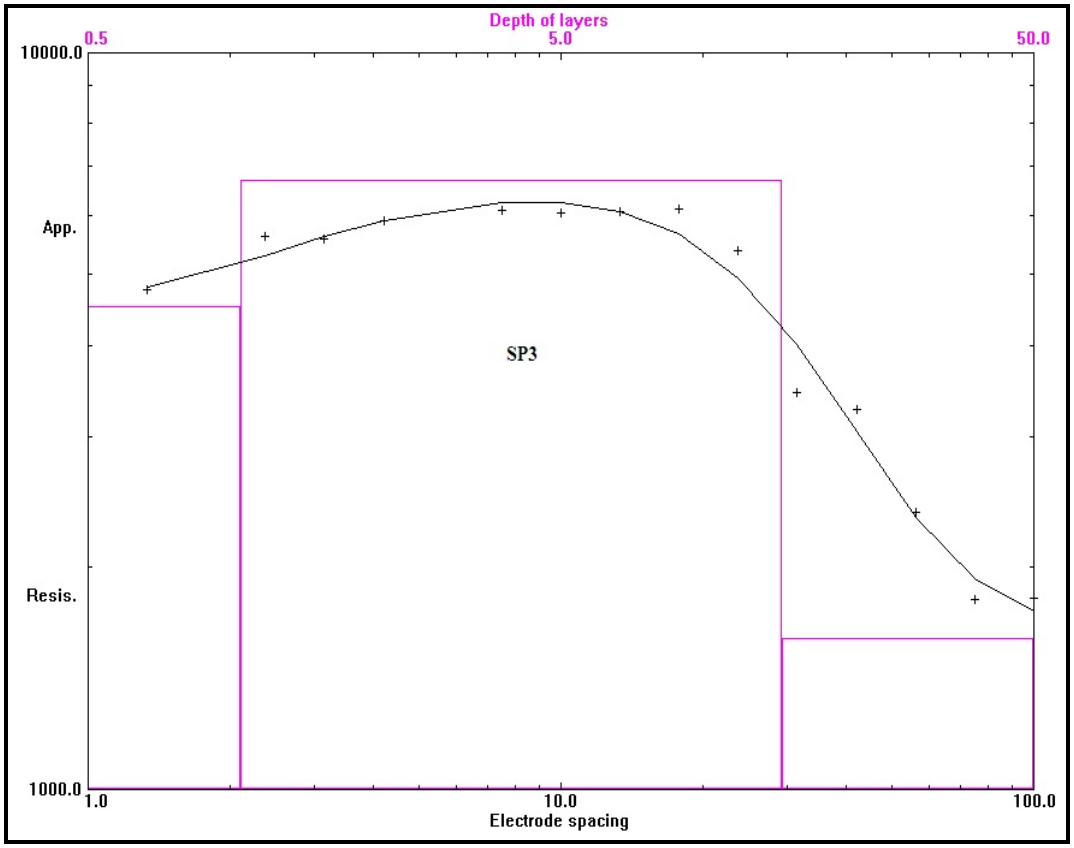


Figure 44: A typical VES modeled curve at Nkrankwanta

Table 39: VES results and their rank list for test drilling

Community	District	Geology	Rank-list of Drilling points		Expected G/W Potential
			VES	2-D Resistivity	
Sabie	Tain	Tarkwaian	1) SP2 2) SP1 3) SP7 4) SP4 5) SP5 6) SP3 7) SP6	-	Low
New Longoro	Kintampo North	BirimianSupergroup	1) SP1 2) SP4 3) SP3 4) SP2	-	Low
Nkrankwanta	Dormaa Municipality	BirimianSupergroup	4) SP1	1) B(140-320) 2) C80 3) C270	Medium
Bassa	Sene	VoltaianSupergroup, Obosum Group	-	1) A180 2) B260	Medium to low
Dotobaa	Nkoranza South	VoltaianSupergroup, Kwahu-'Morago' Group	-	1) C220, 2) C320, and 3) B80 4) C140 5) A150 6) A320	Medium
Dagombaline	Sunyani West	Eburnean Plutonic Suite	4) SP1	1)A(140–200), 2)A300, B100, 3) B(160-240)	Medium
Brosankro	Tano South	BirimianSupergroup	-	1) C(160-240), 2) B280, 3)B420, 4) B540,	High
Krobo	Techiman	Voltaian Supergroup, Kwahu-'Morago' Group	5) SP1 6)SP2	1)A70, 2) A180, 3)A320, 4) B160, 5)B320	Medium
Kotokrom	Sunyani Municipality	Eburnean Plutonic Suite	1)SP9, 2)SP3 3)SP12, 4) SP7 5)SP4 6)SP11 7)SP13 8)SP5 9)SP1 10)SP6 11)SP10	-	High
Prang	Pru	VoltaianSupergroup, Obosum Group	-	1)A360 2)B260 3)B560	Low to medium
Asiri-Jankofa	Jaman	Birimian Supergroup	Asiri: 1) SP3, 5) SP2 6) SP1 Jankofa: SP1	Jankofa: 2) A360, 3) A(560-700) 4) B(80-240)	High
Akuma-Brahoho	Nkoranza South	Voltaian Supergroup, Kwahu-'Morago' Group	-	Brahoho- 1)B480, 2)380, 3)240, 4)A240, 5)A400, 6)A540	Medium to low

3.4.7 Hydrogeological Consultancy Services to Delineate Zones of High Groundwater Potential for the Drilling of High Yielding Boreholes to Supply Sustainable Potable Water in Some Selected Communities and Small Towns along the Fufulso-Sawla Road in the Northern Region of Ghana

(Project Staff: Patrick Amankwah Mainoo – Research Scientist, Dr. Anthony A. Duah – Research Scientist, and Dr. William Atuobi Agyekum – Senior Research Scientist)

The Institute, in collaboration with the Government of Ghana (GoG), Ghana Highway Authority (GHA), African Development Bank (AfDB), CWSA (Tamale, Northern Region), Twum Boafo and Partners, Intercontinental Consulatants and Technocrats Private Limited (India, ICT), Central Gonja District Assembly and Sawla District Assembly, carried out the study to conduct hydrogeological studies to delineate zones of high groundwater potential where boreholes could be drilled. The specific objective was to delineate most promising sites for the drilling of high yielding boreholes to guarantee sustainable potable water supply to some selected communities and small towns along the Fufulso-Sawla Road using appropriate integrated geophysical techniques. The beneficiary communities and small towns are shown in Figure 45 and Tables 40 and 41.

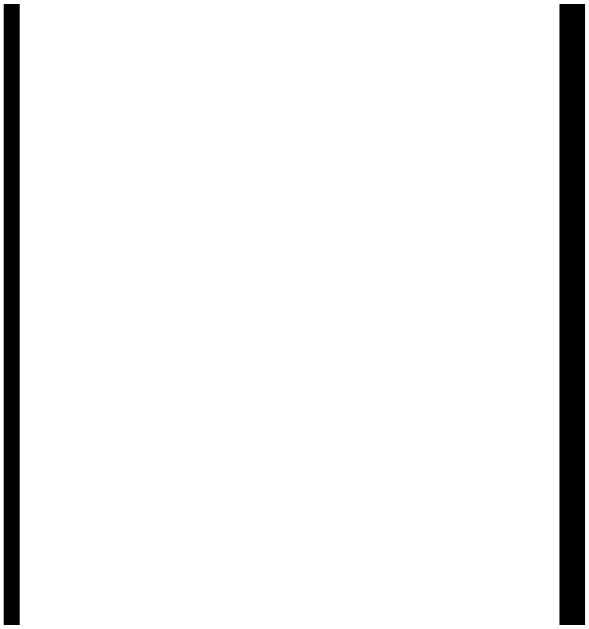


Figure 45: Geological map of the study area

Table 40: List of beneficiary communities and small towns under LOT 1

No.	Location	Geographic Coordinates		Type of Facility
		Latitude	Longitude	
1	Nabori	9.15485N	1.85445W	Borehole with Hand Pump
2	Yipala	9.13351N	1.84831W	Borehole with Hand Pump
3	Damango Township	9.09359N	1.82953W	10 No. Motorized boreholes
4	Solape	9.10540N	1.73546W	Borehole with Hand Pump
5	Bonyanto	9.11141N	1.72907W	Borehole with Hand Pump
6	Achubunyo	9.11849N	1.65875W	Borehole with Hand Pump
7	Jonokponto	9.12350N	1.61771W	Borehole with Hand Pump
8	Mempeasem	9.12352N	1.61771W	Borehole with Hand Pump
9	Kukunde	9.1353N	1.58302W	Borehole with Hand Pump
10	Busunu	9.16354N	1.51126W	Borehole with Hand Pump
11	Kojope	9.15190N	1.39539W	Borehole with Hand Pump
12	Janikuraa	9.13412N	1.33626W	Borehole with Hand Pump
13	Fufulso Township	9.12587N	1.28495W	5 No. Motorized boreholes

Table 41: List of beneficiary communities and Small Towns under LOT 2

No.	Location	Geographic Coordinates		Type of Facility
		Latitude	Longitude	
1	Sawla Poly Clinic	9.26525N	2.40048W	Limited mechanized borehole
2	Nyange School	9.24681N	2.37585W	Borehole with Hand Pump
3	Nyange Community	9.24416N	2.37338W	Borehole with Hand Pump
4	Jentilpe School	9.24260N	2.34948W	Borehole with Hand Pump
5	Jentilpe Health Center	9.24219N	2.34778W	Limited mechanized borehole
6	Jentilpe Community	9.24314N	2.35245W	Borehole with Hand Pump
7	Nasoyiri School	9.23299N	2.31508W	Borehole with Hand Pump
8	Nasoyiri Health Center	9.23423N	2.32221W	Limited mechanized borehole
9	Gurupe Health Center	9.23035N	2.22247W	Limited mechanized borehole
10	Oteiyiri Community	9.23252N	2.30013W	Borehole with Hand Pump
11	Kabambe Health Center	9.21852N	2.0544W	Limited mechanized borehole
12	Kananto Community	9.23672N	2.00230W	Borehole with Hand Pump
13	Larabanga Township	9.22294N	1.85509W	5 No. Motorized boreholes

The scope of work included desk study, data scouting, data analysis, reconnaissance survey and geophysical investigations to delineate zones and points where sustainable boreholes could be drilled. The 2-Dimensional Continuous Vertical Electrical Sounding (CVES) geophysical technique was employed to delineate suitable and most promising sites for the drilling of high-yielding boreholes to guarantee sustainable potable water to the beneficiary communities. The LUND resistivity survey technique was used for the 2D sub-surface resistivity studies. The typical field arrangement for 2-D data collection is presented in Figure 46.

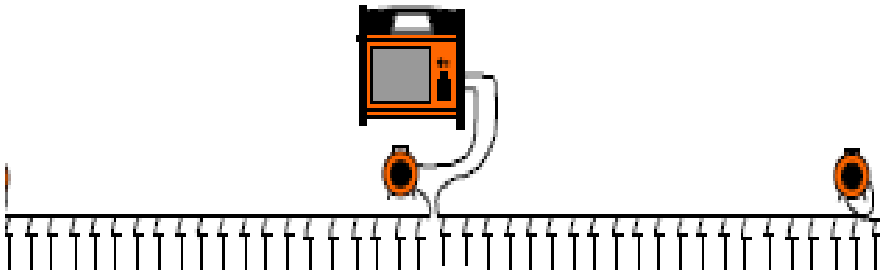


Figure 46: Typical field arrangement of 2 cables X 21 electrodes in 2D Resistivity Imaging Survey

The data obtained was modelled using RES2DINV (ver 3.58) to generate measured, calculated and modelled apparent resistivity pseudo-sections. Sample results in some of the selected communities are presented in Figures 47 – 50. The most promising sites recommended for drilling under LOT 1 and LOT 2 with the estimated depth-to-bedrock and drilling depths are presented in Tables 42 and 43.

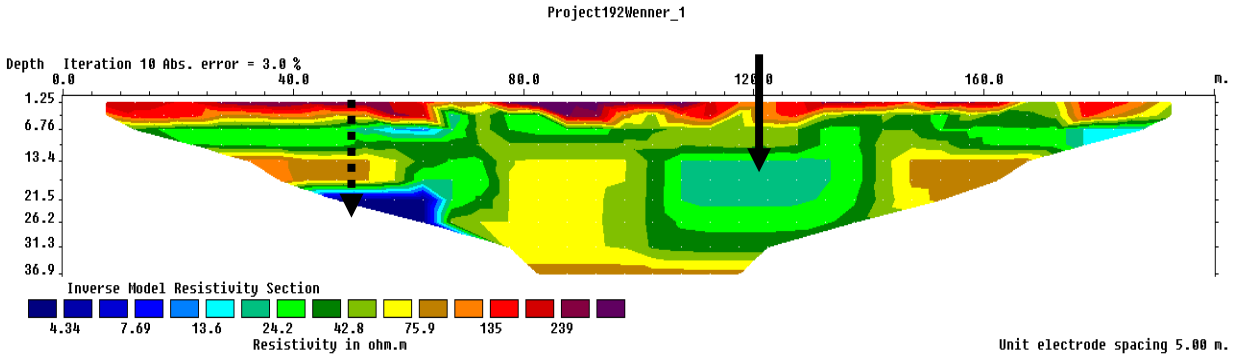


Figure 47: 2D-Apparent resistivity pseudo-section along traverse A, Nabori using Wenner array

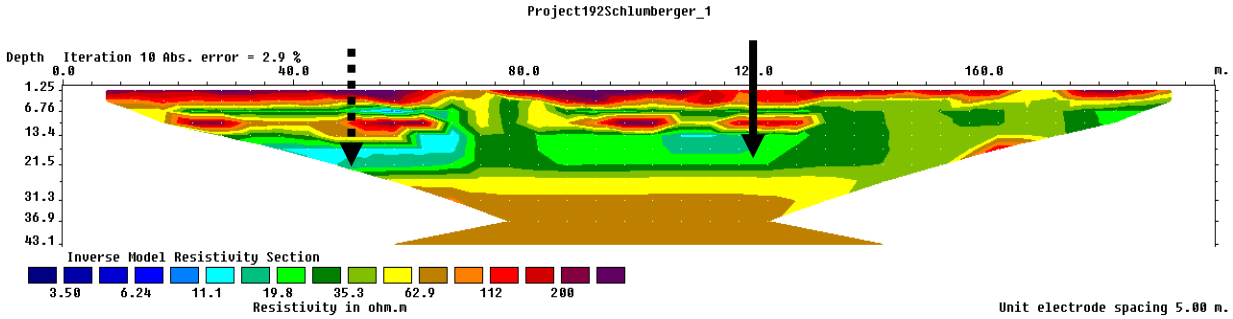


Figure 48: 2D-Apparent resistivity pseudo-section along traverse A, Nabori using Schlumberger array

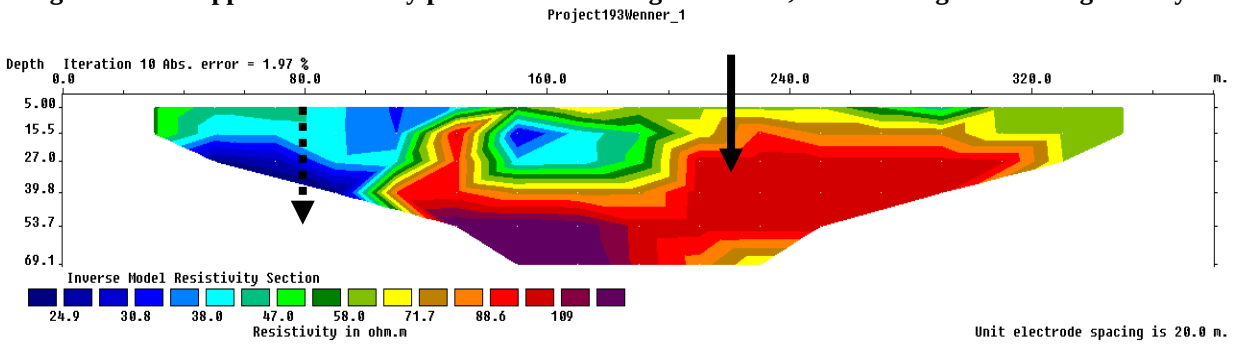


Figure 49: 2D-Apparent resistivity pseudo-section along traverse A, Yipala using Wenner array

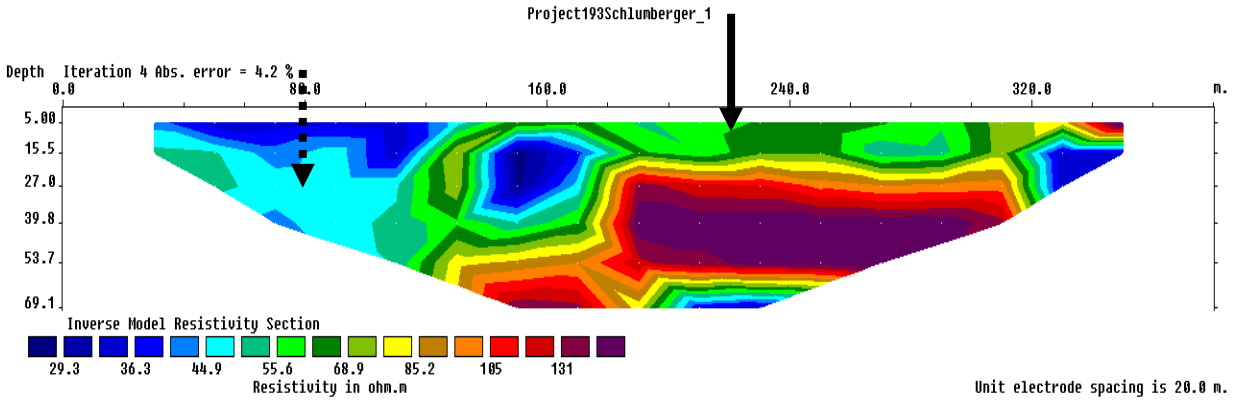


Figure 50: 2D-Apparent resistivity pseudo-section along traverse A, Yipala using Schlumberger array

Table 42: Geolectrical properties of the recommended drilling points under LOT 1

Location	Recommended Drilling Points		Estimated Depth to Bedrock (m)	[1]Estimated Drilling Depth (m)	Apparent Resistivity Ranges (Ω-m)				Bedrock Geology	Expected Rocks
	1st	2nd			Wenner Min.	Wenner Max.	Schlumberger Min.	Schlumberger Max		
Nabori	A50	A120	20	100	3.76	488.07	3.03	411.51	Damongo Formation	Yabraso Sandstone
Yipala	A80	A220	50	100	23.63	142.49	27.81	170.48		
Damango Township	A160	A280	50	200	33.16	121.19	7.26	214.35		
	B260	B120	50	200	23.85	148.58	3.94	272.71		
	C120	C240	50	200	21.51	133.02	5.08	309.02		
	D80	D300	50	200	29.88	289.5	4.51	1648.4		
	E300	E80	50	200	20.36	397.51	16.84	241.17		
	F60	F160	50	200	28.33	221.53	2.11	1957.1		
	G80	G320	50	200	4.85	772.45	3.53	2664.6		
	H140	H320	25	200	16.24	102.09	9.67	466.9		
	I160	I60	25	200	15.62	129.81	21.74	276.79		
	J120	J220	25	200	27.74	151.64	17.97	149.19		
Solape	A300	A120	25	100	27.68	1225	4.09	1719.4	Anyaboni Formation	
Boyanto	A40	A165	30	100	6.88	312.29	4.94	297.34		
Achubunyo	A300	A60	40	100	1.45	1313.7	1.02	304.54		
Jonokponto	A100	A240	50	100	6.81	461.04	4.91	123990		
Mempeasem	A80	A240	50	100	9.98	169.11	2.26	254.95		
Kukunde	A100	A240	30	100	5.69	1439.6	3.38	1208.4		
Busunu	A140	A320	50	100	11.4	122.64	4.94	3144.7	Contact between Anyaboni & Kodjari	Sandstone/Limestone
Kojope	A120	A260	50	100	0.22	1941.2	0.6	18947	Obosum Formation	Mudstone, siltstone, sandstone,
Janikuraa	A80	A160	50	100	0.01	7563.1	0.05	70569		
Fufulso Township	A240	A80	53	200	0.64	1925.2	0.5	34696		
	B80	B240	50	200	0.64	1925.2	0.67	13836		
	C120	C260	50	200	0.12	459049	1.68	39158		
	D100	D320	50	200	0.51	366090	0.35	27629		
	E100	E240	50	200	2.69	9383.4	1.61	5585.6		
	F120		25	200	1.59	8695.2	1.17	217447		
	G300	G80	25	200	0.92	46002	0.04	2420251		
	H80	H300	50	200	0.22	9855.3	0.33	19886		

[1] **Optimal drilling depths should be determined by a Competent Hydrogeologist or Technician during drilling to guarantee efficient utilization of prevailing aquifer systems for sustainable water supply.**

Table 43: Geo-electrical properties of the recommended drilling points under LOT 2

Location	Recommended Drilling Points		[2]Estimated Depth to Bedrock (m)	Estimated Drill Depth (m)	Apparent Resistivity Ranges (Ω-m)				Bedrock Geology	Expected Rocks
	1st	2nd			Wenner Min.	Wenner Max.	Schlumberger Min.	Schlumberger Max		
Sawla Poly Clinic	A50	A160	30	100	16.28 12.03	5823.80 6053.70	7.58 9.83	3685.00 6239.80	Birimian Formation	Granitoid gneiss
Nyange School	A180	A200	50	100	38.21	96355.00	45.48	53006.00		
Nyange Community	A30	A160	30	100	11.57	3683.90	4.16	3944.98		
Jentilpe School	A120	A40	30	100	10.55	2919.30	5.27	4976.80		
Jentilpe Health Center	A140	A60	30	150	19.87 1.54	5599.00 7041.00	10.01 0.64	6483.90 4797.20		
Jentilpe Community	A55	A100	30	150	5.25	310357.00	12.58	21028.00		
Nasoyiri School	A145	A40	30	100	28.99	22687.00	14.01	33926.00		Argillitic/pelitic sediment
Nasoyiri Health Center	A55	A180	30	150	25.35 27.45	99409.00 44791.00	16.54 13.38	26297.00 671378.00		
Gurupe Health Center	A40	B40	20 20	150 150	42.25 30.25	1852.30 7610.80	34.29 30.30	1921.00 7654.70		volcaniclastics
Oteiyiri Community	A50	A160	20	100	25.09	2364.00	13.79	2530.90		Argillitic/pelitic sediment
Kabambe Health Center	A100	A40	20	150	108.60 26.73	6750.00 2918.50	56.54 11.82	8819.70 28095.00		Wacke sediment
Kananto Community	A110	A50	30	100	31.92	3749.00	37.47	5006.00		
Larabanga Township	A180	A320	25	200	19.42	57.18	5.20	176.93	Damongo Formation	Damango Sandstone
	B220	B100	25	200	14.59	139.06	0.69	897.48		
	C220	C80	70	200	16.49	929.41	1.76	1720.00		
	D240	D120	70	200	5.62	75938.00	1.19	1475.70		
	E240	E60	65	200	3.54	160.18	7.75	527.28		
	F220	F80	65	200	19.10	282.15	3.71	692.45		

[2] **Optimal drilling depths should be determined by a Competent Hydrogeologist or Technician during drilling to guarantee efficient utilization of prevailing aquifer systems for sustainable water supply.**

It was recommended at the end of the study that:

- Drilling should be supervised by a competent hydrogeologist/hydrogeological Technician to ensure proper construction of the boreholes.
- Physico-chemical and bacteriological water quality analysis to ascertain the suitability of the groundwater for the intended use should be conducted.
- Pumping test should be conducted on all successful boreholes to ensure sustainable utilization of the groundwater resource.

3.5 SURFACE WATER DIVISION

The long-term objective of the Surface Water Division is to generate, develop and transfer appropriate technologies, information and services for sustainable development, utilization and management of surface water resources for socio-economic development.
The specific objectives include:

- assessment of surface water resources of the country for socio-economic development;
- assessment of sediment transport by streams/rivers and discharges into reservoirs for planning and management of water resources;
- development and adaptation of appropriate technologies and water conservation techniques for water supply to households, communities, farms and industries; and
- assessment of climate change effects and adaptation strategies.

3.5.1 Hydro-Meteorological Station at CSIR WRI Head Office

(Project Staff: Dr. K. Kankam-Yeboah – Principal Research Scientist, Mr. C. K. Asante-Sasu – Principal Technical Officer, Mr. G. Appiah – Senior Technical Officer and Mr. F. T. Oblim – Technical Officer)

The CSIR Water Research Institute has a weather station at the Head Office located at 05° 35705N, 00° 11105W and altitude 45.72 m in Accra. Hydro-meteorological data on rainfall, temperature, evaporation, sunshine duration and wind-run were collected daily and digitally stored during the reporting year. The objective was to describe the environmental conditions at any particular time and determine the water balance of the area.

The total rainfall for the reporting year was 514.5 mm with the major peak in June 2013 and the minor peak in September 2013 (Figure 51). Out of the 365 days in the year, there were only 53 rainy days (Table 44). The amount of rainfall in 2013 was less by 42.7 mm (8.3 %) compared to that of 2012 (Figure 52)

The total potential evaporation for the reporting year (1549.6 mm) exceeded rainfall by 1035.1 mm. however, rainfall exceeded evaporation by 12.1 mm and 2.7 mm in June and September 2013, respectively (Figure 53). It was concluded that there could be water deficit and crops could suffer unless supplementary irrigation is carried out especially during the dry season.

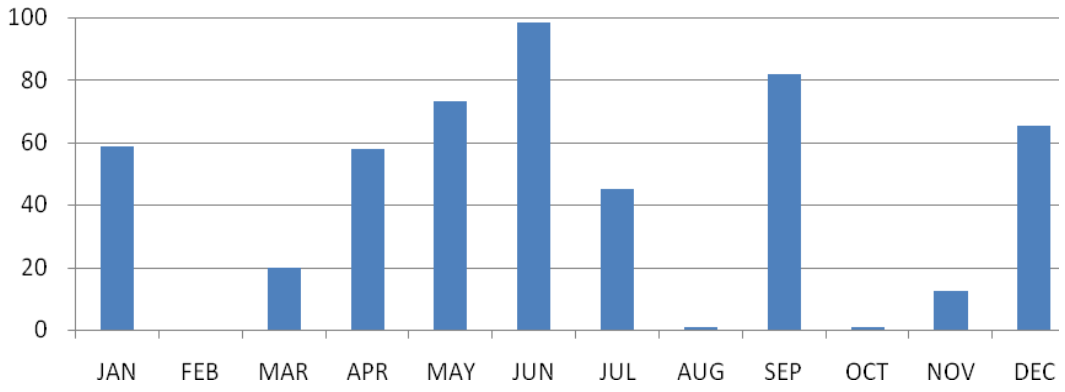


Figure 51: Rainfall Pattern in 2013

Table 44: Monthly hydro-meteorological data at CSRI Water Research Institute Station, Accra, in 2013

Parameter	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
Total Rainfall (2013) mm	58.7	0.0	19.8	57.8	73.4	98.5	45.2	0.9	81.9	0.7	12.4	65.2	**514.5**
Total Rain day	2	0	2	4	10	11	5	2	10	1	1	5	**53**
Total Rainfall (2012) mm	0	132.6	0	120.6	196.4	126.1	67.2	10	37.7	163.3	26.2	0	**880.1**
Total Rainfall (Average 1976 – 2012) mm	8.0	17.4	50.0	85.5	144.8	175.3	59.4	26.7	49.8	66.7	35.5	19.7	738.9
Potential Evaporation (mm)	124.8	138.2	147.5	167.3	143.2	98.5	107.0	110.5	124.7	131.9	135.7	106.9	**1,536.2**
Temperature (°C)													
Mean Temperature	-	-	-	-	-	-	-	-	-	-	-	-	
Maximum Temperature	-	-	-	-	-	-	-	-	-	-	-	-	
Minimum Temperature	-	--	-	-	-	-	-	-	-	-	-	-	
Total Windrun (Knots)	1.90	2.64	2.74	2.52	1.77	2.68	3.25	3.70	3.30	2.80	2.30	2.07	**31.67**
Total Sunshine (Hours)	8.0	7.1	7.2	6.5	6.8	6.0	4.1	5.2	4.8	10.2	8.4	7.6	**81.9**
Mean Relative Humidity (%)	74	76	74	75	79	83	83	81	84	78	79	76	

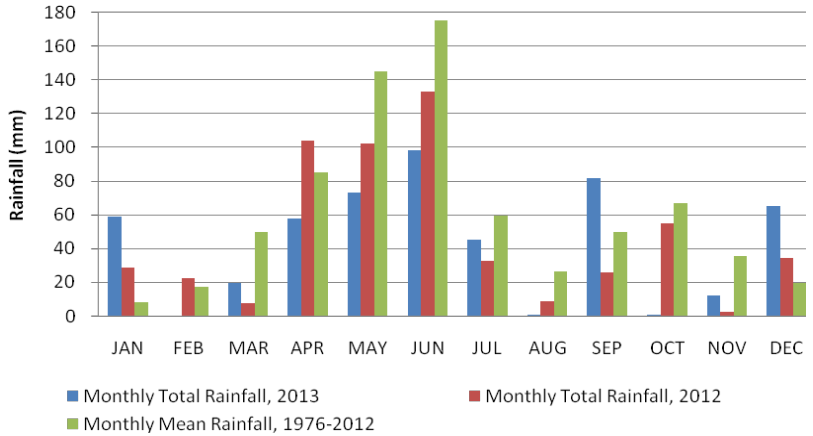


Figure 52: Comparison of monthly total rainfall for the periods 2013, 2012 and monthly average rainfall for 1976 – 2012

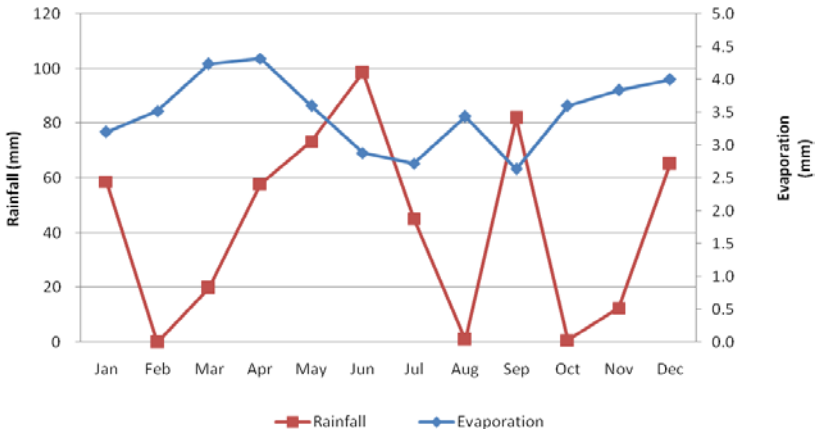


Figure 53: Comparison of rainfall and potential evaporation pattern in 2013

3.5.2 Rainwater Harvesting (RWH) for Resilience to Climate Change Impact on Water Availability in Ghana (RWH4Ghana)

(Project Staff: Dr. B. A. Amisigo – Senior Research Scientist, Dr Fred Amu-Mensah – Senior Research Scientist, Ms. Deborah Ofori – Research Scientist, Dr Emmanuel Bekoe – Research Scientist, Mr. Frederick Y. Logah – Research Scientist, Dr. Kwabena Kankam-Yeboah – Principal Research Scientist, Dr. Kwadwo Asante – Senior Research Scientist, Mrs Regina Banu – Research Scientist, Mr. Frank Oblim – Principal Technical Officer and Mr Gabriel Appiah – Senior Technical Officer)

The Institute in collaboration with SINTEF, Norway and CSIR-STEPRI, started the study in the reporting year and is expected to end in 2015. The overarching goal is to increase resilience to climate change impact on water availability by holistic (environmental, economic and social) sustainability assessment and implementation of appropriate rainwater harvesting (RWH) technology for small-scale application and business development in urban Ghana based on standardized design and implementation procedures. The specific objectives were to:

- increase resilience to climate change impact on water availability in Ghana;
- facilitate local business development;
- improve urban livelihoods;
- increase water availability in selected household and schools;
- make affordable, appropriate and innovative RWH systems more available in Ghana; and
- strengthen human and institutional capacities to implement RWH.

The scope of work included assessment of different technical alternatives for small-scale RWH, and development of standardized design criteria for appropriate and innovative model RWH systems for households and schools; standardization and implementation of the model system in 20 households and 2 schools in Greater Accra Metropolitan Area (GAMA) with each beneficiary paying 25 % of the system cost while the project covers the remaining 75 % cost; training of a corps of artisans in building the RWH systems and using as a basis for local business development; monitoring quantity, use and physico-chemical and microbial quality of harvested water; and stakeholder dialogue, evaluation and marketing of the model systems.

At the end of the reporting year, the first rainwater harvesting (RWH) system (the pilot) was installed for one household. Components and other materials for the system were procured for six (6) additional installations. Although the RWH system cost was estimated for over 25 interested households, less than 50 % were committed to their 25 % payment. The inability of

beneficiaries to pay their 25 % commitment coupled with the slow procurement process accounted largely for the slow pace of the installation. As a result, although RWH systems for 10 households were supposed to be completed in the reporting year, only one was completed with 5 others at various stages of completion. Water quality analyses were also undertaken for the completed pilot system. One stakeholder workshop and training workshop for artisans engaged on the project were also undertaken. It was however recommended that potential beneficiaries should be further educated and urged to make their down payments quickly to enable procurement procedures to start early and ensure timely installations of the systems.

3.5.3 The Impact of a Proposed Water Treatment Plant on the Hydrological Situation of the Dayi and Discharge from the Akosombo Dam

(Project Staff: Mr. F. Y. Logah – Research Scientist, Dr. K. Kankam-Yeboah – Principal Research Scientist and Ms. D. Ofori – Research Scientist)

The institute, in collaboration with the Ghana Meteorological Agency and Hydrological Services Department carried out the study to investigate the impact of proposed Water Treatment Plants (WTPs) at Hohoe, Kpeve and Juapong, all in the Volta Region of Ghana, on the hydrological situation of the Dayi River and discharge from the Akosombo Dam. During the reporting period, flow duration curve was developed and minimum stream-flow was estimated for the Dayi River. Baseflow contribution to streamflow was determined in the Dayi River and the reliabilities of the Dayi and discharges from the Akosombo Dam to supply water to Hohoe, Kpeve and Juapong in the Volta Region of Ghana were determined.

The minimum streamflow at Dayi corresponded to 4,493 m³/day at 90% probability of exceedance. The estimated Base Flow Index (0.06) at Dayi River indicated that groundwater contributed approximately 6% to streamflow in the Region. Figure 54 shows a comparison plot between the mean monthly streamflow pattern at Dayi River and 2011 water demand value of 4,500 m³/day at Hohoe. Daily discharge from the Akosombo Dam was also compared with combined 2011water demand value of 26,000 m³/day at Kpeve and Juapong (Figure 55).

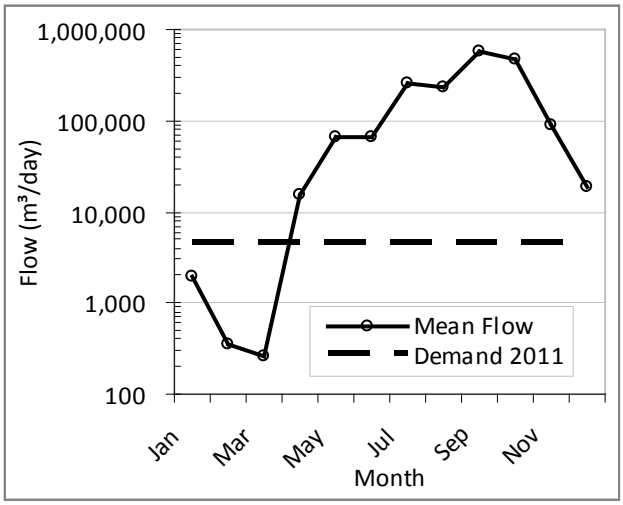


Figure 54: Mean monthly river flow and current (2011) water demand at Dayi in the Volta Region

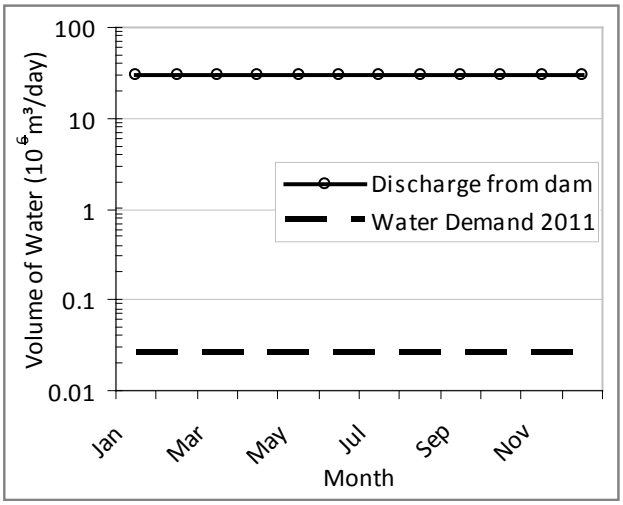


Figure 55: Mean volume of water at Akosombo and combined water demand at Kpeve and Juapong

Based on the estimated minimum streamflow requirement to sustain river flow (4,493 m³/day), the study indicated that the Dayi River cannot be relied upon for continuous supply of water to Hohoe and its environs at the designed abstraction rate of 4,500 m³/day. On the other hand, the

designed daily water abstraction for both Kpeve and Juapong Head-works for 2011 was approximately 0.09% of the daily minimum discharge from the Akosombo Dam. It was concluded from the study that the construction of the Water Treatment Plants at Kpeve and Juapong would have negligible effect on the amount of water discharge from the dam. Discharge from the Akosombo dam can therefore be relied on in terms of use for domestic water supply.

3.5.4 Topography and Surface Hydrology of SAVACEM Concession Area in the Yakombo Forest Reserve, Northern Ghana

(Project Staff: Mr. F. Y. Logah – Research Scientist, Dr. K. Kamkam-Yeboah – Principal Research Scientist and Ms. D. Ofori – Research Scientist)

The objective of the study was to provide information including maps of the SAVACEM concession area describing the details of topography, surface hydrology, contours, drainage and other relevant information in the Yakombo Forest Reserve at Buipe in the Central Gonja District, Northern Ghana.

During the reporting period, reconnaissance survey of the concession area to confirm information gathered from secondary data sources was conducted. Hydro-meteorological data and topographic map of the SAVACEM concession area were acquired and hydro-meteorological data analysis carried out. Detailed description of the study area with detailed information of the topography, surface hydrology, contours and drainage of the study area was also undertaken.

There were five streams namely: Kafeltabon, Toro, Yoyo, Kanwegyenbu and Kukrunbu in the SAVACEM concession area which flow southwards into the Black Volta River. The streams within the concession were highly seasonal and mostly dry during the dry season (October to April). The upstream of all these streams were dried-up during the site visit (in June, 2013). Some dolomite and limestone projections could be seen on the dry bed of the streams, especially at Kafeltabon and Kanwegyenbu. The survey also confirmed that mining of limestone by SAVACEM in the concession area is only carried-out in the dry season. However, mining activities still take place in June and July when the onset of the rains delays and the streams at the mining areas are still dry. Mining limestone in the concession area may increase erosion of top soil in the Yakombo Forest Reserve as a result of loosening the soil. This will result in increase in the rate at which sediment enters nearby streams and the Black Volta River during flooding.

In order to reduce the rate of soil erosion in the concession area and sedimentation in the streams and the Black Volta River, it was recommended that the limestone mining pits should be filled and compacted before the rainy season (i.e. by mid-April, before the May-September rainy season).

3.5.5 Preparatory Survey on the Project for Fisheries Promotion in the Republic of Ghana

(Project Staff: Ing Dr Frederick K. Amu-Mensah – Senior Research Scientist, Dr Kwadjo Ansong Asante – Research Scientist, Mr Mark Akrong – Research Scientist, Dr. Joseph Addo Ampofo – Principal Research Scientist, Mr Frank Teye Oblim and Mr Gabriel Appiah)

In collaboration with ECOH Corporation of Japan, A-M Surveys Ltd., JM and Partners Ltd, Blebs Geo-Consult and JICA, the study was carried out to obtain current data required for designing and expanding the fishing harbour facilities of the Albert Bosomtwe Sam Fishing

Harbour at Sekondi. The scope of work included topographic and bathymetric surveys, soil investigation, sediment quality survey, water quality survey and material analysis.

In the year under review, sediment samples were collected from seven selected locations in the seabed and analysed for moisture content, specific gravity, silt fraction, 50 % diameter indicator and heavy metals. Sieve analysis to produce a Grain Size Distribution Curve was also undertaken on all samples. Water samples were collected from six offshore locations, one wastewater inflow into the sea, and one tap water source for chemical and bacteriological analyses. High tide and low tide samples were also collected both at 50 cm of the bottom and 50cm below the surface of the sea and analysed for salinity, suspended solids (SS), chemical oxygen demand (COD), dissolved oxygen (DO), chlorophyll 'a', total nitrogen, total phosphorus and coliform bacilli. For the tap water sample, pH, salinity, total nitrogen, calcium, magnesium, mercury, lead, zinc, iron, copper, manganese, phenols, *Escherichia coli* (*E. coli*) and Standard bacteria were analysed. Topographic and bathymetric surveys were conducted to produce a composite map of the seabed and land area within the harbour area. Sand, crushed stones and cobble samples were collected from two functional quarries near the harbour, Sofokrom and Justmac quarries, and sieve analysis, specific gravity, moisture content, density, angle of internal friction (shear box test) and compressive strength test conducted. Soil investigation involving two onshore boring and three offshore boring points was also carried out. Two sites were also marked for plate bearing tests. The boring samples were analysed for Natural Moisture Content, Sieve Analysis, Specific Gravity and Unconfined Compression.

The pH of the water samples ranged from 7.44 (site 1, high tide surface) to 7.83 (site 4, low tide surface) and these values were typical of saline waters. The highest pH values of 7.83 and 7.81 for the surface and bottom, respectively, were recorded at Site 4. Site 4 was more inward towards the sea in relation to the other sampling sites and this could account for the higher pH values observed in this survey. Temperatures were within the range of 22.3 °C (Site 2) to 23.8 °C (Site 1, low tide surface) and the highest temperatures were recorded at Site 1 (surface and bottom). Total suspended solids (TSS) varied from 38.3 mg/l (Site 5, low tide surface) to 430 mg/l (Site 5, high tide bottom) with the values of the bottom samples being higher than the surface, reflecting contribution from the sediment. Results of the high and low tide of the samples for COD and faecal coliform are shown in Figure 56.

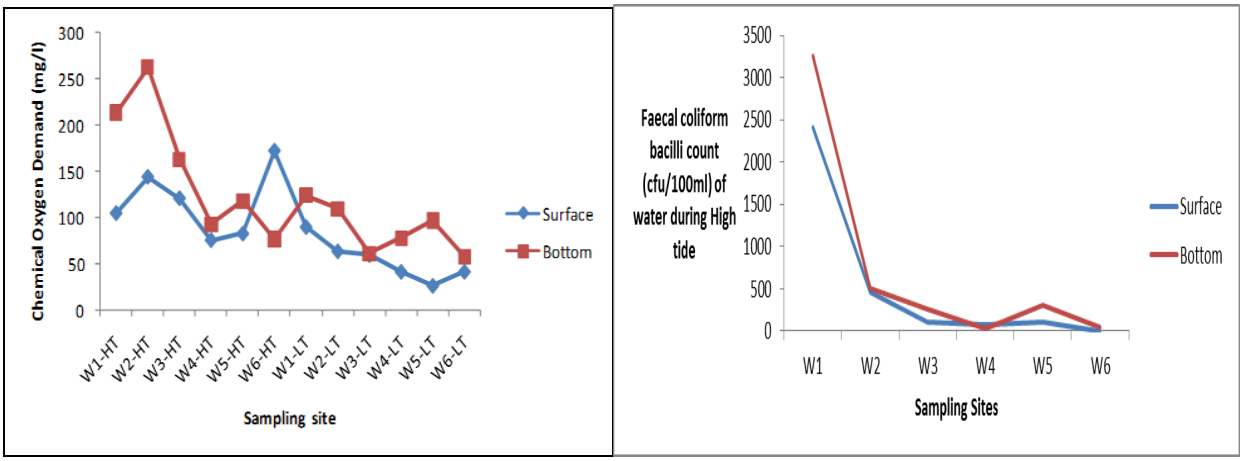


Figure 56: High and low tide results of the samples for COD and faecal coliform

With regard to Material Analyses, the average specific gravity of 2.79 at Sofokrom quarry and 2.67 at Justmac quarry for course aggregate were within the range of 2.6 - 2.9 common to minerals used for construction. The average specific gravity for sand at Sofokrom quarry was

2.87 and that of Justmac quarry was 2.72. Cobble compressive strength was 25 N/mm^2 and 24 N/mm^2 for Sofokrom and Justmac quarries, respectively. Average density of sand for Sofokrom and Justmac quarries were 1985 kg/m^3 and 2065 kg/m^3, respectively, with moisture content of 6.95 % and 6.4 %, respectively, suitable for concrete and road works. The angle of internal friction (ϕ) and cohesion (c) of sand were 31 and 18, respectively, at Sofokrom quarry and 30 and 12, respectively, for Justmac quarry. These values indicated that sand at the two quarries was strong enough to resist shearing stresses. The results for aggregate tests for Sofokrom Quarry is given in Table 45. In addition, Table 46 and Figure 57 show the results of grain size for the 50 % passing obtained from a log-normal graph for sample S-1 while the results of textural classification using the USDA scale, variation of SPT-N-Values, average deflection of plate bearing test at site P2, and composite topographic and bathymetric map of the study area are shown in Tables 47 and 48 and Figures 58 and 59, respectively.

Table 45: Aggregate Test Results for Sofokrom Quarry

Project:	**MATERIAL ANALYSIS**																					
Location:	**ESSIPON, SEKONDI**											**Date:**	**31/07/13**									
Client:	**ECOH COOPERATION**											**AESL Official:**		**JKO**								
Contractor:	**CSIR WATER RESAECH INSTITUTE**																					
Source:	**SOFOKROM QUARRY**																					
Sample	**Type of Test**																					
	Grading (% passing)								**S. gravity**			**Comp strength**	**Density (kg/m^3)**				**M. Content (%)**			**Shear Box**	
	63.5 mm	**50.8 mm**	**14 mm**	**12.5 mm**	**5 mm**	**2.36 mm**	**0.425 mm**	**0.075 mm**	**1**	**2**	**Ave**	**N/mm^2**	**1**	**2**	**3**	**Ave**	**1**	**2**	**Ave**	**c**	**Φ**
Coarse Aggregates	**100**	**97**	**15**	**8**					**2.76**	**2.82**	**2.79**											
Quarry dust				**100**	**94**	**79**	**35**	**3**	**2.90**	**2.84**	**2.87**		**1975**	**1977**	**2003**	**1985**	**7.1**	**6.8**	**6.95**	**18**	**31**
Cobble									**2.90**	**2.84**	**2.87**	**25**	**2690**	**2710**		**2700**					
Comments																					

Table 46: Sample S-1 sieve analysis and grain size distribution

Sieve Diameter [mm]	Weight of Sieve [gr]	Weight of Sample and Sieve [gr]	Weight on Sieve [[gr]	Cumulative Weight [gr]	Percentage on Sieve [%]	Cumulative Percentage through Sieve [%]
10			0	0	0.00%	100.00%
5	559.77	559.77	0	0	0.00%	100.00%
2.5	556.95	557.78	0.83	0.83	0.19%	99.81%
1.25	504.7	520.04	15.34	16.17	3.69%	96.12%
0.63	484.9	494.22	9.32	25.49	5.82%	90.30%
0.5	459.92	465.26	5.34	30.83	7.04%	83.27%
0.315	461.91	463.5	1.59	32.42	7.40%	75.87%
0.2	440.55	452.41	11.86	44.28	10.11%	65.76%
0.16	434.93	442.63	7.7	51.98	11.86%	53.90%
0.071	429.87	449.97	20.1	72.08	16.45%	37.45%
0.05	415.88	421.33	5.45	77.53	17.69%	19.76%
Less	245.72	254.76	9.04	86.57	19.76%	0.00%
Total			**86.57**	**438.18**	**100.00%**	
Clay Fraction	**19.76%**	**19.79%**		**USDA Classification**		
Silt Fraction	**17.69%**	**17.73%**		**Sandy Loam Soil**		
Sandy Fraction	**62.36%**	**62.48%**				
Gravel Fraction	**0.19%**					

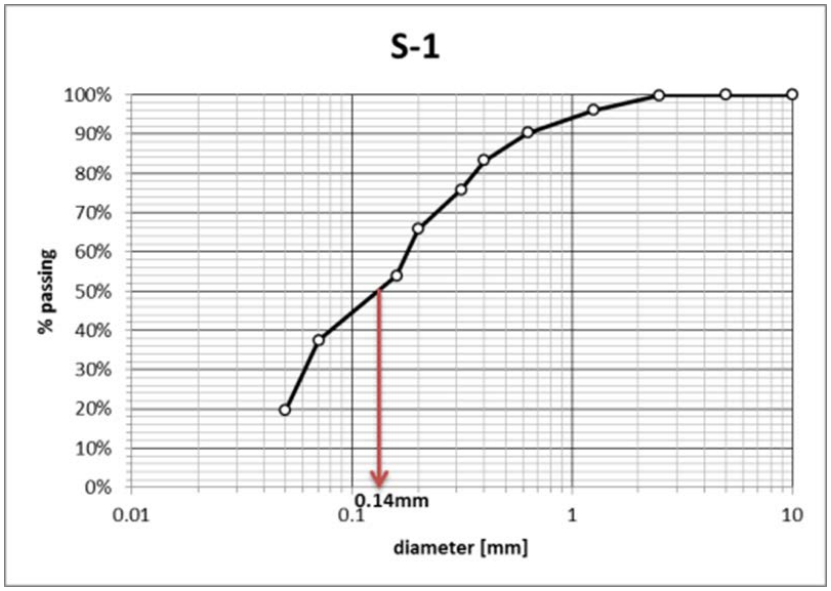


Figure 57: Sample S-1 sieve analysis and grain size distribution

Table 47: Textural classification of seabed sediment samples

Sample Point	Silt Fraction (%)	50% diameter indicator (mm)	USDA Classification
S-1	17.69	0.14	Sandy Loam Soil
S-2	18.88	0.12	Sandy Clay Loam Soil
S-3	22.84	0.078	Sandy Clay Loam Soil
S-4	15.12	0.18	Sandy Loam Soil
S-5	23.45	0.069	Sandy Clay Loam Soil
S-6	19.99	0.11	Sandy Clay Loam Soil
S-7	16.76	0.18	Sandy Loam Soil

Table 48: Variation of SPT N-values with depth for drilled boreholes

Borehole No.	Depth (m)	SPT N-values/300mm	Average SPT N-values/300mm
B-1 (SPT 01)	4.90-5.35	60	
B-1 (SPT 02)	6.40-6.85	72	
B-1 (SPT 03)	7.90-8.35	80	
B-1 (SPT 04)	9.80-10.25	100	**78**
B-2 (SPT01)	5.50-5.90	20	
B-2 (SPT02)	7.10-7.55	28	
B-2 (SPT03)	8.60-9.05	41	
B-2 (SPT04)	10.10-10.55	58	**36.75**
B-3 (SPT01)	4.30-4.75	69	
B-3 (SPT02)	5.80-6.25	85	
B-3 (SPT03)	6.70-7.15	101	
B-3 (SPT04)	8.20-8.65	115	
B-3 (SPT05)	9.70-10.00	100	**94**
B-4 (SPT01)	1.50-1.95	14	
B-4 (SPT02)	3.00-3.45	28	
B-4 (SPT03)	4.50-4.80	50	
B-4 (SPT04)	8.50-8.95	101	
B-4 (SPT05)	11.50-11.95	56	**49.8**

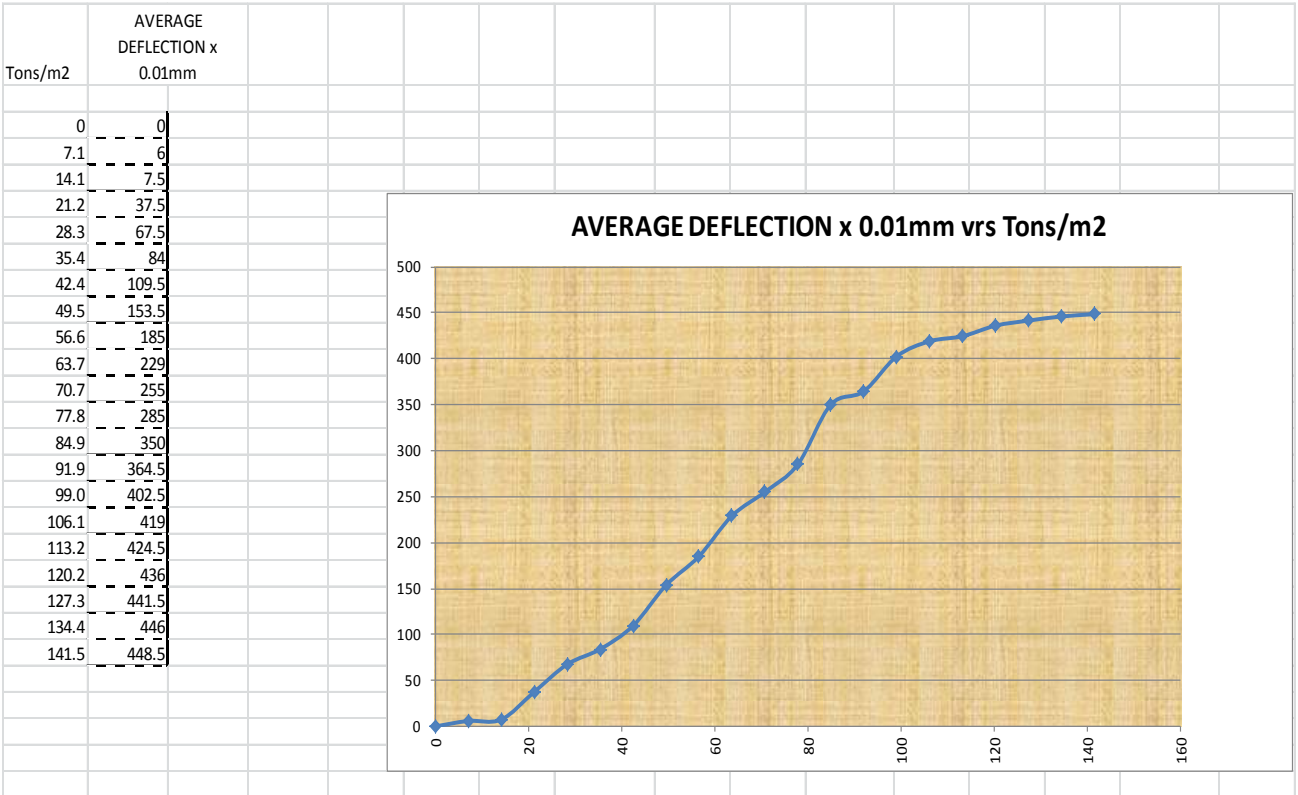


Figure 58: Average Deflection of Plate Bearing Test at test site P2 (Location 1)

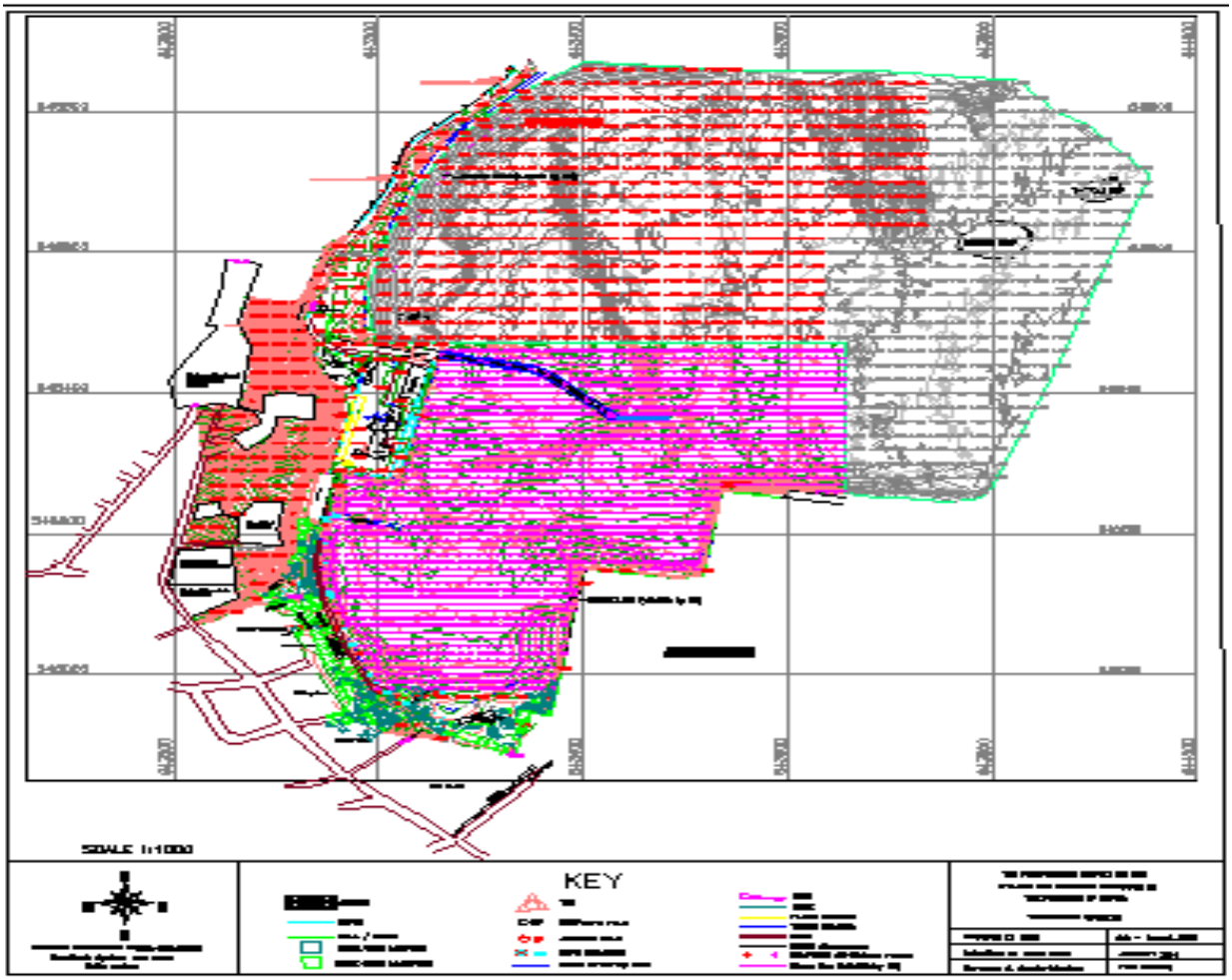


Figure 59: Composite topographic and bathymetric map of Albert Bosomtwe Sam Fishing Harbour

3.5.6 Earth Observation for Regional Water Balance Estimation and Surface Energy Balance Assessment in the Volta Basin, West Africa *(VOLTA-WEB: Volta Water and Energy Balance)*

(Project Staff: Dr. Kwabena Kankam-Yeboah – Principal Research Scientist, Mr. Albert Agyapong (WRI/ITC, The Netherlands) and Mr. Kwaku Adjei (KNUST), Prof, Zoltan Vekerdy (ITC, The Netherlands), Prof. Nick Van de Giessen (TU Delft, The Netherlands)

In collaboration with ITC/University of Twente, The Netherlands, TU Delft, The Netherlands, and KNUST, Kumasi, Ghana, the study was undertaken to build upon research that demonstrates the use of ENVISAT data products to estimate regional water balance through the assimilation of different types of spatial datasets using computationally efficient GIS tools; and retrieve surface values from optical remote sensing as inputs to a distributed solution of the regional water balance equation. The goal of the study was to implement a model at CSIR WRI in Ghana as an operational water balance estimation tool linked to ESA Earth Observation products; facilitating rapid estimation of regional water balance, overcome recognised problems with scarce and poorly distributed field-based hydrological observations in West Africa and strengthen collaboration between institutions/scientists in terms of training and research and development in hydrological modelling and advanced image. The specific objectives were to derive land surface variables (e.g. vegetation cover, albedo and temperature) from ENVISAT products as inputs to the SEBAL model to predict evapotranspiration (ET) and a modified PITMAN model to estimate runoff from savannah catchments within the Volta Basin; and assess the sensitivity of the distributed model to satellite-derived input parameters.

During the reporting year, Earth Observation (EO) data was acquired, processed and analysed. Ground Truthing and ITC/ESA capacity building initiatives (short training courses) were also undertaken. DDS Receiver were installed at the CSIR Water Research Institute, Accra, Ghana (Envisat products made available via Near-Real-Time DDS "Broadcast service": MER_FRS_1P, MER_RR__1P, MER_RR__2P, MER_RRC_2P, MER_RRV_2P: ATS_TOA_1P, ATS_NR__2P, ATS_AR__2P: ASA_GM1_1C) The ENVISAT satellite run its full life and was replaced by SENTINEL with test runs being carried out by ESA. EO data (MERIS Full Resolution and Reduced Resolution, ATS-Top of the Atmosphere (TOA) Images etc.) was downloaded for processing with open source software such as BEAM, NEST and ILWIS. The study area and Correlation of retrieved TRMM rainfall with observed raingauge rainfall measurements are shown in Figures 60 and 61. In the absence of gauged stations, TRMM rainfall data could be reliably used on regional basis.

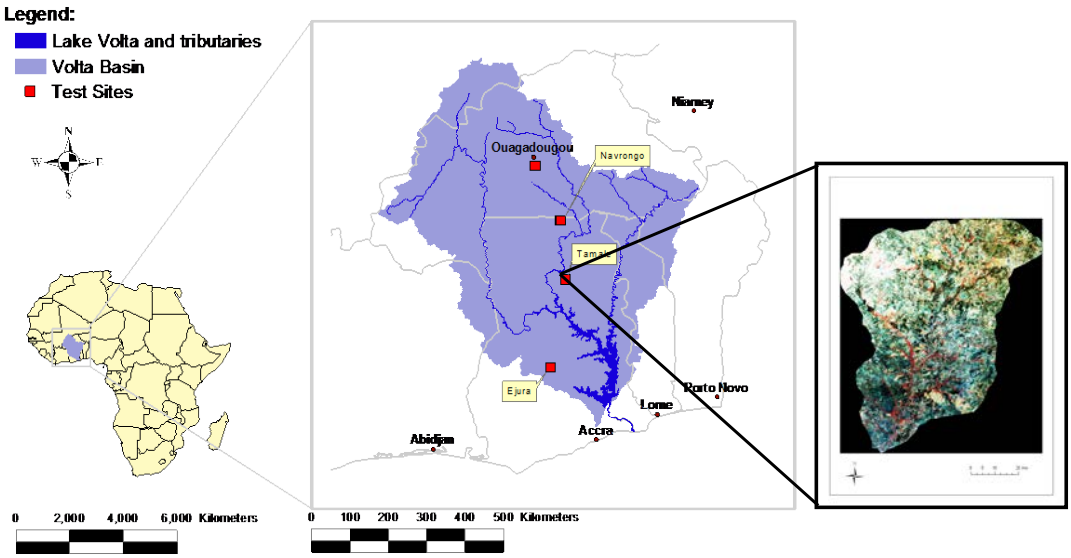


Figure 60: Location of the Volta Basin

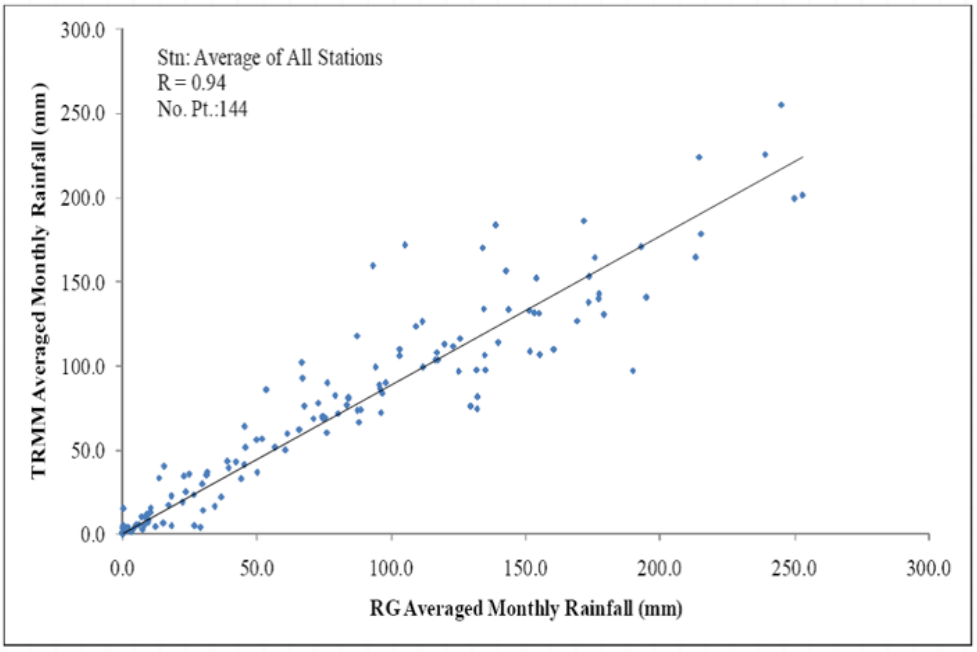


Figure 61: Correlation of TRMM rainfall retrievals and rainfall observations (averaged over 5 rain gauge stations)

3.5.7 Sustainable Management of Lake Bosomtwe in the Ashanti Region of Ghana – Hydrology, Anthropology and Water Quality

(Project Staff: Ing Dr Frederick K. Amu-Mensah – Senior Research Scientist, Dr. Joseph Ampofo – Principal Research Scientist, Mrs. Regina Banu – Research Scientist, Mrs. Marian Amu-Mensah – Research Scientist, Mr. Mark Akrong – Research Scientist, Mr. Humphrey Darko – Research Scientist, Mr. Gabriel Appiah – Technical Officer and Mr. Collins Asante Sasu – Principal Technical Officer)

The study was focused on the identification and documentation of sources of water into Lake Bosomtwe and their seasonality with emphasis on catchment hydrology, development of water quality monitoring programme and investigation of associated anthropological impacts on the hydrologic processes within the catchment. It was carried out in collaboration with Man and Biosphere (MAB) Ghana, CSIR Forestry Research Institute of Ghana (FORIG), Friends of the Earth (FoE), Intelligence Nature International (INI) and A Rocha Ghana. The specific objectives were to:

- identify and document sources of water into the lake and their seasonality with emphasis on catchment hydrology;
- develop a comprehensive and long term water quality monitoring programme as a tool for water quality management;
- assess the microbiological water quality of the Lake Bosomtwe;
- identify flowing stream collection points for water sampling from various communities;
- assess the bacteriological quality of boreholes in some communities; and
- investigate associated anthropological impacts on the hydrologic processes within the catchment.

Activities carried out during the reporting period included collection of water samples from the lake and flowing streams as well as borehole and rain water from some communities within the catchments of the lake. These samples were analysed bacteriologicaliy for the presence of total coliform, faecal coliform, *E. coli*, *Salmonella spp*., *Aeromonas spp*., *Enterococcus spp.* and total heterotrophic bacteria. Inflow records from three flowing streams were collected and analysed. Lake water, stream flow and some rainwater samples were collected and analysed. Some field anthropological observations and questionnaire administration were also undertaken in some communities around the lake. Survey instruments administered and results analysed.

The lake, stream and borehole water samples assessed during the study period were bacteriologically unsafe to be used as drinking water sources without any form of treatment as they did not conform to Ghana Standards and WHO guidelines of Zero (0) total coliform, faecal coliform, *E. coli*, *Salmonella spp*., *Aeromonas spp*., *Enterococcus spp*, as well as <500 cfu/1ml of total heterotrophic bacteria (Figure 62). The bacteria contamination was noted to be high during the raining season. The poor quality of the lake could be attributed to contamination with human faeces, domestic wastes as well as other human activities such as rearing of animals close to the lake.

The study also showed that though the catchment was relatively small hydrologically, there appeared to be significant variation in rainfall occurrence and amounts (Figures 63 and 64). The anthropological investigations revealed that though the lake is used for different purposes (Figures 65 and 66), most people dumped refuse indiscriminately within the catchments (Figure 67; Table 49), engaged in free-range defecation that ended up contaminating the lake and in careless recreational activities in the lake.

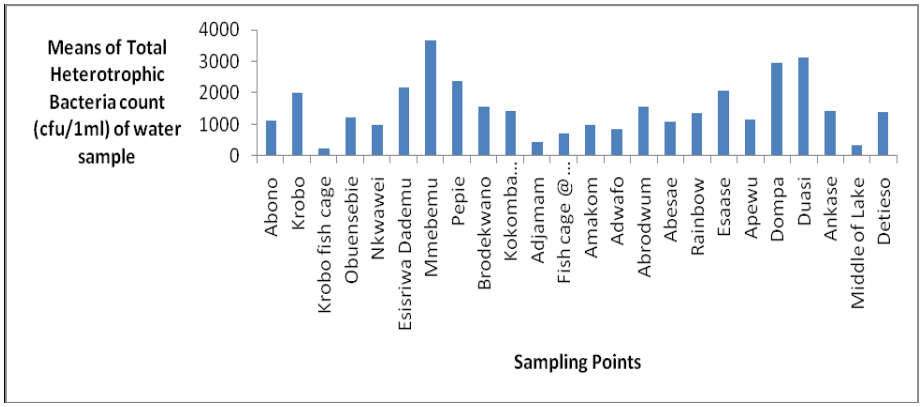


Figure 62: Total Heterotrophic bacteria (THB) in water samples

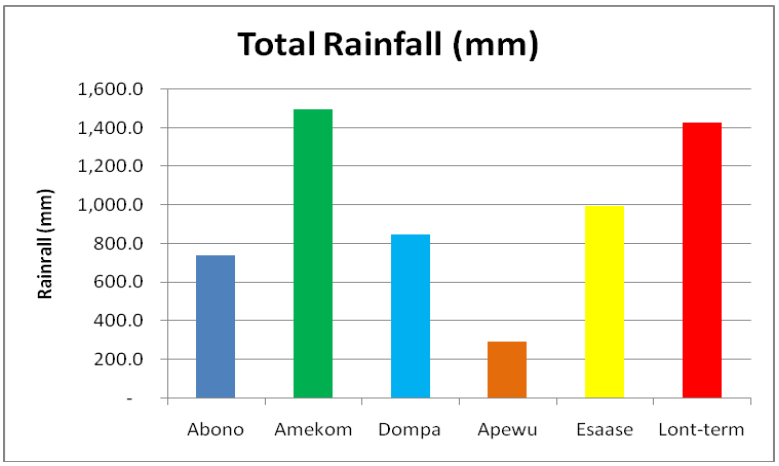


Figure 63: Recorded rainfall values compared to long-term values

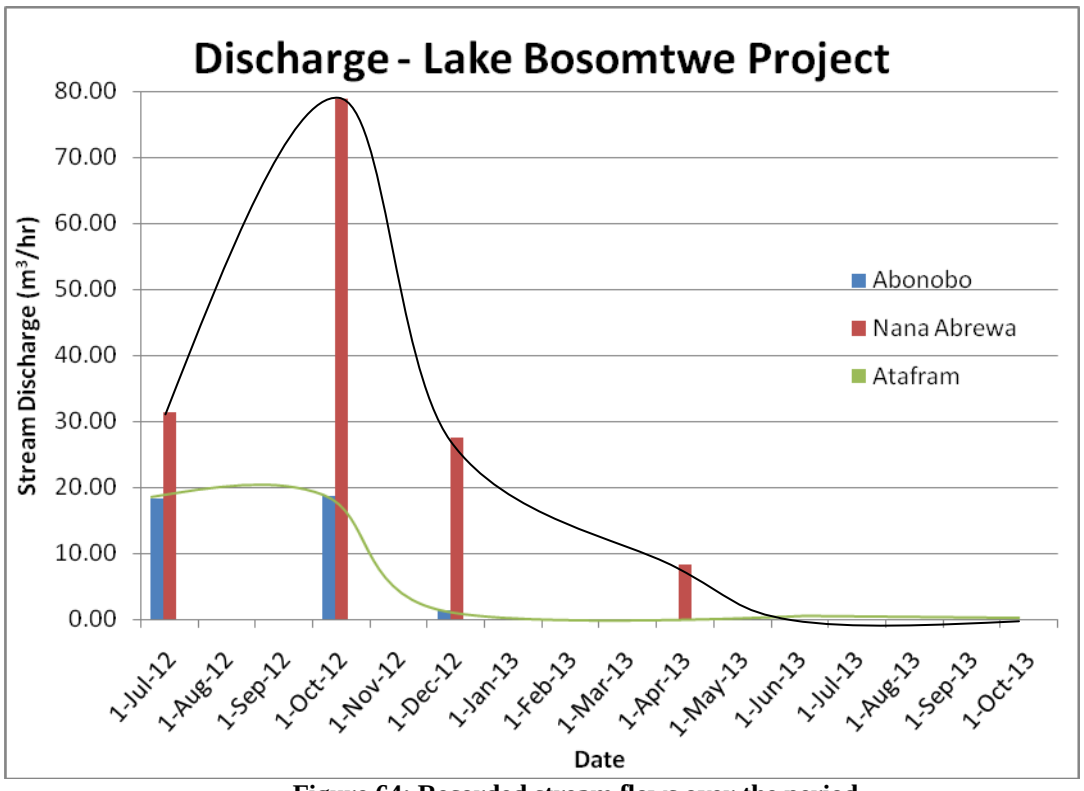


Figure 64: Recorded stream flows over the period

Figure 65: Washing at the immediate bank of Lake Bosomtwe

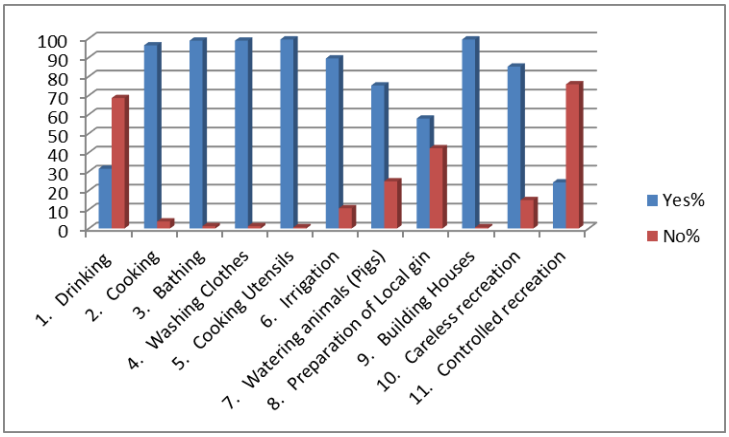


Figure 66: Different uses of the Lake Bosomtwe

Figure 67: Refuse dump at the bank of a stream within the study area

Table 49: Land use - existence of refuse dump close to stream

Dumping refuse close to / in stream channel		Frequency	Percent
Valid	No response	2	1.2
	Yes	119	73.0
	No	42	25.8
	Total	163	100.0

It was concluded from the study that human activities had negatively impacted on the quality of the lake and could endanger the integrity of the lake and its catchment. In addition, population pressures, indiscipline and tourist pressures if not regulated could also seriously affect the sustainable management of the lake and its catchment.

3.6 COMMERCIALIZATION AND INFORMATION DIVISION

The Commercialization and Information Division promotes commercialisation of research and development activities of the Institute. The specific objectives that guide the Division's activities are:

- developing programmes and strategies for commercialization;
- providing requisite information and documentation on the Institute;
- providing specialized services in support of research and development;
- performing public relations functions; and
- organizing open days and internal seminars on research and development activities of the Institute.

3.6.1 Cartography Section

In the year under review, the Cartographic Section supported research and consultancy services through the provision of hydrogeological maps and borehole profiles. Some old maps and graphs were updated. Sketch drawings of a proposed guest house for the CSIR WRI Tamale Station were also prepared. At the end of the reporting year, a total of twenty-seven (27) drawings were prepared and the details shown in Figure 68.

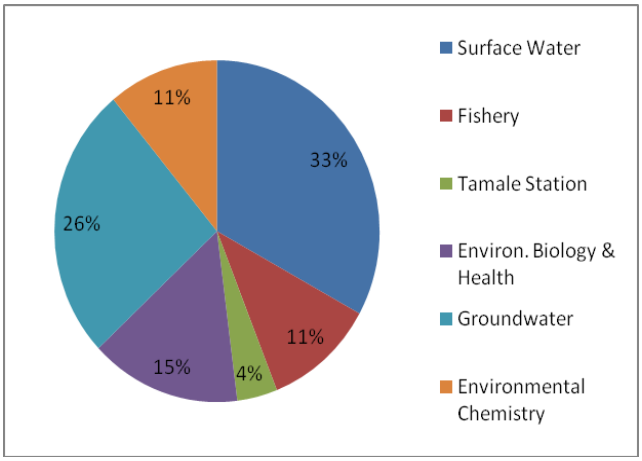


Figure 68: Percentage composition of cartographic drawings prepared during the year 2013

Hydrogeological maps of Greater Accra, Volta, Eastern, Ashanti, Western and Central regions of Ghana are available for sale to groundwater consultants, institutions and individuals.

3.6.2 Development of Research Library and Water Resources Documentation System

A total of 329 books were processed and added to stock during the year under review. Most of these books were gifts from some international organizations such as the International Association of Hydrological Sciences (IAHS), UNESCO and FAO. The library also made some local purchases at the Ghana Statistical Service, ISSER, Ghana Publishing Company, etc. In addition, 67 technical and consultancy reports were deposited at the library by research scientists for reference purposes. Copies of these reports will also be made available at our Tamale and Akosombo branches.

The library had 1,746 staff user visits, comprising of senior members, senior staff and junior staff for various purposes ranging from research, enquiries, deposit of technical and consultancy

reports, internet and on-line bibliographic searches and photocopy of pages of journal articles, etc. A total of 456 external visits were made to the library for reference purposes. Among the external visitors were students, lecturers, consultants and clients. Thus, the total number of user visits for the year was 2,202 as against 2, 442 user visits in 2012. This could be attributed to the fact that the library has not been able to acquire the needed reference materials to support its collection development programmes. However, computerization of the library's resources continued with a total of 1,249 technical and consultancy reports keyed into its database. A total of 86 dissertations and 1,916 books were added to the database for easy and fast retrieval of information.

3.6.3 Internal Seminars

Internal seminars were organized during the reporting year to provide fora for participants to discuss and also bring into the public domain current research activities of the Institute. A total of 39 presentations on various topics were made (Table 50) and scientists from allied institutions, dignitaries, students and the media attended.

Table 50: Internal Seminars 2013

Month	Presenters/Speakers	Topics
March	Mr. Collins Tay	Hydrochemical evaluation of groundwater evolution within the Lower Pra Basin, Ghana: A hierarchical cluster analysis (HCA) approach
June	Dr. Rose-Emma Entsuah-Mensah, Dr. O. D. Ansa-Asare, Dr. Anthony A. Duah, Dr. Barnabas Amisigo, Mr. Benson K. Owusu and Mr. Patric A. Mainoo	Impact of small-scale mining on the water resources of the Pra River Basin
July	Mrs. Victoria Afutu-Vanderpuye	Qualitative survey of mosquito breeding in some parts of the Accra Metropolis - A preliminary study
	Dr Gloria Naa Dzama Addico	Hepatotoxic-microcystins in two drinking water reservoirs in the Central Region of Ghana
	Mrs. Regina Banu	Assessment of water sources used as drinking water in crèches in selected communities in Accra
	Dr. Mike Yaw Osei-Atweneboana, Kwadjo Frimpong Kyeremeh, Edward Jenner Tettevi, Ernest Gyan and Samuel Armoo	Development of genetic Markers for early detection of Ivermectin resistance in *Onchocerca volvulus*: characterization of phenotypic response
	Mr. Samuel Armoo	River blindness: Wolbachian bacteria endosymbionts and genetic response to ivermectin in *Onchocerca volvulus*
	Dr. Ebenezer D. O. Ansa	Inactivation of faecal coliforms in domestic wastewater for re-use
	Dr. Kwadwo Ansong	Contamination by trace elements and arsenic speciation in e-waste recycling workers from Agbogbloshie, Accra, Ghana
	Dr. Ruby Asmah	Water and fish quality assessment of Fosu Lagoon
	Mr. Humphrey Darko	Physico-chemical and bacteriological assessment of rural domestic water supply
	Ms. Saada Mohammed and Dr. I. O. A. Hodgson	Water quality for sustainable use in urban agriculture
	Dr. Ruby Asmah	Planning for Improved and Sustainable Cage Aquaculture in the Volta Lake

Table 50: Internal Seminars 2013 (Continue)

Month	Presenters/Speakers	Topics
July	Dr. Emmanuel Obuobie	Sustainable water management in cereal-based farming systems of Northern Ghana
	Dr Frederick Amu-Mensah, Mr Mark Akrong, Mr Humphrey Darko, Mrs Marian Amu-Mensah, Mr. Gabriel Appiah and Mr. Collins Asante-Sasu	Sustainable management of Lake Bosomtwe in the Ashanti Region of Ghana: Hydrology, water quality and anthropolog
	Mr. Frederick Yaw Logah	Weija reservoir sediment studies
	Dr Kwabena Kankam- Yeboah, Ms. Deborah Ofori, Mr. Fredrick Logah and Mr. Gabriel Appiah	Restoration and renaturation of Fosu Lagoon project: Hydrometeorological assessment
	Dr. Emmanuel Obeng Bekoe	Rainwater harvesting (RWH) for resilience to climate change impact on water availability in Ghana
	Dr. Emmanuel Obeng Bekoe	ICT tools for the enhancement of irrigation efficiency in West Africa (IRRIWEST)
	Mr. Collins Okrah	Provision of boreholes to selected SSNIT property sites in Accra
	Mr. Patrick Amankwah Mainoo	Groundwater database development in Ghana
	Dr. William A. Agyekum	Groundwater Division mid-year review of research and commercialization activities
	Mr. Manu Evans	Sircool project: Assessment of the groundwater potential to select borehole drilling point at the factory
	Mr. Manu Evans	Geophysical investigation and borehole drilling in selected institutions within Cape Coast Municipality
	Mr. Patrick Amankwah Mainoo	Hydrogeological studies for borehole water supply to small and peri-urban communities in Ghana
	Dr. Mike Yaw Osei-Atweneboana	Environmental Biology And Health Division research activities
	Dr. Osmund D. Ansa-Asare	Projects and roles played by CSIR-Water Research Institute laboratory (ECD)
	Dr. Kwabena Kankam-Yeboah	CSIR-WRI internal review 2013: Surface Water Division
	Mr. Solomon A. Owiredu	Impact of mining operations on the ecology of the Ankobra River in the Western Region of Ghana
	Dr. E. K Abban, Dr. J.K. Ofori, A. Dassah and J. Akomea	Studies on Lake Bosomtwe catchment for sustained fish production
	Dr. J. N. Padi	Improving reproductive performance of the African bonytongue fish, *Heterotis niloticus*, for increased fingerling production in aquaculture
	Mr. Francis A. Anani	Survey of commercial fish feeds and feed ingredients used by small-scale pond fish farmers in five selected regions of Ghana
	Dr. Seth Koranteng Agyakwah	Breeding and selection of the Nile Tilapia *Oreochromis niloticus* for faster growth
	Dr. Seth Koranteng Agyakwah	Performance comparison between improved local strains (Akosombo) and imported GIFT strains of *O. niloticus* ("TIVO PROJECT")
	Dr. H. R. Dankwa, Mr. T. Quarcoopome and Mr. Edem Amerdome	Restoration and renaturation of Fosu Lagoon (fishery component)
	Dr. H. R. Dankwa	Re-optimisation and re-operation study of the Akosombo and Kpong Dams
	Dr. Hederick R. Dankwa	CSIR Water Research Insitute: Fishery Division
October	Dr. K. A. Asante	Assessment of human exposure to halogenated contaminants in Ghana
	Mr. Samuel Obiri-Yeboah and Ms. Saada Mohammed	Human health rist assessment as a result of exposure to e-waste at Agbogboloshie scrap yard, Ghana

3.6.4 Industrial Visits

Basic school students of the Greater Accra Regional Science, Technology and Mathematics Innovations Education (STMIE) Camp 2013 and the West Africa Senior High School Band (WASS Band) visited the Institute on 21 – 22 August 2013 and 10 October 2013, respectively, to have practical demonstrations on topics read at their various institutions.

3.6.5 Exhibitions

Current research activities and findings of the Institute were showcased during exhibitions organized during the year to bring to the public domain how these technologies could be accessed. Some who patronized the Institute's stand during such exhibitions came for consultation and collaborative research work after the exhibitions. Among the exhibitions were:

- 6th Africa Agriculture Science Week (15 - 19 July 2013)
- 2013 Ghana Policy Fair (15 - 17 October 2013)
- 29th National Farmers Day (6 December 2013)

3.7 CONSULTANCY AND OTHER SERVICES

3.7.1 Consultancy and Advisory Services

Consultancy and advisory services were carried out by the Institute for various donor agencies, corporate bodies, governmental and non-governmental organizations, universities and polytechnics, public and private sector institutions as well as individuals. The significant ones included:

- Physico-chemical and Bacteriological Quality Assessment of Boreholes and Tap Water (Client: Water and Sanitation Development Board – Oyibi)
- Final Effluent Quality Studies (Client: Pioneer Food Company Limited)
- Potable Water Quality Studies (Client: Pioneer Food Company Limited)
- Groundwater Quality Assessment (Client: Community Water and Sanitation Agency).
- Physico-chemical and bacteriological assessment of raw and treated water (Client: Vicco Ventures Limited)
- Final Effluent Quality Studies (Client: Phyto-Riker)
- Management of water dam and environmental control dams (Client: Newmont Ghana Gold Ltd)
- Cage aquaculture technical guidelines (Client: Water Resources Commission)
- Mapping of fish farms and zonation of potential aquaculture areas in Angola (Client: Food and Agricultural Organisation of the United Nations)
- Physico-chemical analysis of water samples (Client: West African Fish Ltd., Asikuma)
- Advisory services on how to avoid microbial contamination of water sources (Client: Sachet water producers)
- Water quality analysis (Client:Sachet water producers)
- Borehole water quality analysis (Client: NORST)
- Consultancy services on how to reoperate the Akosombo and Kpong dams to restore livelihoods and ecological functions in the Lower Volta (Client: Water Resources Commission)
- Consultancy on restoration and renaturation of Fosu Lagoon (Client: Cape Coast Metropolitan Assembly)
- Advisory services on fish farming (Client: Small-scale fish farmers)
- Advisory services on Consolidating the Gains of existing Fish ponds at Libga Irrigation Site (Client: Junar's Integrated Aquaculture Farms)
- Consultancy on Enhancement of fish production and water conservation in dugouts for climate change adaptation in south-western part of Yendi municipal area (Client: Community Life Improvement Programme)
- Preparatory Survey on the Project for Fisheries Promotion in the Republic of Ghana (Client: ECOH Corporation of Japan)
- Raw Water Quality Studies of proposed Wa Water Treatment plant (Client: ABP Consult)
- Consultancy on Sustainable Management of Lake Bosomtwe in the Ashanti Region of Ghana (Client: UNESCO)

3.7.2 Training Services

Through the Technical Divisions of the Institute, individual research and technical staff offered training in various forms to individuals, groups, non-governmental organizations and students of the Universities and Polytechnics. Among them were:

- Supervision of undergraduate students from Department of Ecotourism and Environmental Management of the Faculty of Renewable Natural Resources, University of Development Studies (UDS)
- Supervision of Accra Polytechnic student's dissertation on quality of water from hand-dug-wells in Adenta and Dome
- Supervision of M. Phil. thesis from the Department of Fisheries and Watershed Management, Kwame Nkrumah University of Science and Technology (KNUST)
- Part-time Lectureship at the Department of Marine and Fisheries Science, University of Ghana, Legon
- Part-time lectureship at the Graduate School of Nuclear and Allied Sciences (SNAS), University of Ghana
- Part-time lectureship on Modelling Tools - PhD studies under the WASCAL program, KNUST, Kumasi
- Part Time Lectureship at the Department of Agricultural Engineering, University of Ghana, Legon
- Part-time Lectureship at the Department of Civil Engineering, KNUST
- Supervision of M. Phil. Students of the SNAS, University of Ghana
- Supervision of WASCAL PhD students at the Department of Civil Engineering, KNUST

4.0 FINANCE

A total amount of GH¢6,903,018.87 was received for the year 2013. Out of this amount, 77.54 % represented government subvention, 14.31 % represented internally generated funds and 8.15 % represented donor assistance to the Institute.

4.1 Government Release in 2013

Receipt for recurrent expenditure was GH¢5,352,463.00. This constituted Personnel Compensation and Goods and Services during the year. The total Government release for the year constituted 77.54 % of total receipt for the year.

4.2 Internally Generated Funds (IGF) in 2013

An amount of GH¢987,942.56 was generated from consultancy services out of which an expenditure of GH¢791,807.43 was made. The IGF constituted 14.31 % of total receipts for the year.

4.3 Donor Assisted Projects in 2013

Receipt for donor assisted projects was GH¢562,613.31 during the year. However, an expenditure of GH¢306,897.75 was made. Donor assistance receipts represented 8.15 % of total receipts for the year.

APPENDICES

APPENDIX I: Membership of the Internal Management Committee (IMC)

1.	Dr. Joseph A. Ampofo	-	Director (Chairman)
2.	Dr. Isaac O. A. Hodgson	-	Deputy Director
3.	Dr. K. Kankam-Yeboah	-	Head, Surface Water Division
4.	Dr. Mike Osei-Atweneboana	-	Head, Environmental Biology and Health Division
5.	Dr. Osmond D. Ansa-Asare	-	Head, Environmental Chemistry Division
6.	Dr. H. R. Dankwa	-	Head, Fishery Division
7.	Dr. William A. Agyekum	-	Head, Groundwater Division
8.	Mrs. Marian A. Jiagge	-	Head, Commercialization and Information Div.
9.	Mrs. M. Azara Sedziafa	-	Head, Administration Division
10.	Mr. Paul Fabalona	-	Head, Finance Division
11.	Dr. Felix Y. Attipoe	-	Officer-In-Charge, ARDEC-Akosombo
12.	Dr. Felix Akpabey	-	Officer-In-Charge, WRI Tamale
13.	Dr. Emmanuel O. Bekoe	-	Representative, Research Staff Association (RSA)
14.	Mr. Alexander A. Dei	-	Representative, Senior Staff Association (SSA)
15.	Mr. Francis A. Boakye	-	Representative, TUC (Local Union)

APPENDIX II: List of Senior Members and Senior Staff

List of Senior Members

NAME	DESIGNATION	QUALIFICATION
Joseph A. Ampofo	Director	B.Sc. (Hons) Botany & Dip. Ed. (UCC) MPhil. Botany (Legon) Ph.D Botany(Bacteriology) (Legon)
Osmund D. Ansa-Asare	Principal Research Scientist	B.Sc. (Hons) Chem.Dip.Ed. (UCC) P.G. Dip. Water Quality Mgt. (Delft) PhD. Env. Chem. (Aberdeen)
Kwabena Kankam-Yeboah	Principal Research Scientist	BSc. Agric. & Dip. Ed. (UCC) MSc. Tropical Agric. (KULeuven, Belgium) MSc. Irrig. Eng. (KULeuven, Belgium) PhD. Earth Science & Env. Eng. (Okaya., Japan)
Isaac O. A. Hodgson	Principal Research Scientist	B.Sc. (Hons) Chem.Eng. (UST) MSc. Chem. Eng. (UBC, Canada) PhD Chem. Eng. (LU, UK)
Hederick R. Dankwa	Principal Research Scientist	BSc. (Hons) Zool../Bot. (Legon) MSc. Marine Ecol. (Brussels) Dip. Fish Mgt. (Bergen/Norway) PhD Fish Biol./Aquac. (UCC)
Joseph K. Ofori	Senior Research Scientist	BSc. (Hons) Biology (UST) MTech. Aquaculture (Port Harcourt) PhD Biol. Sciences (UST)
Frederick K. Amu-Mensah	Senior Research Scientist	BSc. Agric Eng. (UST) MSc. Soil & Water Eng. (Wageningen) PhD. Bioenv. Science (Tottori, Japan)
Barnabas A. Amisigo	Senior Research Scientist	BSc.(Hons) Agricultural Eng. (UST) MSc. Water Res. Eng. (Guelph) PhD. Hydrology/Water Res. Eng. (Delft)
Collins Tay	Senior Research Scientist	B.Sc. Chem. KNUST M.Sc. Env. Res. Mgt. KNUST
Anthony Y. Karikari	Senior Research Scientist	B.Sc. (Hons) UST MSc. Chem. (Univ. of Ryukyns, Japan)
Kwadwo A. Asante	Senior Research Scientist	B.Sc. (Hons) Chem.(UST) Cert. Protection & Utilization Of Oceans (Hamburg) MS.c. Env. Chemistry and Exotoxicology DSc. Science in Env. Chemistry
Margaret Azara Sedziafa	Senior Administrative Officer	BA (Hons) English & Hist.Dip.Ed. (UCC) Graduate Dip. in Library Std. (Legon) MBA Human Resource Mgt. (Legon)
Asmah Ruby (Mrs)	Senior Research Scientist	B.Sc. (Hons) Chem. (UST) M.Sc. Ecol. Marine Mgt. (Brussels, Bel.) Ph.D Aquaculture (Stirling, UK)
Mike Osei-Atweneboana	Senior Research Scientist	BSc. Biological Scien/Nursing (Legon) MPhil Zoology (Legon) Ph.D Medical Parasitology (McGill, Can)
Francis Y. K. Amevenku	Senior Research Scientist	BSc. (Hons) Nat. Res. Mgt. (UST) MPhil. Agric. Economics (UG, Legon)
Felix Akpabey	Research Scientist	BSc Zoology/Botany (UCC) & Dip.Ed. (UCC) MSc Entomology (UG) Ph.D Entomology (Rhodes Univ., Graham Town, SA)

NAME	DESIGNATION	QUALIFICATION
Victoria Afutu-Vanderpuye	Research Scientist	B.Sc. (Hons) Zoology/Bot. (Legon) M.Sc. Med. Ento. (Pondcherry)
Emmanuel O. Bekoe	Research Scientist	BSc. Agric. Eng. (UST) MSc. Soil & Water Eng. (Wageningen, Neth.) PhD. Water & Environment (Cranfield, UK)
Fredrick Yaw Logah	Research Scientist	BSc. Agric. Eng. (KNUST) MSc. Water Res. Eng. (KULeuven, Belgium)
Emmanuel Obuobie	Research Scientist	BSc. Agric Eng. (UST) MSc. Soil & Water Eng. (Wageningen, Neth.) PhD. Natural Science (Univ. Bonn, Germany)
William A. Agyekum	Snr. Research Scientist	B.Sc. Geol. Eng. (UST) M.Eng. (Delft) PhD Geology (Univ. of Gh.)
Anthony A. Duah	Research Scientist	B.Sc. (Hons) Geol. Eng (UST) M.Sc.Hydrogeology & Remote Sensing (ITC) PhD Hydrogeology (Univ. of Western Cape, South Africa)
Patrick A. Mainoo	Research Scientist	BSc Physics (KNUST) MSc Physics (KNUST)
Collins Okra	Research Scientist	BSc (Physics) & Dip. Ed. (UCC) MSc Geophysics (KNUST)
Humphrey F. Darko	Research Scientist	B.Sc. Chem. UCC. MSc Ecological Marine Management
Samuel Obiri	Research Scientist	BED Chemistry/Integrated Science MPhil Inorganic/Analytical Chemistry
Gloria D. Addico	Snr. Research Scientist	BSc. (Hons) Nat. Res. Mgt. (UST) M.Phil. Biological Sciences (UST) Ph.D Biological Sciences (Robert Gorden Univ., Aberdeen-Scotland)
Ebenezer D. O. Ansah	Research Scientist	BSc. Zoology (Legon) M.Phil. Zoology (Legon) PhD (Delft, The Netherlands)
George T. Mensah	Research Scientist	BSc. (Hons) Biol. Sciences (KNUST) MPhil Zoology (Legon) P.G. Dip. In Education (UCC)
Regina Banu (Mrs)	Research Scientist	BSc Botany (Legon) Mphil Botany (Legon)
Samuel Armoo	Research Scientist	BSc. Zoology (Legon) Mphil. Public Health (Legon)
Joseph N. Padi	Research Scientist	BSc. (Hons) Zool./Bot (Legon) MSc. Aquaculture (Auburn) PhD Aquaculture (Auburn)
Felix Y. K. Attipoe	Research Scientist	BSc. (Hons) Zool/Bot. (Legon) MSc. Aquaculture (Stirling, UK) Ph.D Zoology (UCC)
Theodore Quarcoopome	Research Scientist	BSc. (Hons) Nat. Res. Mgt. (UST) Mphil Biological Sciences (UST)
Seth K. Agyakwah	Research Scientist	BSc. (Hons) Biological Sci. (UST) Mphil Fisheries Science (UG) PhD Fisheries Science (UG)

NAME	DESIGNATION	QUALIFICATION
Francis Assogba Anani	Research Scientist	BSc Zoology(UG, Legon) Mphil Fishery Science(UG, Legon)
Marian A. Jiagge (Mrs.)	Librarian	BLS. (A.B.U Zaria-Nigeria) MLS (UG, Legon)
Marian Amu-Mensah (Mrs.)	Research Scientist	BSc. Art (UST) Mphil Sociology (UG)
Kwabena Owusu Benson	Scientific Secretary	BSc. In Ed. Science (UCC) Mphil Env. Science (UG, Legon)
Paul Fabalona	Accountant	BSc. Accounting (IPS) Chartered Accountant(ICA-Gh.)
Deborah Ofori	Research Scientist	BSc. Civil Engineering (KNUST) MSc. Env. Res. Eng.(Suny-esf-Syracuse, N.Y.)
Gerard Quarcoo	Research Scientist	B.Ed. Science (UCC) Mphil Env. Science, U.G
Etornyo Agbeko	Research Scientist	BSc. Agric Technology (UDS) Mphil. Fisheries Science (UG)
Mark Osa Akrong	Research Scientist	BSc. Biological Sciences (KNUST) Mphil. Environmental Science (UG)
Solomon A. Owiredu	Research Scientist	BSc. Oceanography & Fisheries (UG) Mphil. Fisheries Science (UG)
Saada Mohammed	Research Scientist	BSc. Chemistry (UCC) MSc. Pharmaceutical Analysis & Qual. Control (KNUST)
Emmanuel Tetteh-Doku Mensah	Research Scientist	BSc. Oceanography & Fisheries (UG) Mphil. Fisheries Science (UG)
Kumi Michael	Research Scientist	BSc. Chemistry (UCC) MSc. Env. Science & Tech. (Mid. Sweden Univ.)
Evans Manu	Research Scientist	BSc. Physics (UCC) MSc. Geophysics (KNUST)
Esther Wahaga	Research Scientist	BA Sociology (UCC) MPhil Sociology (University of Warwick, Coventry UK PhD Sociology (University of Warwick, Coventry UK)
Godwin Dorhetso	Accountant	BSc. Accounting (IPS) EMBA Finance (UG)
Thomas K.F. Adom	Asst. Marketing Officer	B.A. Dip. Educ. (UCC) CIM-Advanced Cert.
Georgina Badu (Mrs)	Assistant Librarian	Dip. Library & Info.Sci. (Legon) BA – Information Studies & Religions (UG)
Kwame Osei- Mensah	Accountant	BA Accounting (GIMPA) MBA Accounting and Finance (UPS)
David Ebo Ampah	Administrative Officer	BA (HONS) French and Law (KNUST) MBA Business Information Technology (KNUST)

List of Senior Staff

NAME	DESIGNATION	QUALIFICATION
Patience Atsakpo (Mrs)	Chief Technologist	Higher Dip.Microbio. Lab. Techq. (UG)
Kenneth N. Atsakpo	Principal Technologist	H.Dip. Analytical Chem. Lab. Techq. (UG)
Grace Dartey (Ms)	Principal Technologist	Higher Dip.Microbio. Lab. Techq. (UG)
Michael Dorleku	Senior Technologist	BSc. Laboratory Technology (UCC)
Rex John Sapah	Chief Draughtsman	Snr. Sup. Cert. Civil-Building/Roads(ITS-Weija)
Mohammed M Bello	Chief Technical Officer	HND. Science Lab. Tech. (Accra Poly)
Charles K. Dzokoto	Chief Accounting Asst	HND Accounting (Tamale Poly)
Ahmed Hawa	Principal Tech. Officer	BSc. Biological Sciences, KNUST
William E. Arko	Principal Technical Officer	BSc. Chemistry (UCC)
Martha D. Agyemang	Principal Technical Officer	BSc. Chemistry (KNUST)
Zita Naangmenyele	Principal Technical Officer	BSc. Applied Chemistry (UDS)
Salifu Abdul-Latif	Prin. Technical Officer	HND Ind. Chemistry (Inst. Of Chem.-Cuba)
Harrison Komladzei	Principal Draughtsman	Snr. Sup. Cert. Civil-Building/Roads(ITS-Weija)
Sampson Siaw Krodua	Principal Draughtsman	Snr. Sup. Cert. Civil-Building/Roads(ITS-Weija)
Collins K. Asante-Sasu	Principal Technical Officer	BSc. Agric. Eng. (KNUST)
Sena Niampomah	Principal Technical Officer	GCE “A” Level
Lady A. B. Adomako	Principal Technical Officer	BSc. Botany (UG)
Ruth Amole (Mrs)	Prin. Technical Officer	Dip. Nat. Res. Mgt. (KNUST)
Edward Jenner Tettevi	Prin. Technical Officer	BSc. Molecular Bio. & Biotech. (UCC)
Lilly K. Osei	Principal Technical Officer	BSc. Biological Science (KNUST)
Edem K. Amerdome	Technologist	Higher Dip. Microbiol. Techniques (UG)
Sylvia Amponsah	Principal Technical Officer	BA. Political Science (India)
John H. Baffoe	Cheif Accounting Asst.	RSA Stage III Accounting
Johnson-Ashun Mercy	Principal Technical Officer	BSc. Fisheries & Aquatic Science (UG)
Claudia Bentum (Mrs)	Principal Admin. Asst.	BSc. Public Admin. (GIMPA)
Joyce Osibo	Principal Admin. Asst. (Sect)	BA Information Studies & Sociology (UG)
Millicent Adu-Boakye	Principal Technical Officer	BSc. Chemistry (UCC)
Godfried P. K. Acquaah-Arhin	Prin. Admin. Asst.	BBA Management (VVU)
Linda A. Nuamah	Prin. Technical Officer	BSc. Biological Sciences (UCC)
Christopher Nfojoh Yom	Prin. Technical Officer	BSc. Environmental Science (KNUST)
Quansah Jude Ofei	Prin. Technical Officer	BSc. Chemistry (KNUST)
Benedicta Osei-Tutu	Prin. Admin. Asst.	BSc Human Res. Mgt. (Pent.Univ. Col.)
Emmauel A. Ayizemi	Prin. Technical Officer	Cert. Gen. Drilling Theory/Practice (UMaT)
Alexander A. Dei	Prin. Accounting Asst.	RSA Stage III Accounting
Rebecca Yankson	Prin. Admin. Asst (Sect)	BBA Management (VVU)
Vivan Osae	Prin. Admin. Asst (Sect)	BBA Human Resource Mgt. (Zenith Univ. College)
Emmanuel Adu-Ofori	Asst. Technologist	H.Dip. Analytical Chem. Lab. Techq. (IST)
Michael Dankwa Afram	Senior Technical Officer	HND. Science Lab. Tech. (Accra Poly)
Francis Annor Boakye	Senior Technical Officer (Systems Admin.)	City & Guilds. Infor. Technology
E. Nii. Dodoo Koranteng	Senior Accounting Asst.	DBS Accounting (Accra Poly)
John A. Akuoko-Baafi	Senior Accounting Assistant	Cert. Procurement & Material Mgt. (GIMPA)
Esther Mate-Ahmed (Mrs)	Senior Accounting Assistant	DBS Accounting (Accra Poly)
Kenneth K. Opare	Prin. Works Supt. (Auto)	Cert.(Jnr) Mech/Elect. Wrkshp. (ITS-Weija)
Eric J. Darko	Senior Technical Officer	Cert. Gen. Agric. (Damango. Agric. College)
Agnes Darko	Prin. Admin. Asst. (Sect)	Dip. Management Studies (UCC)

NAME	DESIGNATION	QUALIFICATION
Priscilla Ampofo-Yeboah (Mrs)	Senior Admin. Asst. (Sect)	HND Secretaryship & Mgt. (Accra Poly)
Martin A. Adakpeya	Senior Technical Officer	Cert. Gen. Agric. (Damango Agric. College)
Richard Kwapong Kwayisi	Senior Assistant Printer	Cert. Printing (ITS-Weija)
Gabriel Appiah	Snr. Technical Officer	HND. Civil Eng.(Cape Coast Poly)
Eva G. Agbozo (Mrs.)	Snr. Admin. Asst.	HND. Sect. & Mgt. (Adv. Bus. College)
Esther Sowah	Technical Officer	Laboratory Technician
Godwin Amegbe	Technical Officer	Higher Dip. Microbiol. Techniques (UG)
Matilda Asinor (Mrs.)	Accounting Assistant	HND Accounting (Accra Poly)
Eric Yaw Darko	Snr. Technical Officer	HND. Civil Eng.(Takoradi Poly)
Dorothy Krodua (Mrs)	Snr. Admin. Asst. (Sect)	ABCE (Secretaryship)
Bernice Essegbey (Mrs)	Technical Officer	ABCE. Catering (Accra Poly)
Murjanatu Abdul-Hamid	Technical Officer	HND. Science Lab. Tech. (Accra Poly)
Genevieve G. Kwogana	Admin. Asst. (Sect)	HND Secretaryship & Mgt. (Tamale Poly)
Alex Yeboah	Accounting Asst.	HND Accounting (Accra Poly)
Doris Ohene-Lartey (Mrs)	Prin. Accounting Asst.	BBA Accounting (VVU)
Mark Boateng Ofori	Prin. Accounting Asst.	BSc Banking & Finance (UPSA)
John K. Kpamah	Snr. Asst. Transport Officer	Cert. Of Att. Transport Mgt. (STC-Accra)
Alex A. Yeboah	Snr. Asst. Transport Officer	Cert. Of Att. Transport Mgt. (STC-Accra)
Samuel Annang	Snr. Asst. Transport Officer	Cert. Of Att. Transport Mgt. (STC-Accra)
Edem K. Ayegbe	Snr. Asst. Transport Officer	Cert. Of Att. Transport Mgt. (STC-Accra)
Matthew Kwara	Snr. Asst. Transport Officer	Cert. Of Att. Transport Mgt. (STC-Accra)
Samuel K. Nikoi	Snr. Asst. Transport Officer	Cert. Of Att. Transport Mgt. (STC-Accra)
Benjamin K. Kodjo	Works Superintendent	Cert. Wielding Technician
Samuel K. Osafo	Snr. Works Superintendent	Cert.(Jnr) Mech/Elect. Wrkshp. (ITS-Weija)
Simon K. Anane	Snr. Estate Assistant	Full Tech. Cert., Const. Tech. (Accra Poly)
Appiah-Odei Matilda (Mrs.)	Supt. Telephonist/ Receptionist	Cert. Advance Customer Care (Gh. Telecom Univ. College)
Samuel Kanati	Administrative Assistant	Univ. Diploma – Public Admin. (UG)
Solomon K. Mensah	Technical Officer	Cert. General Drilling Theory & Pract.(UMT)
Frank Oblim	Technical Officer	HND Civil Engineering (Accra Poly)
Jonas Asamoah	Works Superintendent	Cert. Civil, Building/Road (ITS-Weija)
Ebenezer Mensah	Works Superintendent	Cert. Effective Practice of Supt. (ITS-Weija)
Ex. WO1 Samuel D.N. Kotei	Snr. Security Officer	MSLC
Anthony Arko	Security Officer	MSLC
Mary M. Quaye	Admin. Asst.	Catering Ind. Part 8/2/1
John K. Mensah	Stores Superintendent	RSA State III
Joyce O. Appiah	Admin. Assistant	HND, Secretaryship & Management (Adv. Bus. College)
Salima Abdulia	Admin. Assistant	HND, Secretaryship & Management (Bolga Poly)
Serapis Asiedu Appiah	Prin. Tech. Officer	BSc Chemistry (KNUST)
Victor Mante	Prin. Tech. Officer	BSc Environmental Science (KNUST)
Daniel K. Amoah	Tech. Officer	HND Science Lab. Tech. (Accra Poly)
Frederick Sekyi	Stores Superintendent	HND, Purchasing & Supply (Koforidua Poly)
Yaa Asaba Agadzi	Snr. Tech. Officer	BSc Oceanography & Fisheries (UG)
Mike B. Niekye	Security Officer	DBS Accounting (Private)

Staff Distribution among the Divisions and Sections

Division/ Section	**Senior Members**	**Senior Staff**	**Junior Staff**	**Total**
Directorate	2	-	-	**2**
Surface Water	7	3	-	**10**
Groundwater	6	3	2	**11**
Environmental Chemistry	9	17	1	**27**
Environmental Biology & Health	10	8	-	**18**
Fishery Division	12	7	5	**24**
Commercialization and Information Division				
• *Scientific Secretariat Section*	4	1	-	**5**
• *Library Section*	2	1	1	**4**
• *Printing Section*	-	1	1	**2**
• *Cartographic Drawing Office Sect.*	-	3	-	**3**
• *Computer Section*	-	1	2	**3**
Finance Division	3	12	1	**16**
Administration Division				
• *Personnel Section*	2	16	9	**27**
• *Transport/Mech. Workshop Section*	-	9	18	**27**
• *Estate Section*	--	3	24	**27**
• *Security Section*	-	3	25	**28**
Temporary Staff	-	4	2	**6**
Contract Appointment	-	2	7	**9**
Total	**57**	**94**	**98**	**249**

APPENDIX III: Human Resource Activities

New Appointment

No.	Name	Designation	Category of Staff	Division/Section	Effective Date of Appointment
1	Felix Akpabey	OIC-Tamale	Senior Member	Env. Biology & Health	1/1/13
2	Dr. Isaac O. A. Hodgson	Deputy Director	Senior Member	Directorate	2/5/13

Temporary Appointment

No.	Name	Designation	Category of Staff	Division/Section	Effective Date of Appointment
1	Emmanuel O. Bekoe	Senior Tech. Officer	Senior Staff	Env. Biology & Health	1/3/13
2	Selom Borbor	Senior Tech. Officer	Senior Staff	Env. Biology & Health	1/3/13
3	Bright K. Idun	Tech. Officer	Senior Staff	Env. Biology & Health	5/2/13
4	Richard Kuddy	Senior Tech. Officer	Senior Staff	Env. Chemistry	1/3/13
5	Rita Atiemo	Accts. Clerk Gd. II	Junior Staff	Finance	1/2/13
6	Joshua Ferguson	Literate Helper	Junior Staff	Administration	1/4/13

Contract Appointment

No.	Name	Designation	Category of Staff	Division/Section	Effective Date of Appointment
1	Adu-Worae Michael	Tech. Officer	Junior Staff	Fishery	1/9/13
2	Gifty Darko	Literate Helper	Junior Staff	Fishery	1/2/13
3	Perpetual Nangude	Literate Helper	Junior Staff	Fishery	1/2/13
4	Richard Savato	Fisherman	Junior Staff	Fishery	2/7/13
5	Ebenezer Tetteh	Literate Helper	Junior Staff	Fishery	1/2/13
6	Godfred Yeboah	Snr. Tech. Officer	Senior Staff	Fishery	1/11/12
7	Emmanuel Quansah	Fishing Asst. Gd. II	Junior Staff	Fishery	1/2/13
8	Shafui Salissu	Labourer	Junior Staff	Estate	1/2/13
9	Agbeko Vuduga	Literate Helper	Junior Staff	Administration	1/2/13

Transfers

Junior Staff

No.	Name	Division/Section	From	To	Effective Date of Transfer
1	Mr. David Ebo Ampah	Administration	Soil Research Institute	Water Research Institute	2/10/13
2	Dr. Esther Wahaga	Commercialization and Information	Savanna Agricultural Research Institute	Water Research Institute	18/9/13

Promotions

Senior Staff

No.	Name	Division/Section	From	To	Effective Date of Promotion
1	Mr. Samuel K. Osafo	Admin.-Workshop	Works Superintendent	Snr. Works Supt.	1/1/13
2	Mr. Kenneth Opare	Admin. - Workshop	Snr. Works Supt.	Prin. Works Supt.	1/1/13
3	Mr. Samuel N. Nikoi	Admin. -Transport	Asst. Transport Officer	Snr. Asst. Transport Officer	1/1/13
4	Mr. Simon K. Anane	Admin - Estate	Estate Assistant	Snr. Estate Assistant	1/1/13
5	Mr. Gabriel Appiah	SWD	Tech. Officer	Snr. Tech. Officer	1/1/13
6	Mr. Alex A. Yeboah	Admin. - Transport	Asst. Transport Officer	Snr. Asst. Transport Officer	1/1/13
7	Mr. Eric Y. Darko	GWD	Technical Officer	Snr. Technical Officer	1/1/13
9	Mr. Samuel Annang	Admin. - Transport	Asst. Transport Officer	Snr. Asst. Transport Officer	1/1/13
10	Mr. J. H. Baffoe	Finance	Prin. Accounting Asst.	Chief Accounting Asst.	1/1/13
12	Mrs. Eva G. Agbozo	Admin.	Admin. Asst.	Snr. Admin. Asst.	1/1/13
13	Mr. John K. Mensah	Finance	Snr. Store Keeper	Stores Superintendent	1/1/13
14	Mrs. Dorothy Krodua	Admin.	Admin. Assistant	Snr. Admin. Assistant	1/1/13
15	Mrs. Agnes Darko	Admin.	Snr. Admin. Assistant	Prin. Admin. Assistant	1/1/13
16	Mr. Edem K. Ayegbe	Admin. - Transport	Asst. Transport Officer	Snr. Asst. Transport Officer	1/1/13
17	Mr. Matthew Kwara	Admin. - Transport	Asst. Transport Officer	Snr. Asst. Transport Officer	1/1/13
18	Mr. John K. Kpamah	Admin. - Transport	Asst. Transport Officer	Snr. Asst. Transport Officer	1/1/13

Junior Staff

No.	Name	Division/Section	From	To	Effective Date of Promotion
1	Mr. Bernard L. Lartey	CID-Printing	Printing Asst. Gd. 1I	Printing Asst. Gd. 1	1/1/13
2	Mr. Samuel Asiedu	Admin.-Security	Security Asst. Gd. I	Snr. Security Asst.	1/1/13

Upgrading

Senior Staff

No	Name	Division/Section	From	To	Effective Date of Promotion
1	Ex WOI D. S. N. Kotei	Admin. -Security	Security Officer	Snr. Security Officer	1/1/13

Junior Staff

No.	Name	Division/Section	From	To	Effective Date of Promotion
1	Mr. David Awudi	Admin. -Estate	Cleaner	Headman	1/1/13
2	Mr. Stephen Teye	Admin. -Security	Security man	Security Assistant Gd. II	1/1/13
3	Mr. Awudu Yahaya	Admin. -Estate	Senior Headman	Supervisor Gd. II	1/1/13
4	Mr. George Asante	Admin. -Estate	Cleaner	Headman (Ordinary)	1/1/13
5	Mr. Bright Awunor	Fishery	Fisherman	Fish Assist. Gd. I	1/1/13
6	Mr. Daniel Sandow Anyorka	Admin. -Estate	Supervisor Gd. II	Supervisor Gd. I	1/1/13
7	Mr. Tetteh Asare	Admin. -Security	Supervising Watchman	Security Assistant Gd. II	1/1/13
8	Mr. Michael Atanga	Admin. -Security	Watchman	Security man	1/1/13
9	Mr. Lawrence A. K. Seshie	Admin. -Security	Supervising Watchman	Security Assistant Gd. II	1/1/13

Resignations

No.	Name	Designation	Category of Staff	Division/Section	Effective Date of Resignation
1	Mrs. Joyce Amoako	Research Scientist	Senior Member	ECD	10/11/13
2	Daniel Akongyuure Nsoh	Research Scientist	Senior Member	Fishery	10/8/13

Compulsory Retirement

No.	Name	Designation	Category of Staff	Division/Section	Effective Date of Retirement
1	Dr. P. Gyau-Boakye	Deputy Director	Senior Member	Directorate	30/4/13
2	Dr. Alex A. Opoku	Senior Research Scientist	Senior Member	EB&H	31/5/13
3	Nana Yaw Biritwum	Chief Stores Supt.	Senior Staff	Finance	30/11/13
4	Johnson C. K. Eworde	Chief Admin. Assistant.	Senior Staff	Administration	31/3/13
5	James Owusu	Chief Technical Officer	Senior Staff	Groundwater	30/6/13
6	Mrs. Wilhelmina Tetteh	Senior Technologist	Senior Staff	EB&H	31/5/13
7	Alhassan Musah	Sup. Watchman	Junior Staff	Administration-Security	30/6/13
8	Peter Amina	Supervisor Gd. I	Junior Staff	Admin.- Estate	30/6/13
9	Samuel Asiedu	Sec. Assistant Gd. I	Junior Staff	Administration-Security	31/3/13
10	Ayaba Mohammadu	Sup. Watchman	Junior Staff	Administration-Security	30/6/13
11	Maleky Alhassan	Sup. Watchman	Junior Staff	Administration-Security	31/5/13
12	Mohammed Haruna	Sec. Assistant Gd. 1I	Junior Staff	Administration-Security	30/6/13

APPENDIX IV: Human Resource Development - Staff Pursuing Various Courses

No.	Name of Officer	Designation	Division/Section	Training Instituition	Course Title	Duration	Date Started	Expected Date of Return	Sponsorship Status
1	Anthony Y. Karikari	Snr. Res. Scientist	Environ. Chemistry	KNUST	**PhD**- Aquaculture & Env. Management	3years	Dec-2012	Dec. 2015	CSIR
2	George T. Mensah	Research Scientist	Env. Biology & Health	UG Medical School	**PhD**-Microbiology	3years + 1year Extension	Aug. 2010	Aug. 2014	CSIR
3	Collins Tay	Snr. Res. Scientist	Environ. Chemistry	Univ. of Ghana	**PhD**-Environmental Science	3years	Jan. 2011	Jan.2014	CSIR
4	Michael A. Danquah	Senior Tech. Officer	Environ. Chemistry	UCC	**BSc.**-Science Lab. Tech.	2years	Aug. 2012	July 2014	CSIR
5	Harrison Komladzie	Prin. Draughtsman	CID-Cartography	Gh. Sch. of surveying and Mapping	**HND**-Surveying & Mapping	2years	Aug. 2011	Jul. 2013	CSIR
6	Francis Anani Assogba	Research Scientist	Fishery	Univ. of Ghana	**PhD**-Fisheries Science	3years	Aug. 2011	Jul. 2014	CSIR
7	Mustapha B. Mohammed	Chief Tech. Officer	Env. Biology & Health	Accra Poly	**BTech**-Science Lab. Technology	18months	Nov. 2011	Mar. 2013	CSIR
8	Zita Naangmenyele	Prin. Tech. Officer	Environ. Chemistry	Inst. Of Water Education, Delft-Netherlands	**MSc**-Environmental Science	2years	Oct. 2012	Sept. 2014	CSIR
9	Francis Y. K. Amevenku	Snr. Res. Scientist	Fishery	Univ. of Ghana	**PhD-**Applied Agric Economics and Policy	4years	March 2013	Sept. 2017	CSIR
10	Mrs. Dorothy Krodua	Snr. Admin. Asst.	Admin.	Pentecost Univ. College	**BSc** Business Admin.	4years	October 2013	Sept. 2017	Self

APPENDIX V: National Service and Industrial Attachments

National Service Personnel Posted to the Institute in 2013

No.	Name	University	Division/Section Attached To
1	Nana Aso Amono	University of Cape Coast	Environmental Biology & Health
2	Sherifatu Mustapha	UDS, Navrongo	Environmental Biology & Health
3	Emmanuel Esi Fletcher	KNUST	Environmental Biology & Health
4	Newton Ato Robert	Univ. of Ghana, Legon	Environmental Biology & Health
5	Yeboah Isaac	Univ. of Ghana, Legon	Environmental Biology & Health
6	Owusu Frimpong Isaac	Univ. f Ghana, Legon	Environmental Biology & Health
7	Dadzie Albert Ato	KNUST	Environmental Biology & Health
8	Mensah Aaron	Accra Polytechnic	Environmental Biology & Health
9	Abubakari Salifu Farouk	UDS,	Environmental Biology & Health
10	Chris Mario	KNUST	Environmental Biology & Health
11	Osafo Nana Osei-Asibey	Univ. of Ghana, Legon	Environmental Chemistry
12	Edmund D. Delle	Univ. of Ghana, Legon	Environmental Chemistry
13	Issahaque Saudafu	KNUST	Environmental Chemistry
14	Kavaarpuo Bertha	UDS,	Environmental Chemistry
15	Antwi Samuel Kwaku	Univ. of Ghana, Legon	Environmental Chemistry
16	Dzaka Florence Sena	Accra Polytechnic	Environmental Chemistry
17	Sarah Opoku	KNUST	Groundwater
18	Yakubu Adams	Univ. of Ghana, Legon	Groundwater
19	Gifty Efiinu	KNUST	Groundwater
20	Bernard Akrong	Accra Polytechnic	Finance
21	Commodore Nadia Naa-Marley	Central Univ. College	Finance
22	Samuel Anderson	Methodist Univ. College	Finance
23	Darko Boahen Emmanuel	Regent Univ. College	Comm. & Info

No.	Name	University	Division/Section Attached To
24	Yussif Fadila	UPS, Accra	Comm. & Info
25	Duah Akosua Nketsiah	Univ. of Mines & Tech., Tarkwa	Groundwater
26	Agbetawokpor Pascal	Ho Poly.	Fishery
27	Antwi Daniel	UDS,	Fishery
28	Awuku Elisha	UDS,	Fishery
29	Sampong Ebenezer	Damango Agric College	Fishery
30	Amponsah Charles	Ejura Agric College	Fishery
31	Fatsi S. K. Patrick	UDS,	Fishery
32	Agbenorku K. K. James	UDS,	Fishery
33	Sackitey Emmanuel Nyarko	KNUST	Fishery
34	Kyeremanteng James Kwaku	KNUST	Fishery
35	Avoer Melshior	KNUST	Fishery
36	Prince Agbenyegah	UCC	Fishery
37	Francis Atsu	Accra Polytechnic	Fishery
38	Appiah Ebenezer Koranteng	KNUST	Fishery
39	Dzakpasu Godwin Kofi	UDS,	Fishery
40	Mustapha Fadi	UDS,	Fishery

Attachment Personnel Posted to the Institute in 2013

No.	Name	Institution	Division/Section Attached To
1	Fredrick Acquah	Accra Polytechnic	EB&H
2	Angela Kafui Amuzu	Central Univ. College	EB&H
3	Agyapong Patrick Gyamfi	Univ. Of Blida	EB&H
4	Rebecca Namoog	ROK. Professional Institute	Admin.
5	Joshua Ferguson	Oda Snr. High Sch.	Admin.
6	Juliana Addo	Jayee Univ. College	Admin.
7	Stephen O. Boateng	IPS	Finance
8	Mary Gyamea	Central Univ. College	Finance

Summary of National Service/Industrial Attachment

National Service	No.	Industrial Attachment	No.
Accra Polytechnic	4	Accra Polytechnic	1
Univ. Of Cape Coast	2	Univ. Of Professional Studies Accra	1
Univ. Development Studies	9	ROK Professional Studies	1
KNUST	10	Univ. of Blida	1
Univ. Of Ghana	7	Oda Snr. High Sch.	1
Methodist Univ. College	1	Jayee Univ. College	1
Regent University	1	Central Univ. College	2
Univ. Of Professional Studies Accra	1		
Univ. of Mines and Technology	1		
Central Univ. College	1		
Ho Polytechnic	1		
Damongo Agric College	1		
Ejura Agric College	1		
Total	**40**	***Total***	**8**

APPENDIX VI: List of Staff Publications

Conference Papers

Attipoe, F. Y. K., J. Blay Jr., S. Agyakwah, R. W. Ponzoni, H. L. Khaw and E. K. Abban (2013) Genetic parameters and response to selection in the development of Akosombo strain of the Nile tilapia, Oreochromis niloticus, in the Volta Basin, Ghana. Paper presented at the 10th International Symposium on Tilapias in Aquaculture (ISTA10), 6 - 10 October 2013, Jerusalem, Israel.

Asmah, R. (2013) Aquaculture site selection and carrying capacity estimates for inland and coastal water bodies in West Africa. In: Ross, L. G., Telfer, T. C., Soto, D. and Aguilar-Manjarrez, J. (Eds) 2013. Site selection and carrying capacities for inland and coastal aquaculture. FAO Fisheries and Aquaculture Proceedings 21. Pp 197-206. FAO, Rome.

Borovski, T., G. Rubinstein, J. Shapiro, S. K. Agyakwah, G. Hulata and L. David (2013) Low genetic variation and the decline in population size of *Sarotherodon galilaeus* in the Sea of Galilee. Paper presented at the 10th International Symposium on Tilapias in Aquaculture (ISTA10), 6 - 10 October 2013, Jerusalem, Israel.

Kankam-Yeboah K. and Ofori D. (2013) Water crisis in Ghana's cities and water safety. Paper presented at the West Africa and Construction Exhibition seminar, 22 – 24 May 2013, Accra.

Mohammed, S. and Hodgson I. O. A. (2013) Quality of the Nima Creek and its suitability for urban agriculture. Paper presented at the 28th Bi-annual Conference of GSA, 15 – 18 July 2013, Accra.

Obiri S. (2013) Food security and climate change in drought-sensitive savannah zones of Ghana. Paper presented at the 2nd Organisation of Women in Science from Developing World (OWSD) African Regional Conference, 15 – 18 October 2013, Sunyani.

Obiri S. (2013) Life cycle assessment of small-scale gold mining in Ghana. Paper presented at the Ghana Science Association Bi-annual Conference, 15 – 17 July 2013, Accra.

Ofori D. and Asare R. (2013) Rainwater harvesting for resilience to climate change impact on water availability in Ghana: Water within your reach. Paper presented at the Bi-annual Ghana Real Estate Developer Association (GREDA) seminar, 19 April 2013, Accra.

Osei-Atweneboana M. Y., (2013) Long term effect of doxycycline on populations of *Onchocerca volvulus* responding sub-optimally to ivermectin treatmet. Paper presented at the Expert Meeting on Sub-optimal Responses of *Onchocerca volvulus* to Ivermectin treatment, 22 – 24 April 2013, Accra.

Osei-Atweneboana M. Y., Taylor M. J., (2010) Development of genetic markers for early detection and monitoring of ivermectin resistance in *Onchocerca volvulus* and its implication for onchocerciasis control. Paper presented at the Knowledge for Tomorrow – Cooperative Research Projects in Sub-Saharan Africa, 12 – 15 October 2013, Hanover – Germany.

Takahashi, S., Asante, K., Tue, N., Itai, T., Muto, M., Ansa-Asare, O. and Tanabe, S. (2013) Contamination status of dioxin related compounds in soils and ash mixtures from Agbogbloshie e-waste recycling site in Accra, Ghana. Proceedings of the 33rd International Symposium on Halogenated Persistent Organic Pollutants (POPs), 25 – 30 August,Daegu, South Korea.

Consultancy Reports

Agbeko, E., Kwarfo-Apegyah, K. and Akongyuure, D. N. (2013) Enhancement of fish production and water conservation in dugouts for climate change adaptation in south-western part of Yendi Municipal Area, CSIR WRI, Accra.

Agyakwah, S. K., Attipoe, F. K. Y., Mensah, T-D. E., Atsakpo, P. and Darko, E. J. (2013) Assessment of water quality and spawning behavior of the Akosombo strain of Nile Tilapia, *Oreochromis niloticus,* at the Crystal Lake Farm, CSIR WRI, Accra.

Agyakwah, S. K. (2013) Bio-economic survey of selected commercial fish farms in the Volta Basin, Ghana, CSIR WRI, Accra.

Agyekum, W. A., Darko, H. F. and Akrong, M. (2013) Pumping, sampling and quality re-assessment of 15 small towns water supply boreholes in selected communities in the Brong-Ahafo Region, CSIR WRI, Accra.

Akrong M. O., Darko, H. and Banu R. (2013) Physico-chemical and bacteriological quality of boreholes and tap water from selected communities at Oyibi in the Damgbe West District, CSIR WRI, Accra.

Ametefe W., Allotey, E., Asmah R., Kankam-Yeboah, K. and Ampofo J. A. (2013) Subri River water discharge management update report, CSIR WRI, Accra.

Ampofo, J. A., Kankam-Yeboah, K., Dankwa, H. R., Asmah, R., Akpabey, F., Ofori, D., Logah, F. Y., Akrong, M., Quarcoopome, T., Appiah, G., Arkoh, W., Amedome, E., Amegbe, G. and Nuamah, L. (2013) Restoration and renaturation of Fosu Lagoon, CSIR WRI, Accra.

Asante K. A., Asmah R., Akrong M. and Adu-Ofori E. (2013) Water quality survey for upgrading and expansion of the Albert Bosomtwe – Sam Fishing Harbour, CSIR WRI, Accra.

Asmah R (2013) Technical guidelines for cage aquaculture for the Water Resources Commission, CSIR WRI, Accra.

Asmah R., Akpabey F., Akrong M., Dankwa, H. R., Opoku A. and Mensah G. T. (2013) Ecological study of the water dam and other water bodies in the catchment area of the Ahafo Mine - Minor dry season report, CSIR WRI, Accra.

Asmah R. and Ansa-Asare O. A. (2013) Water and fish quality of the Fosu Lagoon, CSIR WRI, Accra.

Dankwa, H. R., Agyekum, W. A., Duah, A. A., Akpabey, F. J., Addico, G., Amevenku, F., Owiredu, S., Akrong, M. and Darko, H. (2013) Re-optimisation and re-operation study of the Akosombo and Kpong Dams on the Volta River in Ghana, CSIR WRI, Accra.

Darko, H. F., Akrong, O. M., Ansa-Asare O. D. (2013) Independent investigation of drinking water quality in the Eastern Region of Ghana, CSIR WRI, Accra.

Darko H. F. and Ansa-Asare O. D. (2013) Potable water quality studies for Pioneer Food Company Limited, CSIR WRI, Accra.

Darko H. F. and Ansa-Asare O. D. (2013) Assessment of effluent quality for Pioneer Food Company Limited, CSIR WRI, Accra.

Darko H. F. and Ansa-Asare O. D. (2013) Assessment of final effluent quality for Phyto-Riker (GIHOC) Pharmaceuticals, CSIR WRI, Accra.

Logah, F.Y., Kankam-Yeboah, K., Ofori, D. and Ampofo, J. A. (2013) Topography and surface hydrology of SAVACEM concession area in the Yakombo Forest Reserve, Northern Ghana, CSIR WRI, Accra.

Okrah C. and Agyekum W. A. (2013) Installation of water treatment facilities on five boreholes at the premises of SSNIT properties in Accra, CSIR WRI, Accra.

Okrah, C., Agyekum, W. A. and Duah, A. A. (2013) Hydrogeological Investigation for 20 boreholes in the Sunyani-West (point sources), CSIR WRI, Accra.

Okrah, C., Agyekum, W. A. and Duah, A. A. (2013) Hydrogeological Investigation for 18 boreholes in the Techiman Municipal (point sources), CSIR WRI, Accra.

Okrah, C., Agyekum, W. A. and Duah, A. A. (2013) Hydrogeological investigation for 19 boreholes in the Dormaa Municipal (point sources). CSIR WRI, Accra.

Okrah, C., Duah, A. A. and Agyekum, W. A. (2013) Hydrogeological investigation for 18 boreholes in the Sunyani Municipal (point sources), CSIR WRI, Accra.

Okrah, C., Manu, E., Duah, A. A. and Agyekum, W. A. (2013) Borehole drilling at Asiafo-Amanfro in the Yilo Krobo District, CSIR WRI, Accra.

Osei-Atweneboana, M. Y., Ansa-Asare, O. D., Kankam-Yeboah, K., Dankwa, H. R., Logah, F. Y., Darko, H., Owiredu, S. A., Amegbe, G. B., Ansah, E. D. O., Appiah, G., Arkoh, W. E. and Amedorme, E. (2013) Sustainable land and water management, wet season, CSIR WRI, Accra.

Osei-Atweneboana, M. Y., Ansa-Asare, O. D., Kankam-Yeboah, K., Logah, F. Y., Darko, H., Amegbe, G. B., Ansah, E. D. O., Appiah, G. and Arkoh, W. E. (2013) Sustainable land and water management, dry season, CSIR WRI, Accra.

Ward A., Phillips M., Jens P., Dalsgaard T., Baidoo-Forson J. J., Dankwa H. R., Agyakwah S. K., Katic P., Ameyaw G., Sarfo A. and Sidibé Y. (2013) Report of the Joint CGIAR Research Program (Aquatic Agricultural Systems and Livestock and Fish) and New Partnership for African Development Agency (Rural Futures Programme) Strategic Scoping Mission, CSIR WRI, Accra.

Journal Papers

Acheampong, M. A., Ansa, E. D. O. and Adiyiah, J. H. (2013) Physico-chemical characteristics of a gold mining tailings dam wastewater, *Journal of Environmental Science and Engineering* A2: 469-475.

Amu-Mensah F. K. and Yamamoto T. (2013) Improving soil surface conditions for enhanced rainwater harvesting on permeable soils, *Int. Journal of Water Res. Environ. Eng*, Vol. 5 (11), pp. 616-621.

Amu-Mensah F. K., Yamamoto T. and Inoue M. (2013) Investigating rainwater harvesting on highly permeable soils - baseline conditions, *Int. Journal of Water Res. Environ. Eng*, Vol. 5 (7), pp. 426-433.

Anim-Gyampo M., Kumi M. and Zango M. S. (2013) Heavy metals concentrations in some selected fish species in Tono irrigation reservoir in Navrongo, Ghana, *Journal of Environmental and Earth Science*, Vol 3. No.1, pp. 109-119.

Asante F., Agbeko, E., Addae G. and Quainoo, A. K. (2013) Bioaccumulation of heavy metals in water, sediments and tissues of some selected fishes from the Red Volta of Ghana, *British Journal of Applied Science and Technology*, Vol.1, 594-803.

Asante, K. A., Takahashi, S., Itai, T., Isobe, T., Devanathan, G., Muto, M., Agyakwah, S. K., Adu-Kumi, S., Subramanian, A. and Tanabe, S. (2013) Occurrence of halogenated contaminants in inland and coastal fish from Ghana: Levels, dietary exposure assessment and human health implications, *Ecotoxicology and Environmental Safety*, 94, pp. 123-130.

Asante, K. A., Agusa, T., Biney, C. A., Agyekum, W. A., Bello, M., Otsuka, M., Itai, T., Takahashi, S. and Tanabe, S. (2012) Multi-trace element levels and arsenic speciation in urine of e-waste recycling workers from Agbogbloshie, Accra in Ghana. *Science of the Total Environment*, 424, pp 63-73.

Bekoe, E. O. and Logah, F. Y. (2013) The impact of droughts and climate change on electricity generation in Ghana, *Environmental Sciences Journal,* Vol. 1, pp. 13-24.

Cobbina S. J., Kotochi M. C., Korese J. K. and Akrong M. O. (2013) Microbial contamination in vegetables at the farm gate due to irrigation with wastewater in the Tamale Metropolis of Northern Ghana, *Journal of Environmental Protection,* 4. 676-682.

Cobbina, S. J., Kumi, M. and Abdul-Latif S. (2013) Water quality assessment of the Bontanga reservoir, *Journal of Environmental and Earth Science,*Vol.3, No 4. Pp. 112-121.

Cobbina, S. J., Michael, K., Salifu, L. and Duwiejua, A. B. (2013) Rainwater quality assessment in Tamale Municipality, *International Journal of Science and Technology Research,*Vol.2, Issue 5. Pp. 1-5.

Cobbina, S. J, Myilla, M. and Michael, K. (2013) Small-scale gold mining and heavy metal pollution: assessment of drinking water sources in Datuku in the Talensi-Nabdam District, *International Journal of Science and Technology Research,*Vol.2, Issue 1. pp. 96-100.

Cobbina, S. J., Nkuah, D., Tom-Dery, D. and Obiri, S. (2013) Non – cancer risk assessment from exposure to mercury (Hg), cadmium (Cd), arsenic (As), copper (Cu) and lead (Pb) in boreholes and surface water in Tinga in the Bole-Bamboi District, Ghana, *Journal of Toxicology Environmental Science*, Vol. 5 (2), pp. 29-39.

Darko, H. F., Ansa-Asare, O., Paintsil, A., (2013) A number description of Ghanaian water quality: A case study of the southwestern and coastal rivers systems of Ghana, *Journal of Environmental Protection*, 4, 1318-1327.

Duwiejuah A. B., Cobbina S. J and Akrong M. O. (2013) Effect of storage on the quality of sachet-vended water in the Tamale Metropolis, Ghana, *Journal of Environmental Protection,* 4. 629-637.

Forkuor, G., Pavelic, P., Asare, E. and Obuobie, E. (2013) Modelling potential areas of groundwater development for agriculture in Northern Ghana using GIS/RS, *Hydrological Sciences Journal*, 58 (2), 1–15, doi:10.1080/02626667.2012.754101

Gioia, R., Akindele, A. J., Adebusoye, S. A., Asante, K. A., Tanabe, S., Buekens, A. and Sasco, A. (2013) Polychlorinated biphenyls (PCBs) in Africa: a review of environmental levels, *Environmental Science and Pollution Research* (DOI 10.1007/s11356-013-1739-1).

Kankam-Yeboah, K., Logah, F., Amisigo, B., Bekoe, E. O. Ofori, D. and Akudago, J. A. (2013) Low flow analysis of the Black Volta River at Lawra in Ghana, *Journal of Environmental Hydrology*, Vol. 21, Paper 2, pp. 1-16.

Kankam-Yeboah, K., Obuobie, E., Amisigo, B. and Opoku-Ankomah, Y. (2013) Impact of climate change on streamflow in selected river basins in Ghana, *Hydrological Sciences Journal*, DOI:10.1080/02626667.2013.782101,Vol. 58, No. 4, pp. 1–16.

Kankam-Yeboah, K., Okrah, C., Agyekum, W. A., Duah, A. A., Ofori, D. and Logah, F. (2013) Water resources management of shared transboundary aquifer systems – The case of the Keta Basin, *Ghana Journal of Science*, Vol.53.

Kumi M., Quainoo, A. K. and Antwi, C. K. (2013) The role of maize tassel in amelioration of heavy metals from contaminated soils and its effects on vegetables, *Journal of Environmental and Earth Science*, Vol 3. No.1, pp. 192-199.

Logah, F. Y., Kankam-Yeboah., K. and Bekoe, E. O. (2013) Developing short duration rainfall intensity frequency curves for Accra in Ghana, *International Journal of Latest Research in Engineering and Computing*, Vol. 1, Issue 1, pp. 67-73.

Logah, F. Y., Obuobie, E., Ofori, D. and Kankam-Yeboah, K. (2013) Analysis of rainfall variability in Ghana, *International Journal of Latest Research in Engineering and Computing*, Vol. 1, Issue 1, pp. 1-8.

Mensah, E. T. D., Attipoe F. K. and Ashun-Johnson M. (2013) Effect of different stocking densities on growth performance and profitability of *Oreochromis niloticus* fry reared in hapa-in-pond system, *International Journal of Fisheries and Aquaculture*. Vol. 5(8), 204-209.

Nkoom M., Cobbina S. J. and Kumi M. (2013) Assessment of endocrine disrupting trace metals in River Samre at Samreboi in the Wassa Amenfi West District of the Western Region of Ghana, *Journal of Water Resources and Protection*, Vol. 5, No. 10. Pp. 983-992.

Nkrumah, F. K., Acheampong, M. A., Ansa, E. D. O.and Adiyiah, J. H. (2013) Wastewater quality assessment of a petroleum refinery in Ghana, *Journal of Environmental Science and Engineering* (Accepted for publication).

Obuobie, E and Ofori, D (2013) Analysis of water storages and groundwater potential in the Volta Basin, West Africa. *Journal of Water Sciences* (In-Review).

Obuobie, E, Ofori, D., Agodzo, S. K. and Okra C. (2013) Groundwater potential for dry season irrigation in north-eastern Ghana, *Water International*, 38:4, 433-448.

Obiri, S., Cobbina, S. J., Armah, F. A. and Luginaah, I. (2013) Assessment of cancer and non-cancer health risks from exposure to PAHs in street dust in the Tamale Metropolis, Ghana, *Journal of Environmental Science and health*, Part A, Vol. 48, pp. 408-416.

Ofosu-Asiedu, L., Cobbina, S. J. and Obiri, S. (2013) Non-cancer human health risk assessment from exposure to cadmium, copper, lead and mercury in surface water and groundwater in Konongo-Odumasi Municipality, Ghana, *Journal of Environmental Chemistry and Ecotoxicology*, Vol. 5 (4), pp. 106-112.

Post, R. J., Cheke, R. A., Boakye, D. A., Wilson, M. D., Osei-Atweneboana, M. Y., Tetteh-Kumah, A. (2013) Stability and change in the distribution of cytospecies of the *Simuliumdamnosum* complex (Diptera: Simuliidae) in southern Ghana from 1971 to 2011 *Parasites and Vectors*, 6:205

Segbefia, J., Nunoo, K. E. and Dankwa, H. R. (2013) Species composition, abundance and growth of three common fish species of the Volta estuary, Ghana, *International Journal of Fisheries and Aquaculture Sciences*, ISSN 2248-9975 Vol.3 No.1 pp. 79-97.

Sigrid, D., Helness, H., Ofori, D., Azrague, K., Bjorkvoll, T. and Asare R. (2013) Integrated approach to rainwater harvesting for resilience to climate change impact on water availability in Ghana, *International Journal of Geography* (In-review).

Silverman, A. I., Akrong, M. O., Amoah, P., Drechsel, P. and Nelson, K. L. (2013) Quatification of human norovirus GII, human adenovirus and faecal indicator organisms in wastewater used for irrigation in Accra, *Journal of Water and Health*.

Sossoukpe, E., Nunoo, F. K. E. and Dankwa, H. R. (2013) Population structure and reproductive parameters of the Longneck croaker, *Pseudotolithus typus* (Pisces, Bleeker, 1863) in nearshore waters of Benin (West Africa) and their implications for management, *Agricultural Sciences* Vol.4 No. 6A, 9-18.

Sossoukpe, E., Nunoo, F. K. E.,Ofori-Danson, P. K, Fiogbe, E. D. and Dankwa, H. R. (2013) Growth and mortality parameters of *P. senegalensis* and *P. Typus* (Sciaenidae) in nearshore waters of Benin (West Africa) and their implications for management and conservation, *Fisheries Research*, 137, 71-80.

Su, B., Perera, D. A., Zohar, Y., Abraham, E., Stubblefield, J., Fobes, M., Beam, R., Argue, B., Carel, L., Padi, J. N., Waters, P., Umali-Maceina, Chatakondi, N., Kristanto, A., Hutson, A., Templeton, C., Ballenger, J., Chaimongkol, Gima, A., Gima, M., Zuberi, A., Lambert, D. M., Kim, S., Mandour, M., Dunham, R. A. (2013) Relative effectiveness of carp pituitary extract, luteinizing hormone releasing hormone analog (LHRHa) injections and LHRHa implants for producing hybrid catfish fry, *Aquaculture*: 372 – 375 (2013) 133-136.

Turner, H. C., Churcher, T. S., Walker, M., Osei-Atweneboana, M. Y. and Prichard, R. K. (2013) Uncertainty surrounding projections of the long-term impact of ivermectin treatment on human onchocerciasis, *PLoS Negl Trop Dis* 7(4): e2169. doi:10.1371/journal.pntd.0002169.

Turner, H. C., Osei-Atweneboana, M. Y., Walker, M., Tettevi, E. J. and Churcher, T. S. (2013) The cost of annual versus biannual community-directed treatment of onchocerciasis with ivermectin: Ghana as a case study, *PLoS Negl Trop Dis* 7(9): e2452. doi:10.1371/journal.pntd.0002452

Agyekum, W. A., Klitten, K., Armah, T., Banoeng-Yakobo, B. and Amartey, E. O. (2013) Geophysical borehole logging for control of driller's records: hydrogeological case study from Voltaian sedimentary rocks in Ghana, *Journal of Applied Water Science,* Vol 3, Issue 2, pp. 491-500.

Technical Reports/Papers

Agyekum, W.A., Manu, E. and Duah, A. A. (2013) Borehole drilling in three selected institutions in Cape Coast Municipality, CSIR WRI, Accra.

Agyekum, W., Klitten, K. and Armah, T. (2013) Geophysical borehole logging for control of drillers records: hydrogeological case study from voitaian sedimentary rocks in Northern Ghana, CSIR WRI, Accra.

Ampofo, J. A., Andah, A, Tetteh, W. and Bello, M. (2013).Microbiological profile of some Ghanaian herbal preparations safety issues and implications for the health professions, CSIR WRI, Accra.

Amu-Mensah, F., Akrong, M., Amu-Mensah, M., Darko, H. F. (2013) Sustainable management of Lake Bosomtwe in the Ashanti Region of Ghana: Hydrology, water quality and anthropological factors, CSIR WRI, Accra.

Ansa, E. D. O. (2013) The removal of faecal coliforms in waste stabilization pond systems and eutrophic lakes, CSIR WRI, Accra.

Ansa-Asare, O. D., Duah, A. A., Benson, K.O., Amisigo, B., Mainoo, P. A. and Enstua-Mensah, R.E.M. (2013) Impact of small-scale mining on the water resources of the pra river basin, CSIR WRI, Accra.

Bekoe, E. O., Logah, F. Y., Amisigo, B. (2013) Developing short duration rainfall intensity frequency curves for Accra in Ghana, CSIR WRI, Accra.

Bekoe, E. O.and Logah, F. Y (2013) The Impact of droughts and climate change on electricity generation in Ghana, CSIR WRI, Accra.

Dankwa, H. R., Amevenku, F., Owiredu, S. and Edem, A. (2013) Impacts of mining operations on the ecology of River Ankobra in Ghana, CSIR WRI, Accra.

Kankam-Yeboah, K., Logah, F. Y., Amisigo, B., Bekoe, E. O., Ofori, D. and Akudago, J. A. (2013) Low flow analysis of the Black Volta River at Lawra in Ghana, CSIR WRI, Accra.

Karikari, A. Y. (2013) Systematic implementation and maintenance of a quality system in environmental laboratories, CSIR WRI, Accra.

Karikari, A. Y. and Ampofo, J. A. (2013) Chlorine treatment effectiveness and physico-chemical and bacteriological characteristics of treated water supplies in distribution networks of Accra-Tema Metropolis – Ghana, CSIR WRI, Accra.

Kombat, E. O., Nunoo F. K. E, Ampofo, J. A. and Addo, P. G. A. (2013) Effects of environmental conditions on the micro-biological quality of two small marine pelgic fishes landed in Accra and Tema, Ghana, CSIR WRI, Accra.

Kizito, F., Namara, R., Akoto-Danso, E. K., Agyare, W. A., Oboubie, E., Quansah, C., Naminong, K., Panyan, E., Amegashie, B. and Logah, F. Y. (2013) Sustainable agricultural water management in cereal-based farming systems of Northern Ghana, CSIR WRI, Accra.

Lawton, L., Addico, G. and Edwards,C. (2013) Hepatotoxic-microsystins in two drinking water reservoirs in the Central Region of Ghana, CSIR WRI, Accra.

Logah, F. Y., Kankam-Yeboah, K. and Ofori, D. (2013) The impact of a proposed water treatment plant on the hydrological situation of the Dayi and Volta Rivers in the Volta Region of Ghana, CSIR WRI, Accra.

Mainoo P. A, Agyekum, W. A. and Duah, A. A. (2013) Geophysical investigations to select most promising sites for drilling high yielding boreholes to supply sustainable water to twenty (20) communities in the Tain District of the Brong Ahafo Region of Ghana, CSIR WRI, Accra.

Mainoo, P. A, Agyekum, W. A. and Duah, A. A. (2013) Geophysical investigations to select most promising sites for drilling high yielding boreholes to supply sustainable water to eleven (11) communities in the Jaman North District of the Brong Ahafo Region of Ghana, CSIR WRI, Accra.

Manu, E., Agyemang, C. O., Agyekum, W. A., Duah, A. A. and Mainoo, P. A. (2013) Geophysical investigation for borehole sites selection at Sambuli and Buma communities, CSIR WRI, Accra.

Manu, E., Agyekum, W. A., Duah, A. A. and Maino, P. A. (2013) Hydrogeological investigations for 12 mechanized borehole water supply in the Brong-Ahafo Region, CSIR WRI, Accra.

Manu, E. and Agyekum, W. A (2013) Geophysical investigation to select drilling points in selected institutions in Cape Coast Municipality, CSIR WRI, Accra.

Obuobie, E., Diekkoueger, B. and Reichart, B. (2013) Modelling potential areas of groundwater development for agriculture in the Northern Ghana using GIS/R, CSIR WRI, Accra.

Obuobie, E and Asante-Sasu C. K. (2013) Climate change scenarios in onchocerciasis-endemic Black Volta and Pru river basins, CSIR WRI, Accra.

Obuobie, E., Barry, B., Asante-Sasu, C. K. (2013) Situational analysis of groundwater in Ghana, CSIR WRI, Accra.

Obuobie, E.and Ofori, D. (2013) Analysis of groundwater potential in the Volta River Basin, CSIR WRI, Accra.

Okrah, C., Denvor, S. K., Dapaah-Siakwan, S. (2013) Geophysical investigations for groundwater in the middle precambrian province of Upper Denkyirah District using electromagnetic and electrical resistivity methods, CSIR WRI, Accra.

Okrah C., Manu, E., Duah, A. A. and Agyekum, W. A. (2013) Assessment of groundwater potential to select borehole drilling point at Paradise Estate, Pampanso, CSIR WRI, Accra.

Mainoo, P. A., Agyekum, W. A. and Duah, A. A. (2013) Hydrogeological investigations for 4 small towns water supply project in the Brong-Ahafo Region, CSIR WRI, Accra.

Tay, C. K. and Biney, C. A. (2013) Levels and sources of Polycyclic aromatic hydrocarbons (PAHS) in selected irrigated urban agricultural soils in Accra, Ghana, CSIR WRI, Accra.

Newsletter Article

Agbeko, E. (2013) Aquaculture can offset fish deficit – Scientist, Ghana News Agency, Science. (http://www.ghananewsagency.org/science/aquaculture-can-offset-fish-deficit-scientist--64305) Published: 2013-09-03 17:00:36

Policy Brief

Ansa-Asare, O. D., Akrong, M. O. and Obiri, S. (2013) Impact of Small-Scale Mining Activities on the Water Quality in the Communities of Wassa Amenfi East District, *Policy Brief No 2/2013,* Send-Ghana and Southern African Trust, pp. 1-4.

Book

Ansa, E. D. O. (2013) The removal of faecal coliforms in waste stabilization pond systems and eutrophic lakes, Taylor and Francis/Balkema, Leiden, The Netherlands.

Book Chapter

Asmah, R., Muir, J. F. and Ross, L. G. (2013) Development potential of fish farming in Ghana. In: Meaden, G. J. and Aguilar-Manjarrez, J., eds., Advances in geographic information systems and remote sensing for fisheries and aquaculture. FAO Fisheries and Aquaculture Technical Paper No. 552. Rome, FAO. pp. 98.

Thesis

Asante, K. A. (2012) Contamination and risk assessment of PCBs, PBDEs and HBCDs in biological samples from Ghana, PhD Thesis, Ehime University, Japan, pp.157.

Location map of CSIR Water Research Institute, Accra