PERFORMANCE EVALUATION OF SOLAR POWERED BOREHOLES AND USE OF CAPPED BOREHOLES FOR IRRIGATION IN THE UPPER EAST REGION OF GHANA

By

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Declaration

I hereby declare that this submission is my own work towards the MSc and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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ABSTRACT

The supply of potable drinking water in Ghana has not been adequate and the situation has worsened in recent years, especially in the Upper East Region. The response of Government has been the drilling of boreholes as water points. With the associated drudgery in drawing water, the Community Water and Sanitation Agency (CWSA) piloted a number of solar powered boreholes in the region. However a sizable number of these boreholes have been abandoned (capped) for quality reasons, mostly due to high fluoride levels.

The study evaluated the performance (in terms of water output per day) of solar powered boreholes and assessed the possible use of capped boreholes for irrigation in the region.

Two solar powered boreholes at Zorbisi (Lat: $10^0$48’03’’ N and longitude: $00^0$52’42’’W) and Nayagnia (Latitude $10^0$53’12’’ N and longitude $01^0$01’55’’ W) in the Bolgatanga Municipality and the Kasena Nankana districts respectively were used for the study.

Water meters were installed in the system, where daily recordings were made. Data from successful boreholes in the region was also collected and analysed to determine trends inherent in them. It was found out also that the minimum depth to ground water in the region is below 20m, and that discharge decreases with increasing depth. The system was manually operated and the water output also measured and compared with the solar system and was found out that; the manual operation gave more water than the solar because it had longer operation time than the solar whose operation was limited to (8:30AM-3:15pm). The per capita water demand for Zorbisi and Nayagnia was found to be 17.30 and 16.32 l/p/d respectively. From the South African agricultural water quality guide lines, it was found out that about 50% percent of the boreholes could have been used for Agriculture; and that the rest of the capped boreholes could also be used for Agriculture on neutral to alkaline soils.

DEDICATION

I dedicate this to my late brother, Mathew K. Asaa, you left us too soon. Rest in peace and to my wife, Elizabeth Awaafo Azumah, you woke me up in my slumber. Thank you for being there for me always.

ACKNOWLEDGEMENT

I wish to extend my deepest gratitude to God Almighty for guiding me along my journey on earth with life's experiences.

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A. A. Akunai.

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LIST OF ABREVIATIONS

BH	Borehole
CWSA	Community Water and Sanitation Agency
FAO	Food and Agriculture Organisation
GDP	Gross Domestic Product
GIDA	Ghana Irrigation Development Authority
GSGDA	Ghana Shared Growth and Development Agenda
GSS	Ghana Statistical Service
HAP	Hydrogeological Assessment Project
IFAD	International Fund for Agricultural Development
IPTRID	International Programme for Technology and Research in Irrigation Drainage
MOFA	Ministry of Food and Agriculture
MPPT	Maximum-power-point tracker
NEPAD	New Partnership for Africa's Development
NRC	National Research Council
RWSN	Rural Water Supply Network
UER	Upper East Region
UNICEF	United Nations International Children's Emergency Fund
USA	United States of America
UWR	Upper West Region
WHO	World Health Organisation
WRC	Water Resources Commission

CHAPTER ONE

INTRODUCTION

1.0 General Introduction

Population growth and climate change have put a lot of pressure on water resources the world over. Water is in high demand to meet the varied needs of the ever-growing population. It is estimated that 884 million people lacked access to potable water supply and that 84% of them lived in rural areas (WHO/UNICEF, 2010). Two billion people worldwide depend on groundwater for drinking and its regional significance is evidenced by its provision of 70% of potable water in the European Union, 80% of rural water supply in sub-Saharan Africa, and 60% of agricultural irrigation water in India (IAH, 2006).

A recent groundwater study in Africa has shown that there is possibly 20 times more water available as groundwater compared with that available in lakes and rivers (MacDonald *et al*., 2012). The relative importance of groundwater in staple crop production is between 14-18% of global cereal production and up to 50% or greater of cereal production from irrigated areas (Burke *et al.*, 2012).

Although the whole world is working to meet the 'Millennium Development Goals (MDG) target, to *halve, by 2015 the proportion of the population without sustainable access to safe drinking water*, it may not be met in rural sub-Saharan Africa. Improved groundwater supplies (particularly drilled and hand dug water wells) provide a lot of the water needs of 'rural dwellers' within a reasonable distance of their home'. It is estimated that about 60,000 boreholes per year need to be drilled in sub-Saharan Africa alone to meet the MDG target. But this is yet to be done thus creating a deficit.

Again, the rapid expansion of housing developments; often, far ahead of utility services, has resulted in public water provision being inadequate and not able to meet current demands as well as tackle the deficit (RWSN, 2010). Given the expected urban population growth rates and in view of some climate change scenarios, groundwater expansion is considered as one of the preferred responses in areas of Africa where suitable aquifers are present (Foster *et al*., 2010). An innovative approach to water management is therefore needed in Africa as water scarcity in the region has been predicted due to the rapidly growing population. The complexity of challenges and the uncertainty about the future necessitate a more sustainable, integrated, and adaptive water management approach (Jacobson *et al*., 2012).

In Ghana, agriculture is pivotal in the national economy although it is predominantly dependent on rainfed. Irrigated agriculture is catching up in recent times, though in a limited scale as a result of the seasonality and unreliability of natural rainfall (Kyei-Baffour and Ofori 2006).

The 2010 population of Ghana was 24.2 million with an annual growth rate of 2.5%. About 60% of the population is classified as being in the rural sector. Total agricultural land area is estimated at about 13.6 million ha, of which 29% is said to be under production. Agriculture produces 32 % of the Gross Domestic Product (GDP) and employs 55% of the 10-million-person workforce (GSS, 2011).

1.1 Problem Statement

Groundwater is being exploited for purely drinking water supply purposes mainly and the Water Resources Commission (WRC) recently prepared a groundwater management strategy to guide the long-term decision-making, actions, and investments, as the Commission continues to strengthen its approach for groundwater management in Ghana under a decentralized stakeholder engagement model. The objective of the strategy is to provide a five to ten year road map for investments and actions to be undertaken by the WRC to achieve decentralized sustainable groundwater management (WRC, 2011).

Water supplies in rural areas, however, are obtained almost exclusively from groundwater sources. The various groundwater development programmes have successfully established more than 10,000 boreholes countrywide. With a large number of the boreholes classified as unsuccessful because of the chemical composition of trace elements and others that just dry up. At present, irrigation development does not play an important role in the overall water resources balance considerations. However, the potential for irrigation has been shown to be considerably larger than the present land area being irrigated (WRC, 2012).

According to Dzokoto (2000), access to good drinking water is a problem to rural folks in most developing countries mainly because they have no access to electrical grid. Solar energy has been identified as a reliable and less costly energy source for water pumping in some of these rural areas. He also reported tremendous increase in water delivery of the borehole when the solar pump was used to draw water as compared to manual action. In 1990, Acres International Limited in a joint venture with Wardrop Engineering Inc. conducted a study of small scale irrigation potential and to prepare a project to be implemented through the Ghana Irrigation Development Authority with support from the World Bank in the Northern, Upper East and West Regions. Both surface and groundwater sourced irrigation schemes were to be considered. The objective of the groundwater component of the study was to identify locations where there was good prospects for developing small scale irrigation based on tube wells of less than 20 m depth using mechanised pumps (Wardrop-Acres, 1990). They found out after studying information from over 3,000 boreholes completed within the Northern and Upper Regions that the depth to water bearing zone was in excess of 20 m and generally beyond the reach of a centrifugal pump, with yields in most locations inadequate to support irrigation.

Boreholes constructed in the Upper East Region in five years, indicated that the minimum depth to the water bearing zone is 28 metres and 76 metres maximum, confirming the findings of (Wardrop-Acres, 1990). There are also water quality issues to which fluoride is the most prevalent. Over 50 boreholes have been capped in the Upper East Region alone because of these problems. Data gathered from the Community Water and Sanitation Agency show that boreholes had discharges of 400 litres per minute and depths of more than 20 m.

The Community Water and Sanitation Agency, is currently implementing a project to drill and install 200 boreholes in the Upper East Region to draw groundwater (powered by solar and manual pumps) for drinking water supply. Research into solar pumps has also made it possible to draw water to heads of 60-120 m, with relatively high discharges of up to 13,500 l/d and 44,700 l/d at depths of 120m and 40m respectively, (Mono pumps, 2004; Groundfus, 2012).

The existence of solar pumps with these capabilities with good borehole yield information coupled with the need to be innovative in harvesting water to enhance agricultural productivity in the Upper East Region therefore formed the basis of this study.

1.2 Research Objectives

The overall objective of this study was to measure the performance of solar pump (amount of water pumped out daily) and assess the use of the existing capped boreholes for irrigation.

The specific objectives were:

- Analyse recent boreholes data;
- Determine the working discharge of water from both the solar and manual pumps;
- Determine the existing and projected yearly water demand for the community with respect to population increase;
- To establish whether there is excess water produced in relation to demand and supply;
- Determine the number of capped boreholes for quality reasons and their yields.

1.3 Research Hypothesis

The research objectives were formulated based on the hypothesis that the mechanised borehole will provide water in excess of the community demand; and that with ease of access to water, water usage will change. Thus there would be options for the beneficial use of the excess water until community demand meets the system supply. There may also be capped boreholes that can be useful for agricultural purposes.

1.4 Significance of the study

The study will help support investments in solar pumps for agricultural production. If justified, options for beneficial use to fast-track returns to the investment would be provided to create opportunities. This information will also be of significance to policy makers, scientists and environmentalists especially in the Upper East Region of Ghana. Increase agricultural production in the region especially vegetables such as tomatoes, onions and pepper the main cash crops in the area.

CHAPTER TWO

LITERATURE REVIEW

2.0 Importance of water

Water is life is a common saying and it is universally acclaimed as the most important natural resource the world over. The importance of water is so great that it has been given credence by the following statements:

- Living things depend on water but water does not depend on living things; it has a life of its own (Pielou, 1998)

- Water is an integral part of the natural environment and the habitat for many forms of life, be it human, animal and plant (Opoku-Agyemang, 2005).

- *Water is earth's eye, looking into which the beholder measures the depth of his own nature''* (Thoreau, 1854)

Water's importance on earth is therefore undeniable for human beings and is increasingly so as water is becoming more and more scarce in major parts of the world (Sandwidi, 2007).

Next to air, the other important requirement for human life to exist is water. The importance of water in human life is so much that the development of any city of the world has practically taken place near some source of water supply (Rangwala, 2011). He adds that, water is nature's free gift to the human race, and its availability in various forms such as rivers, lakes, streams, etc, solid, liquid and gas is basically important for human beings' comfort, luxury, and various other necessities of life.

2.1 Water Quality

2.1.0 Introduction

Consumers of water expect it to be both aesthetically pleasing and safe to drink. That is to say the water supplied for domestic use must meet some basic requirements (potable and wholesome) so as to ensure that, that water consumed has no inherent public health issues. The essence of purification of domestic water supply or waste is not to make it physically or chemically pure, but to remove pathogenic bacteria; toxic substances and excessive organic matter to levels that are considered harmless to the human body or crops when such water is used in agriculture.

There is no single definition of water quality, because it depends on the intended use.

There are many methods for determining water quality; with each measuring a specific parameter of water and differ in precision, speed, and cost (Dojlido and Zerbe, 1998)

Real time water quality determination is expensive and complicated.

The purity of water is also a significant factor in the economy and in agriculture (Blignaut and van Heerden, 2009). For example, poor water quality affects the quality of crops (Ratajkiewicz, 2007; Woźnica and Waniorek, 2008).

According to community water and sanitation agency (CWSA) 'a good number of drilled wells have been capped especially in the Northern parts of the country due to high levels of fluoride found in these wells.' This was confirmed by the Hydrogeological Atlas prepared from the Hydrological Assessment Project (HAP) of Northern Ghana

Water quantity in recent years has been reported to be dwindling making access to fresh water scarce.

Intensifying water scarcity is now a global phenomenon. The water resources of many regions of the world are insufficient to meet the demands for food and fibre, municipal and industrial and environmental uses. Even countries that are relatively richly endowed with water may have to address regional or temporary water scarcity. Virtually no region or area of the world has water resources that are sufficient to meet demands in all times and regions. The arid and semi-arid regions of the world are experiencing the most intense water scarcity. Elsewhere, it has been shown that science and the development of technology, including soft technologies, will be crucial in enabling countries and regions are or will be short of water to manage increasingly severe scarcity (Vaux and Jury, 2004).

2.1.1 Water requirements for common crops

Table 1:Recommended maximum concentrations of trace elements in irrigation waters for long-term protection of plants and animals

Element	Recommended Maximum Concentration (mg/liter)[a]	Comments
Arsenic	0.10	This guideline protects sensitive crops grown on sandy soils. Higher concentrations can be tolerated by some crops for short periods when they are grown in fine-textured soils.
Beryllium	0.10	Toxicities to plants have been reported at concentrations of as low as 0.5 mg/liter in nutrient solutions and at levels in the soil greater than 4 percent of the cation-exchange capacity.
Cadmium	0.01	Concentrations equal to or less than 0.01 mg/liter require 50 years or more to exceed the recommended maximum cadmium loading rate. Removal in crops and by leaching partially compensates and perhaps allows use of the water indefinitely.
Chromium	0.10	Toxicity in nutrient solutions has been observed at a concentration of 0.50 mg/liter and in soil cultures at a rate of 10 kg/ha. Toxicity depends on the form of chromium existing in the water and soil and on soil reactions.
Cobalt	0.05	A concentration of 0.10 mg/liter is near the toxic threshold for many plants grown in nutrient solution. Toxicity varies, depending on the type of crop and soil chemistry.
Copper	0.20	Concentrations of 0.1 to 1.0 mg/liter in nutrient solutions have been found to be toxic to plants, but soil reactions usually precipitate or adsorb copper, so that soluble copper does not readily accumulate.
Fluoride	1.0	This concentration is designed to protect crops grown in acidic soils. Neutral and alkaline soils usually inactivate fluoride, so higher concentrations can be tolerated.
Lead	5.0	Plants are relatively tolerant to lead, and soils effectively sorb or precipitate it. Toxicity to animals typically is caused not by lead adsorption from soils but by aerial deposition of lead on the foliage of pasture and forage plants.
Lithium	2.5[b]	Most crops are tolerant to lithium up to 5 mg/liter in nutrient solutions. Citrus, however, is highly sensitive to lithium. Lithium is a highly mobile cation that leaches from soils over an extended period of time.
Manganese	0.20	Some crops show manganese toxicities at a fraction of an mg/liter in nutrient solution, but typical soil pH and oxidation-reduction potentials control manganese in soil solution, so that the manganese concentration in irrigation water is relatively unimportant.

Source: National Research Council (1993) **http://www.nap.edu.**

Table 2: Effects of fluoride on crop yield and quality

Concentration Range (mg/•)	Crop Yield, Crop Quality and Soil Sustainability
Target Water Quality Range • 2.0	*No adverse effects on crops*
2.0 - 15.0	Maximum acceptable as concentration for fine textured neutral to alkaline soils
> 15.0	Acceptable for irrigation only over the short term on a site-specific basis

Source: Department of Water Affairs and Forestry, (1996)

2.2 Solar Pumping Systems

A pump is a mechanical device or arrangement by which water is caused to flow at increased pressure (Rangwala, 2011). The purpose for which pumping is adopted in water supply (especially in groundwater) is to lift water from a lower (inaccessible) to a higher (accessible) level. That is, water available from wells/boreholes lifted for direct distribution or to an elevated storage tank for storage and re-distribution to communities.

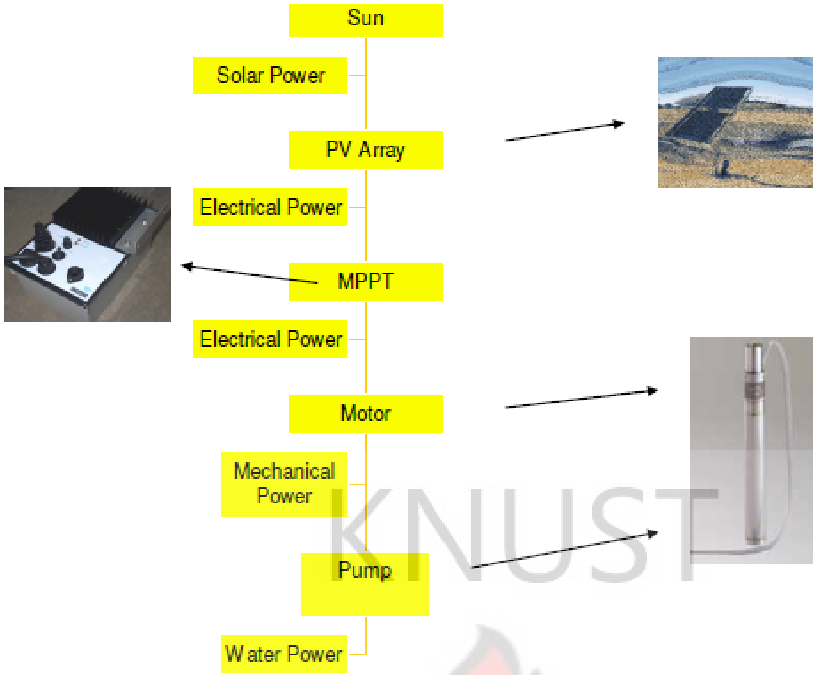


Figure 1: Components of a Solar Water Pumping System

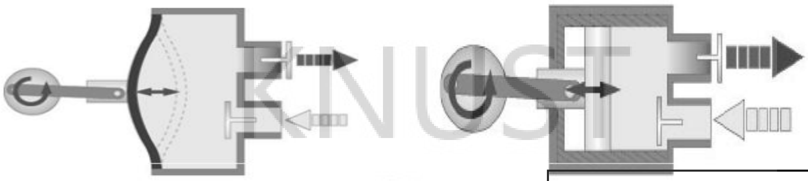
Pumps can generally be classified under two major headings:

1. Rotodynamic (the most common being centrifugal) and

Figure 2: Water flow in a typical centrifugal pump

2. Positive displacement

The Roto dynamic pump transfers the energy of the pump to the water by rotating components of the pump. The Positive displacement pump works by drawing a known amount of fluid into a chamber and then pushing it out again through the mechanical rotation of the pumping elements.



A simple piston pump, with an inlet valve (bottom) and an outlet valve (top) that allows the chamber to fill and drain with the motion of the piston

Figure 3: Diaphragm and piston pumps

Example of the operation of a diaphragm pump.

Source: Arthur (2012) DSTC workshop presentation on solar pump installation in Bolgatanga

Pumps generally require power to work. This power can come from steam engine; diesel engine, gasoline engine; or electric motor. The electric motor require electricity to work and can easily be used where there is grid connectivity or electric generator. Solar energy has also been developed to a point that it can generate electricity to power these motorised pumps and so can be used at any location that has enough solar radiation.

In Africa and Ghana, there is enough solar radiation. Solar energy has high potential as shown by the world distribution of solar radiation and energy potential in Figure 4.

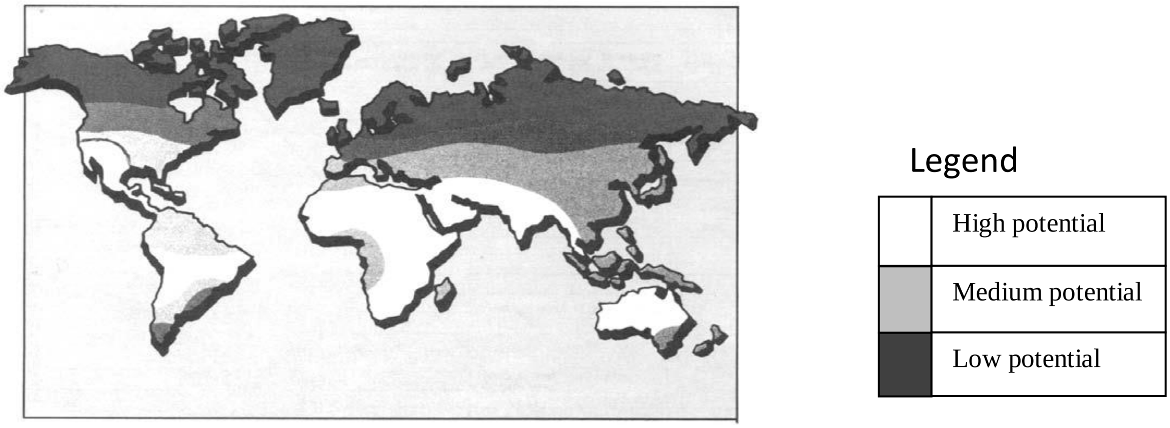


Figure 4: Solar radiation by regions of the world

Source: Patel (1999)

2.3 Irrigation

According to Sahasrabudhe (2012), irrigation is a systematically developed knowledge, based on long observations and experimentations, of handling available sources of water for economic growth of bumper crops. It includes:

- Training and tapping of sources of water supply;
- Storing of water;
- Conveying that water effectively to the fields with drainage of surplus water and then;
- Using that supply of water economically for the bumper crop production.

Cuenca (1989) saw irrigation as basically an attempt by man to locally alter the hydrologic cycle and to promote increased agricultural productivity. The irrigation design manual published by the ARC-Institute for Agricultural Engineering (ARC-ILI), defines irrigation as the artificial application of water to the soil to meet crop water requirement. The definition vividly demonstrates why the Upper East Region and in general the whole of northern Ghana needs irrigation infrastructure. The source of water for irrigation has been historically, surface water but groundwater use has of late gained roots because of its several advantages as compared with surface water.

2.3.1 Groundwater versus surface water as source of irrigation water

As in most semi-arid regions, surface water resources are considerably unreliable due to the high inter- and intra-annual variability in rainfall. In addition, surface water bodies are highly vulnerable to contamination due to natural alteration and anthropogenic intervention. In the long term, groundwater resources are reliable, consistent, safe, and more importantly accessible to people. Since agriculture is the predominant land use within the Upper East Region (UER) of northern Ghana, groundwater irrigated agriculture becomes vital for economic development of that region (Anayah and Kaluachchi, 2009).

Surface water also acts as breeding ground for vectors (e.g. mosquitoes and guinea worms), as well as takes up fertile agricultural soils which are normally located in the valleys used for the storage of surface water. In addition to its capacity to answer growing water demand, groundwater also provides unique opportunities to cope with increased climate variability due to climate change. While this ever increasing reliance on groundwater has gone largely unnoticed, it has become a vital economic input. Groundwater has become a major contributor to GDP and in a large number of countries, it is the foundation on which agriculture, urban development; rural jobs and safe drinking water supply systems have been built. Indeed, access to groundwater through private tubewells was a key factor in South Asia's Green Revolution (World Bank, 2012).

Nevertheless, groundwater irrigated agriculture does have limitations as the water source is dependent on recharge which is variable from season to season. Again, according to Garduño (2010), *in most regions (Table 1), with an extended dry season, consumptive water use by agriculture (if unconstrained) usually generates a demand for crop irrigation in excess of the availability of renewable groundwater resources (given that extensive areas of cultivable land usually occur above aquifers). In some cases inappropriate irrigated agriculture has become established (without planning) through exploitation of non-renewable groundwater resources or very weakly recharged aquifer systems.*

Table 3: Global survey of land area for and using groundwater irrigation

REGION	GROUNDWATER IRRIGATION AREA		GROUNDWATER VOLUME USED	
	M ha	*propn total*	*km^3/a*	*propn total*
GLOBAL	112.9	38%	545	43%
South Asia	48.3	57%	262	57%
East Asia	19.3	29%	57	34%
South East Asia	1.0	5%	3	6%
Middle-East & North Africa	12.9	43%	87	44%
Latin America	2.5	18%	8	19%
Sub-Saharan Africa	0.4	6%	2	7%

Source: Garduño and Foster (2010)

A more balanced approach to rationalizing groundwater use in irrigated agriculture is urgently required which recognizes its key role in rural livelihoods but also values it's other roles more realistically.

2.3.2 Importance of Irrigation

Irrigation contributes immensely to agricultural production in the world. About 40% of the total world food crops produced is through irrigation undertaken on only 17% of the total agricultural land in the world (Upton, 1996; IPTRID, 1999). This means that 60% of food crops are produced with rain-fed agriculture. The marginal productivity of irrigated agriculture is therefore higher than that of rain fed agriculture. Shah (2008) has therefore concluded that irrigation is the lifeline for sustained agriculture. Iterating the importance of irrigation and arguing for its provision, Sahsrabudhe (2012) puts it simply, the *necessity for the provision of more and more irrigation facilities needs no emphasis; in fact irrigation can be rightly called the backbone of agriculture*.

Irrigation increases agricultural production in a year by providing all year round farming opportunities through the artificial supply of water to crops. It has the ability to regulate water supply to crops especially at times when the crops need water most and provides drainage facilities for the disposal of excess water, which is impossible with rain-fed agriculture (Rydzewski, 1987). Together with other agricultural inputs like fertilizer, improved seed varieties, and technologically improved cropping systems; the yield per hectare of irrigated land far outweighs that obtained through rain-fed agriculture on the same size of land (Shah, 2008). Yilma (2005) identified that the yield per hectare of rice cultivated on irrigated land on the Tono and Vea irrigation schemes in the Upper East Region of Ghana is more than four times that produced using rain-fed agriculture.

Shah (2008) also found an increment of over 76% in wheat yields in Khutti village in Pakistan which is attributed to irrigation technology. This is because there is no single requirement of plant life which is more vital than provision of water (Sahsrabudhe, 2012).

Caruthers (1997) therefore suggested that irrigation development is the most effective tool for poverty alleviation than any other public development in arid and semi arid climates.

Irrigation reduces poverty by offering employment especially to rural households, ensuring food security and by stabilizing (or lowering) food prices both in rural and urban markets (Lipton, 2003).

According to Agodzo (1987), farm incomes and employment opportunities in properly managed irrigated areas can be significantly higher when compared to the pre-irrigation periods. Adding that this will in turn contribute to the improvement of socioeconomic conditions, including nutrition of the people in the irrigated area and with employment successfully created in the rural areas, urban migration can be reduced.

Irrigation also increases the supply of agricultural input to industry thereby fostering agro-industrial growth (Hussain, *et al*., 2003; Shah, 2008). The supply of cheap raw materials to industry will also ensure price stability or low prices of industrial output or goods. Irrigation therefore alleviates suffering, preserves life, averts famine and advances the material prosperity of a country (Shah, 2008). The agricultural sector in most African countries, which provide the main livelihood of rural people, constitutes the largest proportion of the workforce (Moyo, 2006).

However, the practice of agriculture during the rainy season alone, lasting for about just five months in the year especially in the savannah countries in Sub-Saharan Africa, offers seasonal employment to rural dwellers (farmers). Irrigation can therefore provide a year-round employment for these farmers, thus improving their lives as well as ensuring food security.

The New Partnership for Africa's Development (NEPAD) identified agriculture as central to achieving poverty alleviation, and food and nutrition security, and to attaining the Millennium Development Goals (MDGs) in the Region (MOFA and GIDA, 2012). This is because agriculture even though practiced under rudimental methods was providing about 80% of Ghana's agricultural products. Sirte (2008) stated it bluntly that agriculture is predominantly practiced on small scale family operated farms using rudimentary technology to produce about 80% of Ghana's total agricultural output. The contribution of Agriculture sector to GDP has dwindled recently such that in 2010, its share of the economy was 30% (of GDP) and provided employment to 63% of the workforce in rural areas (IFAD, 2012). This therefore implies that with a little support to double farming seasons in northern Ghana, parts of Volta, Brong Ahafo and other parts of the country which experience a single wet season per year our agricultural productivity will improve significantly. Again, employment to the farmers in the dry seasons would have been ensured.

'Under the 2010-2013 Ghana Shared Growth and Development Agenda (GSGDA), agriculture was expected to drive the new economic development agenda of the country, given its central role in generating income and providing subsistence for the majority of the people. Under this agenda, the main focus of the agricultural development policy was to accelerate the modernization of agriculture and ensure its linkage with industry through a more intensive application of science, technology and innovation (MOFA and GIDA, 2012).

According to Dinye and Ayitio (2013), irrigated agriculture offers opportunities for greater livelihoods security and poverty reduction in northern Ghana where climatic conditions do not allow for an all-year-around agricultural production.

Due to its perceived inadequate availability, groundwater is largely associated with domestic use and the potential of using groundwater for agriculture are not well reflected in the country's water and irrigation policies. However, contrary to the official statistics and priorities, farmers have experience in groundwater for irrigation since some do use shallow groundwater to produce horticultural crops in many parts of Ghana. In the Upper East Region, which is the most populous of the three poorer northern regions of Ghana, groundwater infrastructure is developed using rudimentary technologies banking on the relative abundance of human labour during the long dry Season (Namara, 2011). These are shown in Figure 5 and 6.

Figure 5: Digging to harvest groundwater

Figure 6: Groundwater irrigation in UER

Source: van den Berg (2008)

Peasant tomatoes farmer drawing groundwater to irrigate his farm in U.E.R. is shown in Figure 7.

Figure 7: Groundwater use in U.E.R.

A--- A peasant farmer drawing groundwater from a well.

B--- Filling an improvised watering can

C--- Groundwater Irrigated tomato farm

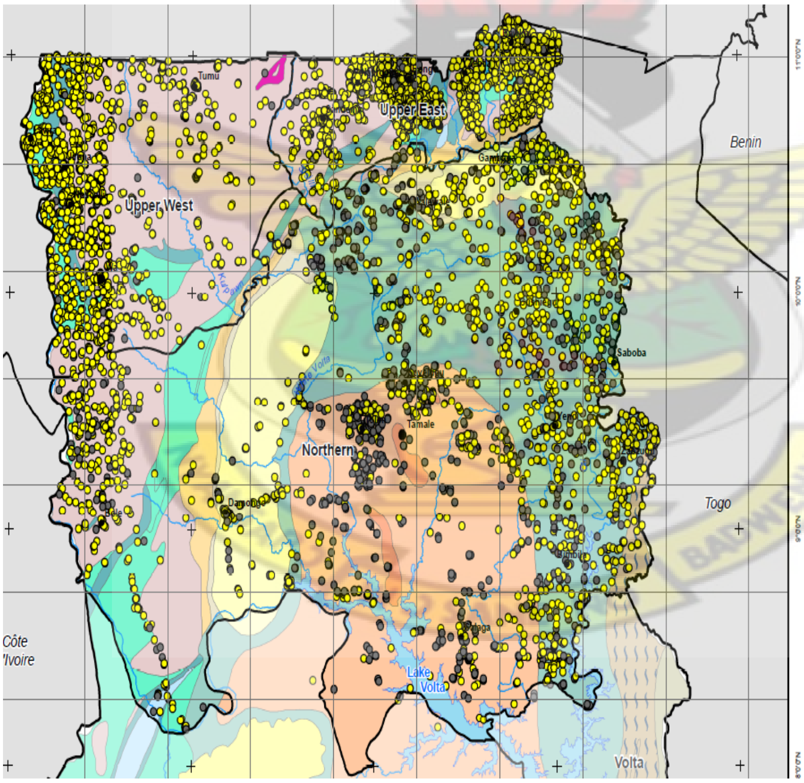
D--- Harvesting tomato

According to Obuobie and Barry (2010), the average cost for constructing a borehole is as given in Table 4.

Table 4: Estimated cost of constructing a borehole

Average cost for a typical borehole (Depth:60m; Diameter 140mm)	**Cost in 2010**
Particulars	Cost (USD)
Borehole drilling and construction in any type of rock including borehole development(Additional cost of 14USD per meter	3,215
Pumping Test	285
Total	3500

Source: Obuobie and Barry (2010). Figures are based on data from several drilling companies.



Key

Well

Dry or technically negative (1,898)

Successful (5,914)

Source:

(Carrier et al., 2009)

Figure 8: Borehole locations in Northern Ghana as at 2009

Figure 8 indicates that one thousand eight hundred and ninety-eight (1,898) boreholes drilled in Northern Ghana are dry or technically dry. The dry boreholes are made up of capped boreholes which are capped purposely for quality reasons and others that do not meet the minimum discharge rate of 13L/minute as well as all boreholes that previously met the discharge criteria but later could not.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Location of Study area

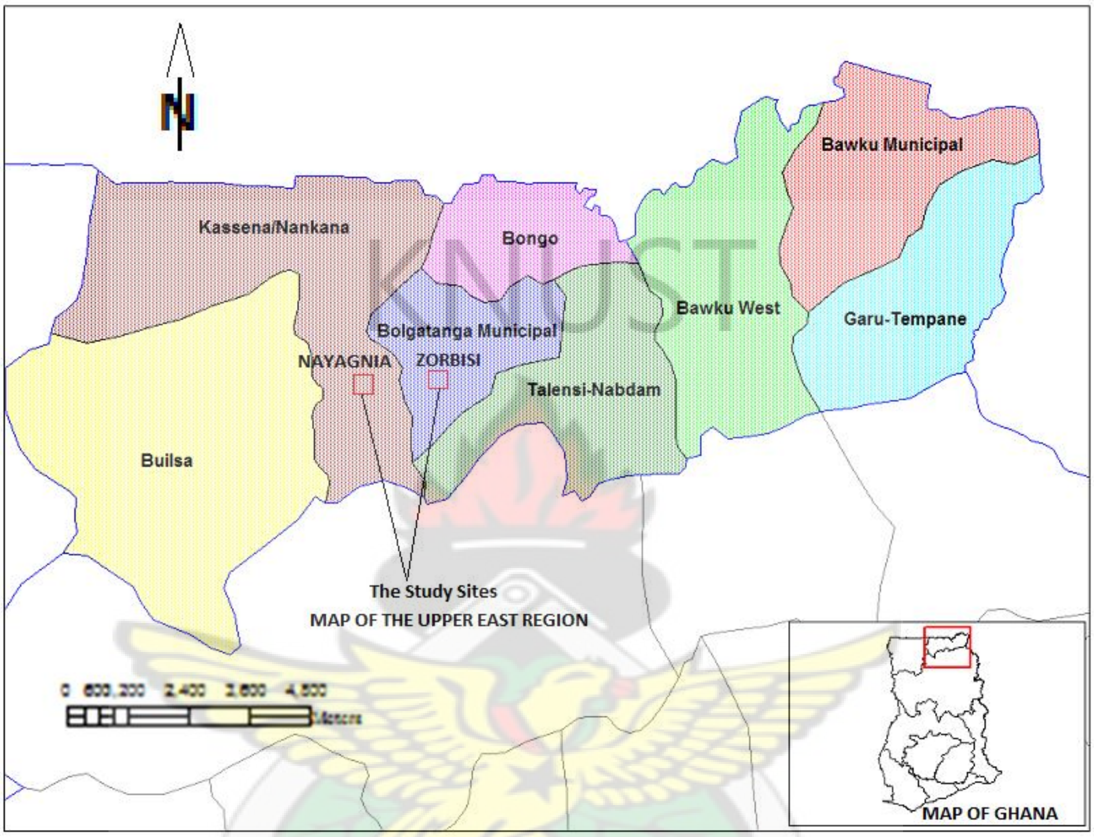


Figure 9: Location of Study Area

The study was carried out at Nayagnia (latitude 10°53'12'' N and longitude 01°01'55'' W) and Zorbisi (Latitude 10°48'03''N and longitude 0°52'42''W) solar/manual powered borehole sites in the Upper East Region of Ghana. Their locations are as shown in Figure 9. These sites were selected to meet the condition the Community Water and Sanitation Agency gave in granting permission for the installation of flow meters at the sites. The region is in the north-eastern part of Ghana and is located between latitudes $10^0$15'and $11^0$10' north and longitudes 0^0 and $1^0$40' west. The Upper East Region is bordered to the north by Burkina Faso; Togo to the east; Northern Region to the south and to the west by the Upper West Region. The region has a gross land area of 8842 km^2 (IFAD, 1991), nine (9) administrative districts and a population of 1, 031,478 according to the population and housing census of 2010 (GSS, 2011). It has a population density of 117 persons per km^2 as compared to the national average of 102 persons per km^2. The rainfall in this area is unimodal with annual mean rainfall of 1,100mm and a growing period in the range of 150-160 days (MoFA, 2010). Majority of the residents' income is generated from rainfed and partly irrigated agriculture, livestock rearing and traditional craft. The high population density in the region places pressure on the water and land resources. According to the Interim HAP Report, the pH of groundwater in UER generally ranges from 6.50-12.00, except for Bawku where there are localised areas with pH less than 6.5 as illustrated in Figure 10.

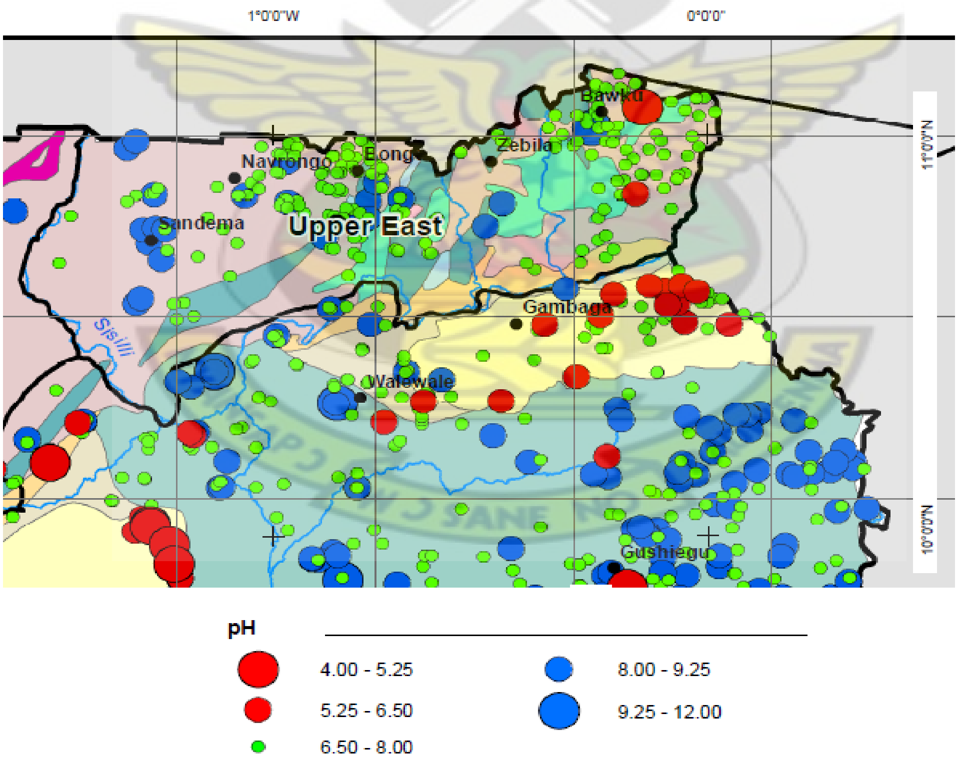


Figure 10: Variation of pH in UER as at 2009

Source: (Carier et al., 2009)

3.1.1 Zorbisi Site

Zorbisi is located on Latitude $10^{0}48'03''$ North and longitude $00^{0}52'42''$ West in the Bolgatanga municipality and is ethnically mixed (local inhabitants and settlers; peasant farmers and government workers). The site can be described as partly rural and partly urban because the municipality is classified by the Ministry of local Government as Urban town but has rural characteristics. The community has some social infrastructure such as pipe borne water to some of the households especially settlers and staff bungalows located within the area. There are also other households made up mostly of local inhabitants, who do not have access to pipe borne water but have hand-dug wells. Farmers are knowledgeable in irrigation and have been practicing it for many years. According to Akologo (personal conversation on 26th November 2012), he has been farming tomatoes in the nearby valley for many years in the dry season with other members of the community. The siting of this borehole according to the CWSA was to provide potable water to this sector of the community.

3.1.2 Nayagnia

Nayagnia is located on latitude $10^{0}53'12''$ North and longitude $01^{0}01'55''$ West and in the Kasena Nankana District and is a rural community, made up predominantly of a single ethnic group who are peasant farmers. The community's previous source of water was more than 500 m away from their homes which met the aims of CWSA, to provide potable water to communities within 500m radius. The community members are knowledgeable in irrigation as the community is only 6 Km from the Tono irrigation site.

3.2 Materials Used

The materials used for the study include:

- manual flow meters,
- Calibrated bucket,
- Calibrated gallons,
- Stop clocks,
- Hand held GPS, and
- Tape measure.

3.3 Methods Used

The study was done in stages. During the first stage, permission was sought from CWSA to select the sites as well as install the two required flow meters to measure the amount of water the system lifts in total per day. Permission was obtained with the condition that the meters could only be installed at sites where pump installation was on-going. And at the time of the installation of the flow meters, the Zorbisi and Nayagnia sites were being installed with pumps by CWSA and this informed the choice of these sites. The meters were installed between the pump and the storage tank; with a tee attached to the tank supply pipe (just after the meter) with a stop cork on the branched line (Figure 12). The branching and the stop-cork were to control the water flow to allow the pumping system to continue non-stop, even if the storage tank was full and the system's stopping mechanism initiated.

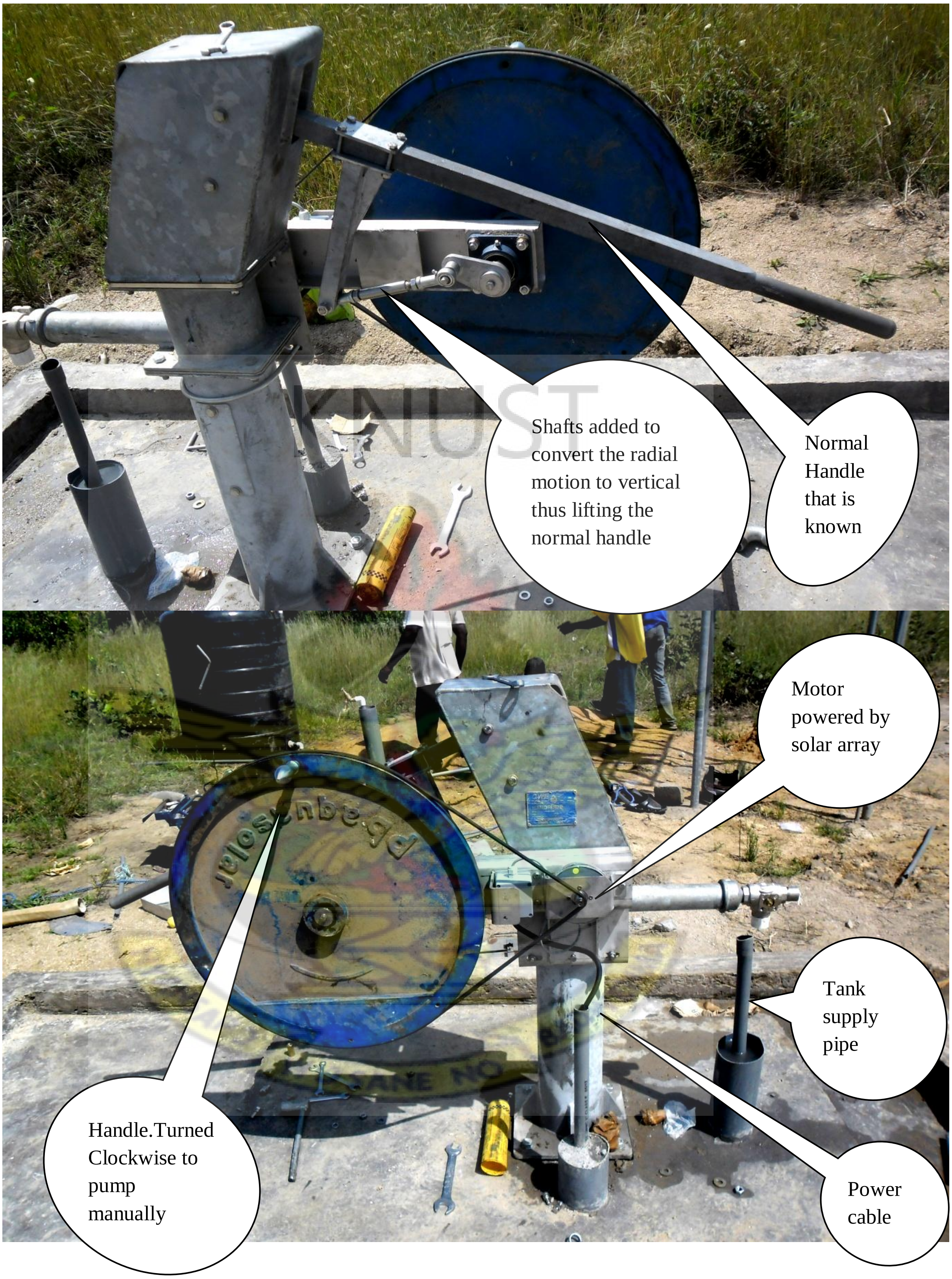


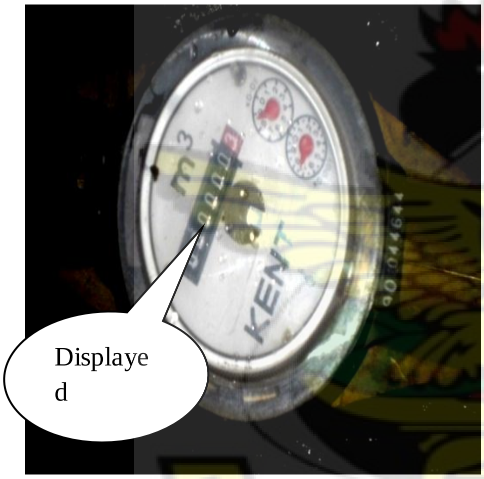
Figure 11: Parts of the Hand Pump

3.3.1 Calibration of Measuring Tools and Equipment

All measuring tools used in the study were calibrated as explained subsequently.

3.3.1.1 Flow meter calibration

The flow meters were calibrated by passing known volume of water through it and noting the readings. That is, the initial reading was taken before the known volume was passed through. After all of the known volume had passed, the reading was taken again. The difference of these two readings consistently gave values comparable to the known volume passing through. The two meters were therefore installed to measure the flows, as shown in Figure 12.



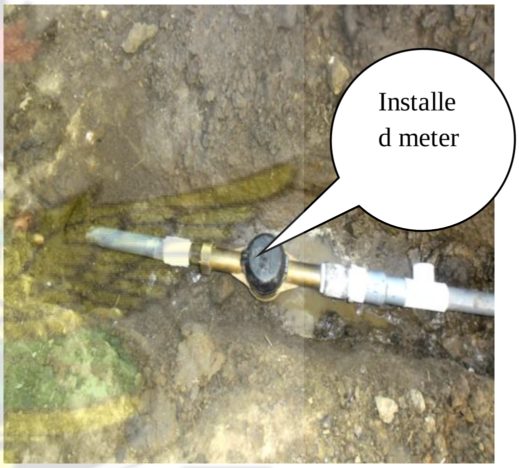


Figure 12: Displayed reading and installed flow meter

3.3.1.2 Calibration of Containers

To reduce the losses of water in transit, containers with lids were given to households under study to be used in carting water from the boreholes to their homes. There was therefore the need to know the actual volumes of the containers used. The containers were individually filled with water to the brim, the practice the community are used to, and then emptied into a graduated bucket noting the volume from the graduation.

The average (for five readings) for each container was taken and it was realised that 21 litres was the average container volume (Figure 13).

Figure 13: Container and Calibration bucket

3.4 Data Collection

There were five main components of the study for which data were collected as listed below.

i. Pump evaluation and discharge measurement studies

ii. Collection and Analysis of recent borehole data in the region

iii. Collection and Analysis of capped borehole data in the region

iv. Drinking water demand studies and estimates

v. Water usage measurement (increases and changes).

3.4.1. Pump Evaluation and Discharge Measurement

The discharge of the pumps was measured using the calibrated flow meters installed in the systems. Daily readings were taken throughout the study period of 4-5 months for time series graphs to be drawn.

Manual and solar power pumps were used at each site for the half-hourly pumping but at different dates for the purposes of comparison. Five active men were used at the

Zorbisi site while four were used at the Nayagnia site. This was to observe the changes in the pump output with reduced labour.

3.4.2 Recent Successful Boreholes in the Region

Data from recent boreholes drilled in the Upper East Region were collected from the CWSA and analysed to determine trends inherent in them. Different graphs were drawn from the data; these included mean yield against depth, discharge against depth, etc as presented in Chapter 4.

3.4.3 Analysis of capped boreholes data in the Upper East Region

Data on capped boreholes from CWSA were also collected and analysed by plotting graphs, to show trends that may exist. Especially the borehole yields and depth as well as the fluoride content were of interest in this study.

3.4.4 Drinking water demand estimate

The community water demand was estimated by counting the people in each household whose source of water were these boreholes alongside the amount of water consumed. Two calibrated gallons (with lids), were given to each of the five selected households and were encouraged to use it to fetch water for all their needs required in a day. This was to reduce losses in transit. The numbers of gallons taken to each house per day for seven consecutive days were recorded. The household numbers as estimated was used with the amount of water consumed to estimate household water demand as well as the per capita water consumption.

3.4.5 Water usage measurement (increases, decreases, losses and labour)

A group of 20 members of each of the communities made up of seven (7) women, five (5) girls, five (5) boys and three (3) men held a discussion at each of the sites.

The composition of the focal group was because women and children hold the responsibility of fetching water in these communities while the men generally take decisions affecting infrastructure in the houses. The focal groups discussed the following at each of the sites:

Zorbisi

- Water usage changes (from drinking to flushing toilets)
- Change in water use (number of buckets of water fetched because of the investment).
- Time spent in fetching water
- Changes (Improvement or decline) in access to cleaner water
- Changes (Improvement or decline) in access to education and
- Labour input to access water.

3.4.6 Estimating Population

According to the Ghana Statistical Service, the 2010 population and housing census, the intercensal growth rate of the Upper East Region is 1.2% per annum, and as these districts are located in the Upper East Region, it is applied in estimating the population increase for the communities in the project location up to the year 2020 using the geometric increase method. The formula employed was:

$$Pop_{Future} = Pop_{Present}\, x(1 + i)^{n}$$

Where;

$Pop_{present}$ = Present population,

Pop_{future} = Future population,

i = growth rate and

n = number of periods (in this case years).

For the year 2013, the population of the two communities counted from the households were 182 and 210 for Nayagnia and Zorbisi respectively.

Therefore for the population in 2014, we have for Nayagnia,

$$Pop2014 = Pop2013(1+0.012)^1 = 182(1+0.012)^1$$

$$= 182(1.012)$$

$$= 184.184$$

$$= 185 \text{ People}$$

Similarly, for Zorbisi (2014), we have the population as;

$$Pop2014 = Pop2013(1+0.012)^1$$

$$= 210(1+0.012)^1$$

$$= 210(1.012)$$

$$= 213$$

The rest are so calculated and tabulated in Table 5.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

The results gathered from the study using various methods are presented and discussed in this chapter. These included half-hourly readings (for both manual and solar pumping system), data of boreholes drilled or constructed in recent years obtained from the CWSA. Also, water demand results, population estimation and flow measurements are also analysed and discussed.

4.2 Successful Boreholes and their Properties

This section deals with data collected from CWSA on successful boreholes. These are boreholes that passed both the water quality test as well as the minimum yield criteria, and so were developed for use.

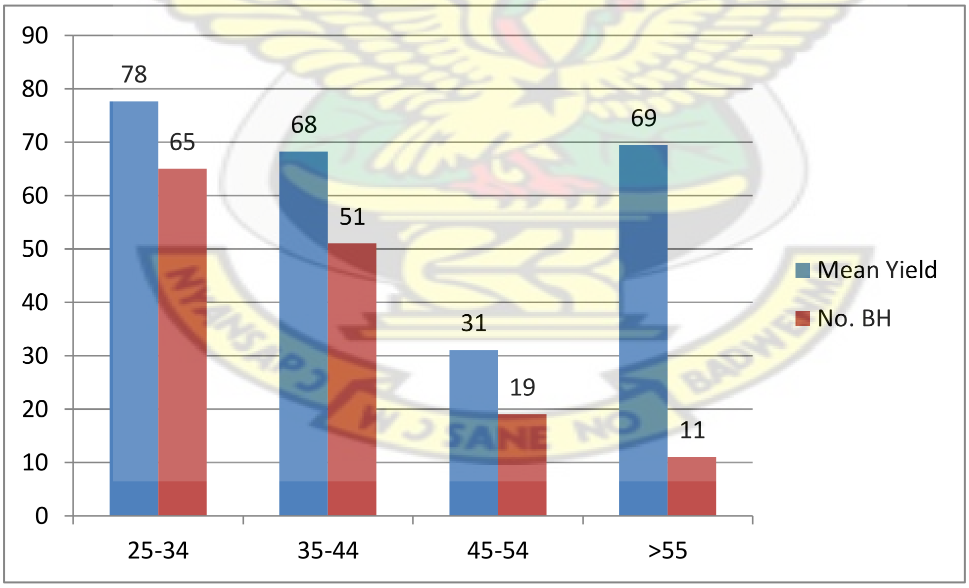


Figure 14: Mean Yield, Depth Class and number of Boreholes

From Figure 14 it can be seen that groundwater is obtained mostly after 20 m depth of drilling. The majority of the borehole depths ranged from 25-55 m with yield generally decreasing with increasing depth. The highest mean yield of 78l/min is obtained at the depth 25-35m followed by 35-44m. Therefore in most areas, there is no need drilling too deep and drilling short at 20m will also not yield any appreciable water. It also indicates that majority of the bore holes have meal yield less than 100 l/min although a sizable number of the raw data had yield ranges from 100-400 l/min.

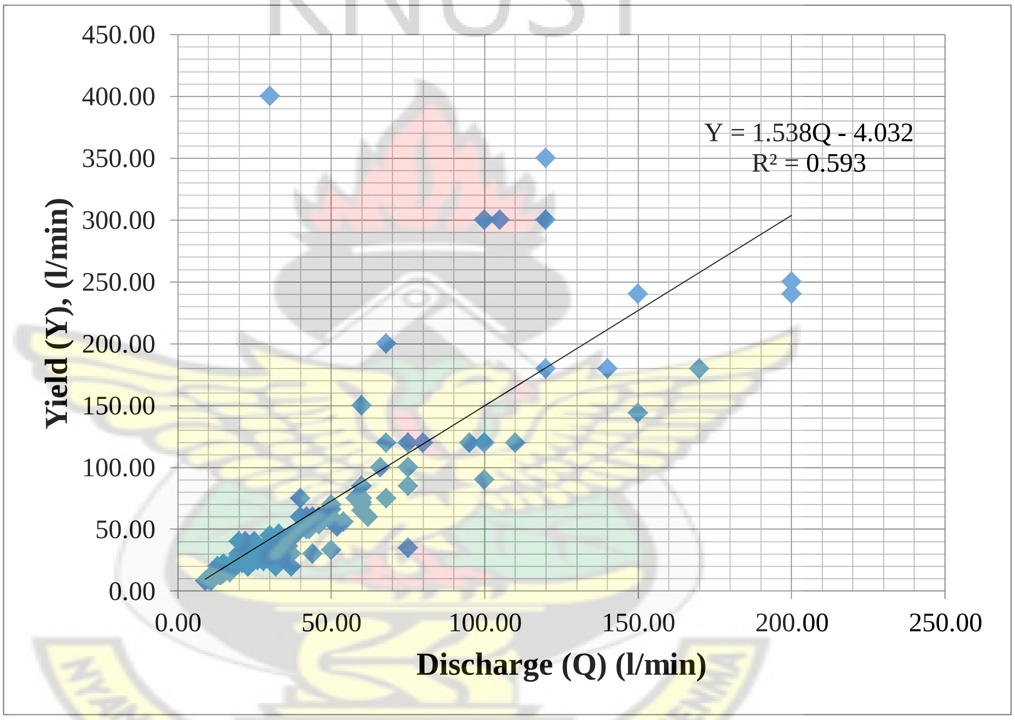


Figure 15: Borehole Yield Against Discharge

From the yield/discharge graph in Figure 15, there exists, a linear relation between borehole yield and discharge. And the relationship is near perfect in the lower range of yield (10-130 l/min) and discharge (10-80 l/min). This therefore implies that within the lower ranges of yield and discharge, it may be concluded that there is a direct relationship between the data and that the higher the yield of the borehole, the higher the discharge.

4.3 Flow measurements from the studied boreholes

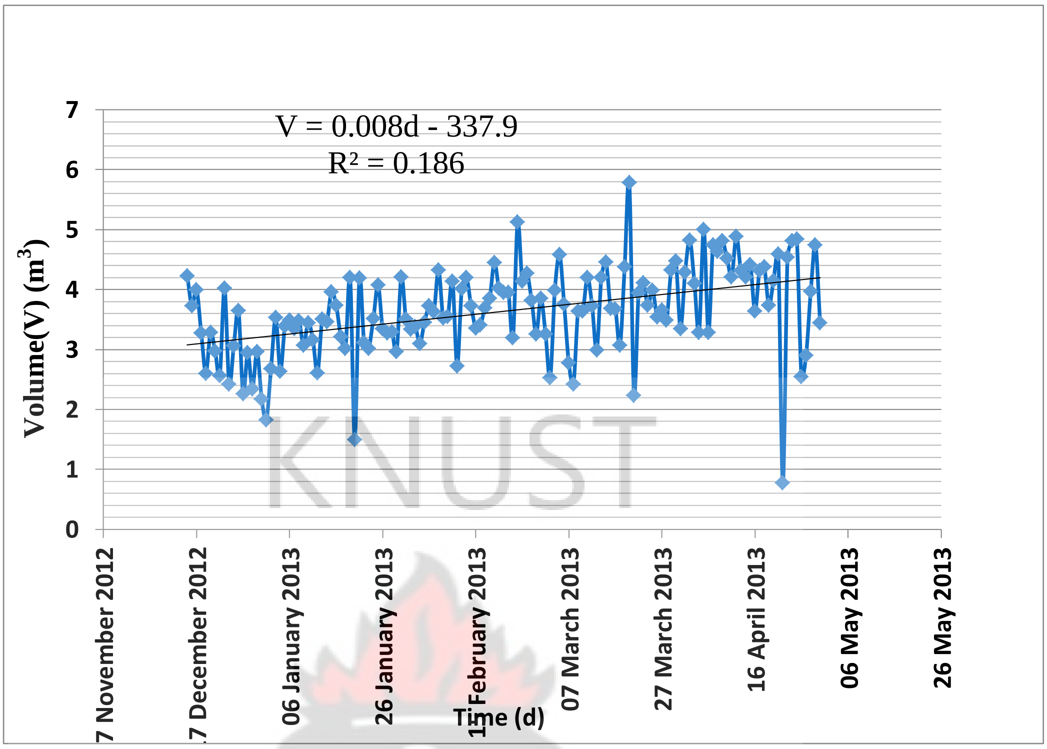


Figure 16: Borehole Discharge per day (Nayagnia)

The discharge at the Nayagnia site is shown in Figure 16. It generally shows that the average daily discharges increase with time within the study period. The abrupt disparities are indicative of the environmental variations which consequently reduce the irradiance on the solar panel.

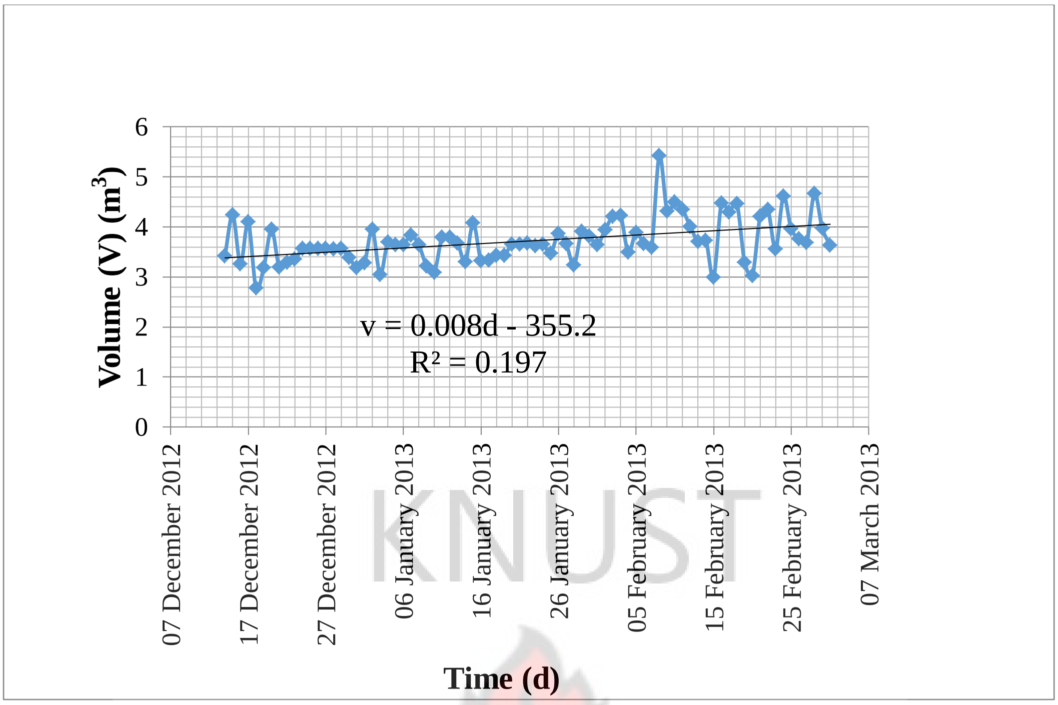


Figure 17: Borehole Discharge per Day at Zorbisi

The discharges at the Zorbisi site are as shown in Figure 17. It is generally also indicative of an average daily discharge which increases with time within the study period as the gradient of the equation of the line of best fit is positive. The similarity of the equations of the lines of best fit for the Figures 16 and 17 is an indication that the suctioning ability of the pumps was similar.

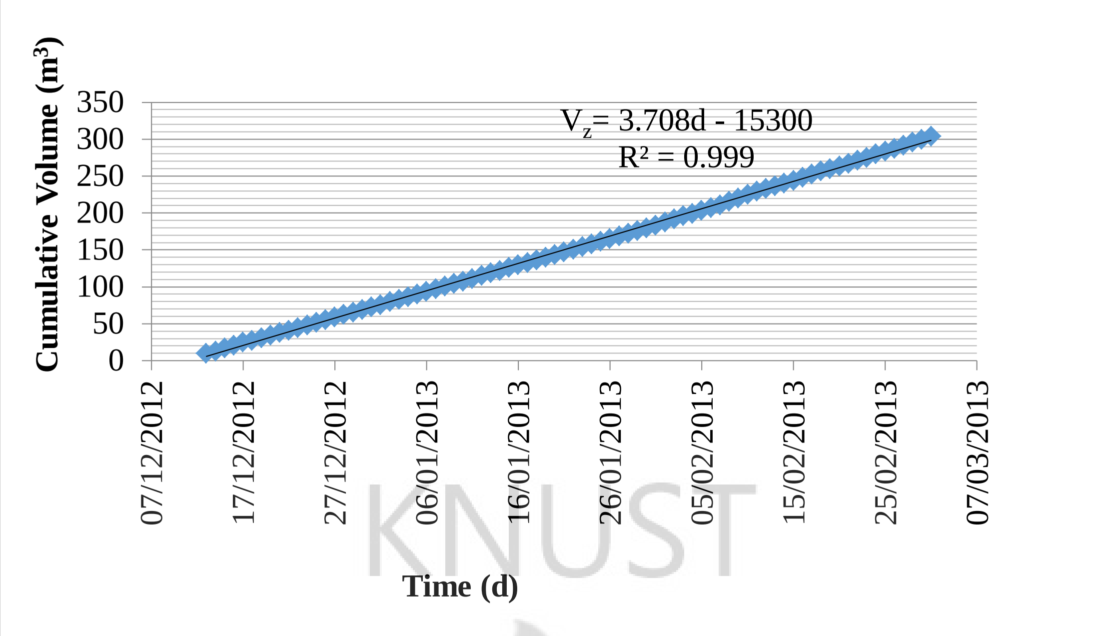


Figure 18: Cumulative Volume Against Time (Zorbisi)

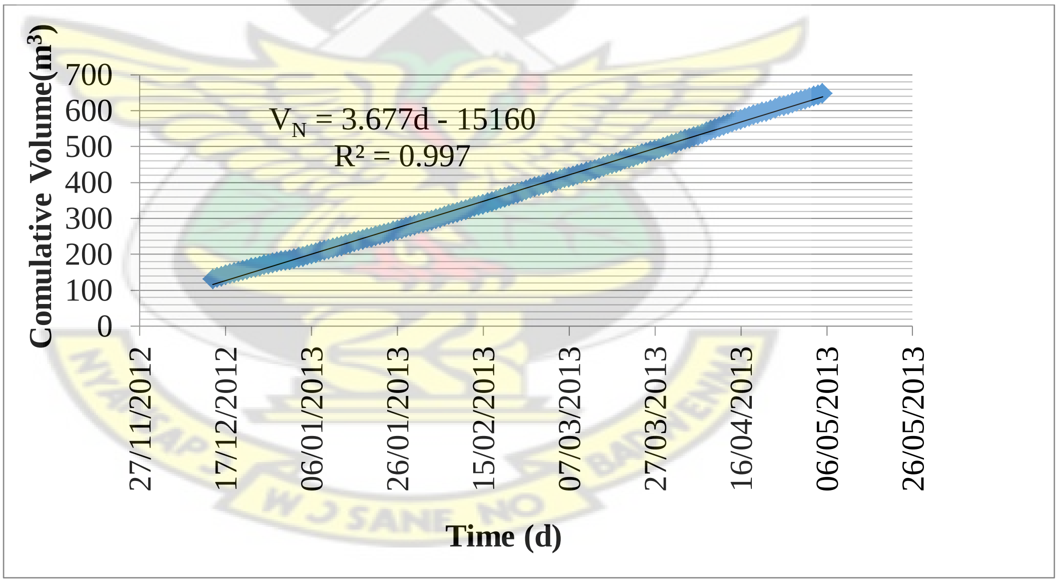
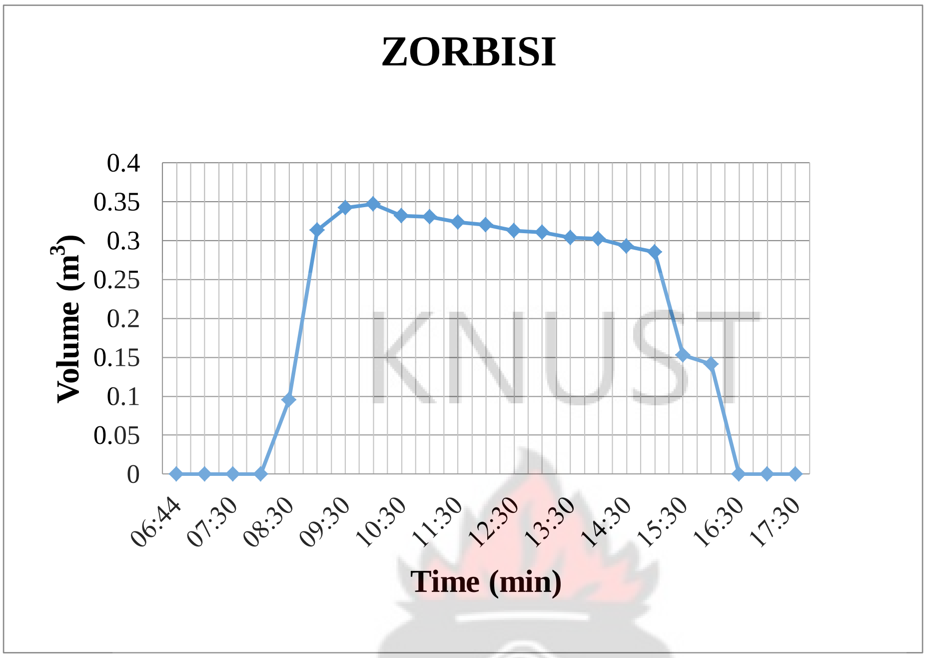


Figure 19: Cumulative Volume Against Time (Nayagnia)

The cumulative volume against time graphs for both sites (Figure 18 and 19) show near similarity as their linear functions portray nearly equal gradients (to one decimal place) $V_N = 3.677d - 15160$

$$V_Z = 3.708d - 15300$$

The loss of the solar panels at the Zorbisi and Nayania site to thieves in early March and late May made it impossible to take readings up to early June as planned.



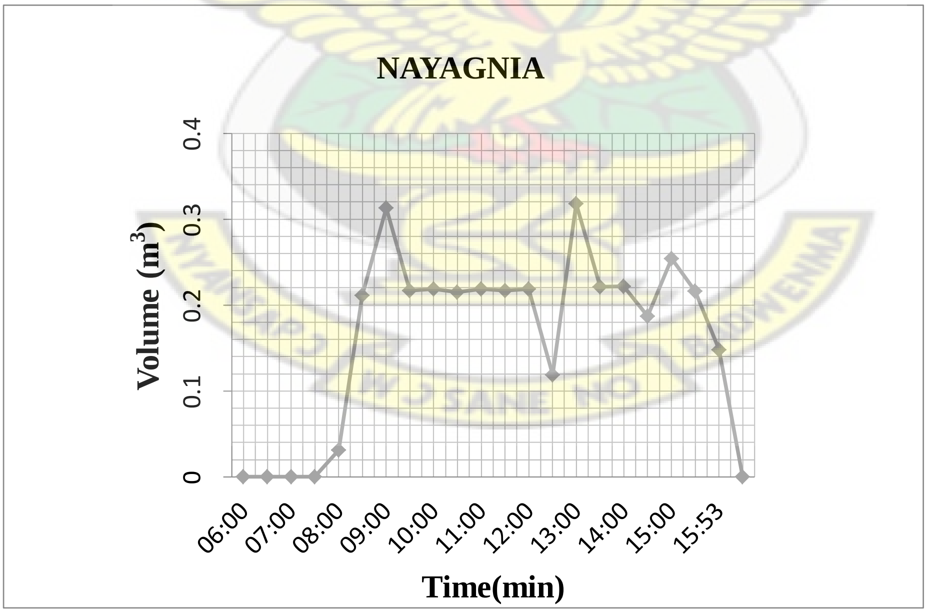
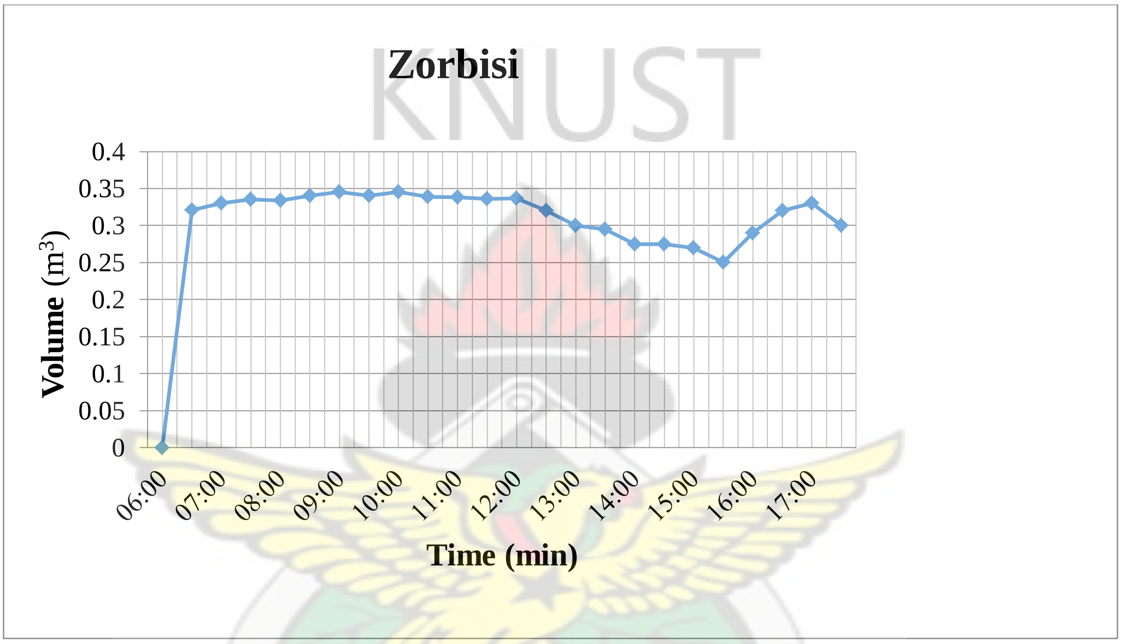


Figure 19: Volume Against Time for the Nayagnia and Zorbisi sites for Solar pumping

The half-hourly discharge plots (Figure 20) describe the trend in the pump volume output throughout a day with solar energy. It also explains the power generation with time since solar energy is transformed to volume of water pumped. Thus the trend also indicates solar radiation variation per day, as well as the period in the day solar energy generated is enough to power the system normally (between 8:00-8:30 am, peaks at 9:00 am and then reduces to zero at 3:00 pm).



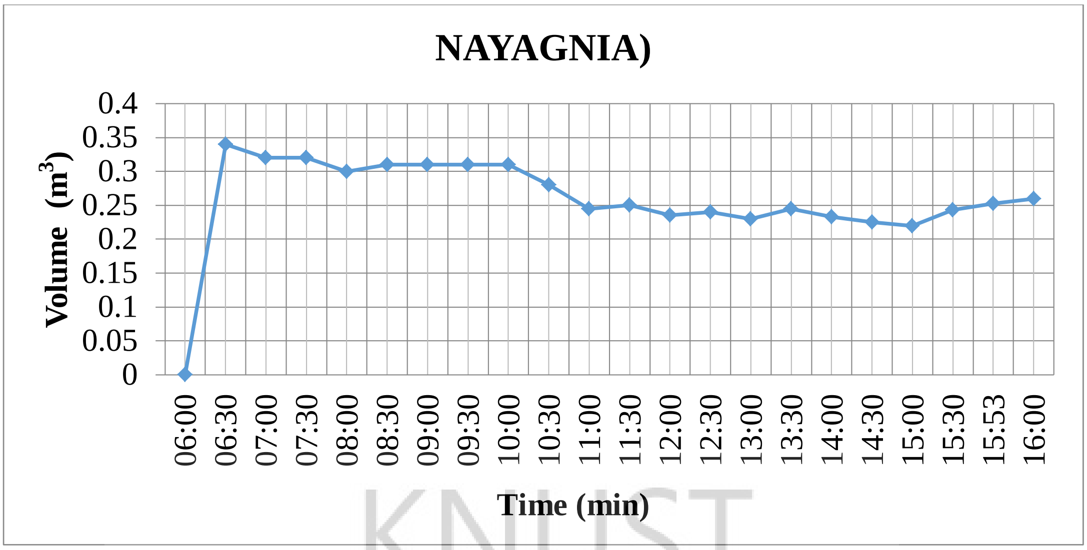


Figure 20: Volume Against Time for Nayagnia and Zorbisi sites with Manual Pumping

From the graphs of the manual pumping (Figure 21), it is seen that the manual pumping starts with larger discharges as the men were still strong and reduced as the pumping aged. This trend is seen quite clearly at the Nayagnia site where we used only 3 people for pumping as compared to five in the Zorbisi site.

4.4 Household and Per Capita Water Demand Estimates and projections

The household water demand from the five households that were studied as well as the projection for the community population are as shown in Table 5 and 6.

From Table 5, the demand per capita for Zorbisi and Nayagnia are 17.30 and 16.32 l/d respectively.

Table 5: Water use characteristics

ITEM / COMMUNITY	ZORBISI	NAYAGNIA
Household	22	17
Population	210	182
Household under study	5	5
Understdied household population	60	25
Unit volume of gallons (litres)	21	21
Number of gallons per week	346	136
Volume taken home in a week (litres)	7,266	2,856
Volume demanded per person per week	121.1	114.24
Volume demanded per person per day	17.3	16.32
Volume demanded per day for the whole population	3,633	2,970.24
Volume demanded per year for the whole population	1,326,953.25	1,084,880.16

Table 6: Yearly estimated population and attendant water demand

Year	Population		Water Demand	
	Nayagnia	Zorbisi	Nayagnia	Zorbisi
2013	182	210	1,084,880.16	1,326,953.25
2014	185	213	1,102,762.80	1,260,331.65
2015	187	216	1,065,507.30	1,278,082.80
2016	189	218	1,076,903.10	1,289,916.90
2017	191	221	1,088,298.90	1,307,668.05
2018	194	223	1,105,392.60	1,319,502.15
2019	196	226	1,116,788.40	1,337,253.30
2020	198	229	1,128,184.20	1,355,004.45

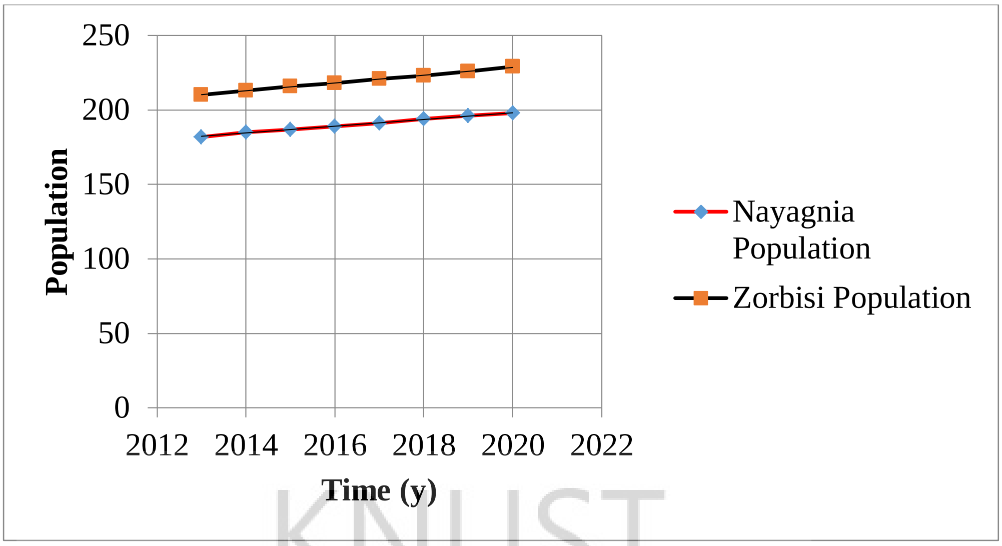


Figure 21: Population projection in Nayagnia and Zorbisi

The general population trend increase with time. The population projection as illustrated in Figure 22 may hold for Nayagnia but not Zorbisi. Zorbisi population will be non-linear since the area is within an urban area and attractive to settlers. The area also accommodates private students at the Bolgatanga Senior High Technical Institute and so the population behaviour will vary. As such, the population growth estimate may be under or over estimated. The generally rural setting in the Nayagnia site makes it unattractive to settlers.

4.6 Fluoride concentration in Capped Boreholes

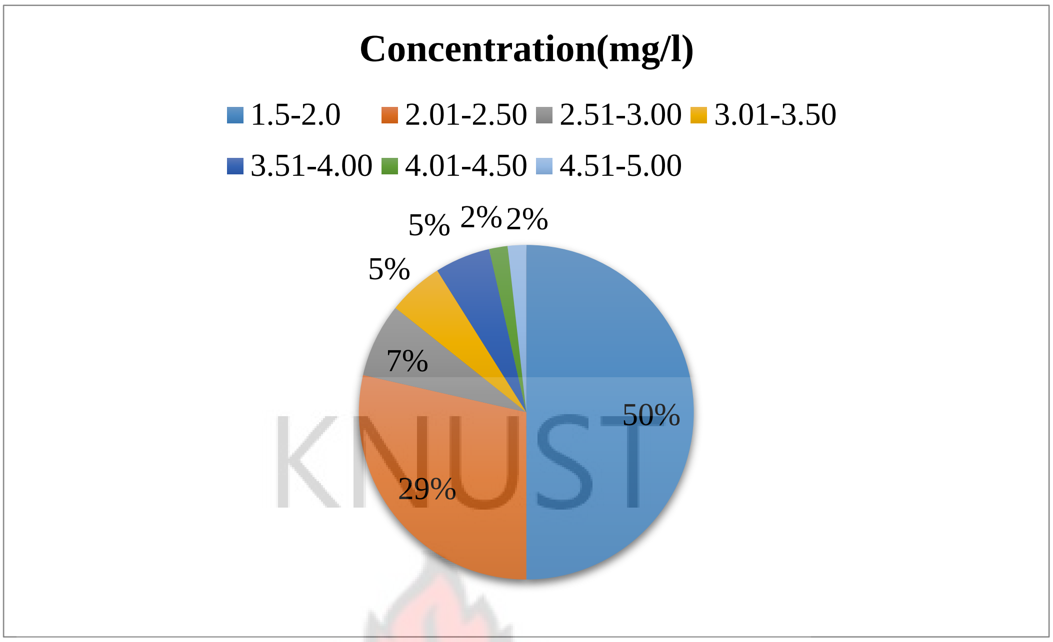


Figure 22: Fluoride Content Distribution in Capped Boreholes in UER

The World Health Organisation baseline for fluorinated water is that fluoride in drinking water should be less than 1.5mg/l (WHO, 2006). The capped boreholes had acceptable discharges but could not be used to supply drinking water because of the high fluoride content (i.e. 1.5mg/l). Fifty (50%) of the capped boreholes were found to have fluoride content ranging from 1.5-2.0 mg/l. However these are suitable for irrigation (NRC, 1993; Department of Water Affairs and Forestry, 1996) and therefore can be adopted.

Again the role of the CWSA is to provide drinking water and sanitation services to the communities in which they operate and so consideration for other uses are not made. This has resulted in the capping of boreholes that would pass agricultural water quality tests but not that of drinking water supply.

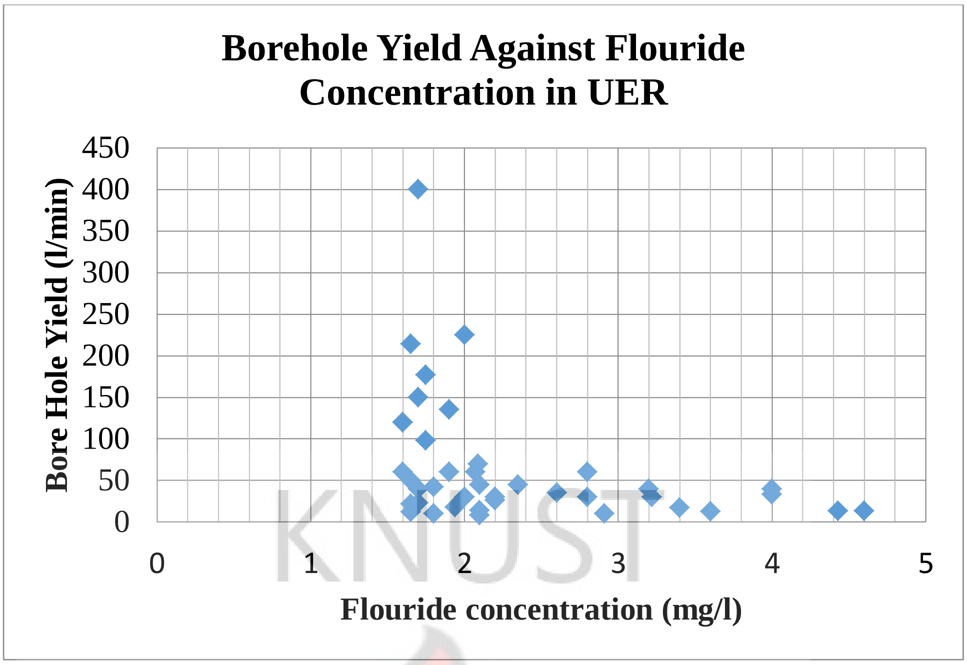


Figure 23: Borehole Yield Against Fluoride Concentration in UER

Figure 24 shows that, the high yielding boreholes are also having the lower fluoride content in the capped boreholes. The effect of fluoride on plant growth is dependent on the amount of exposure, soil pH and the type of plant. For instance, according to Greenwood (1956) and also based on Tables 1 and 2, plants grown in acid soils can tolerate fluoride up to 1mg/l while neutral and alkaline soils usually inactivate fluoride and so can take higher levels of fluoride. It may be possible to use such water sources for irrigated agriculture although fluoride tolerance varies from crop to crop.

4.7 Water usage measurements (improvement/decline, losses and labour)

The focal group discussion held at the two sites to result in following:

Nayagnia

- Water usage changes (from drinking to flushing toilets)

The community were in consensus that they do not have water closets and so do not use the water for flushing. In fact, the community still practice indiscriminate defecation (free range) in the disposal of faecal matter.

- Change in water use (number of buckets of water now fetched because of the investment)

  Under this the discussants were divided as about 50% of them agreed that they now take more water home as compared to the time the facility was not installed. While the remainder said they had gone to the borehole on several occasions and the reservoir was dry and they had to resort to the use of the manual winding which they found difficult because the process was ergonomically not friendly to them. In other words the process was new and they were adapting.

  From my observation, those that had much water now were those residing close to the site and because of the shortages explained earlier, they horded the water by taking more than enough for a day.

- Time spent in fetching water

  The discussants agreed that they now spend less time in the borehole because the taps run faster when the reservoir is full but maintained that it is seldom the case and they spend more time using the manual process. When asked to estimate the time spent in manually filling the same bucket and how much time the system uses to do same, a participant indicated that it took 5 and 2 minutes respectively.

- Changes (Improvement or decline) in access to cleaner water

  The group were in consensus under this. A member intimated that the borehole from which they accessed water was leaking and allowed all manner of waste water from their feet inside as compared to the new system borehole which is designed to be watertight. In sum, in terms of cleanliness/portability of the water it was generally agreed that water from the system is of a higher quality than the old borehole they formally accessed drinking water from. They agreed that management of the resource is crucial to maintain its current quality status for years to come.

- Changes (Improvement or decline) in access to education

  The discussant were in consensus, as they all admitted that their children now spend little time to fetch water because:

  - The system is very close to the community as compared to the old borehole they previously relied on.
  - Fetching from the tank is relatively faster, as the water flows under pressure.

- Labour input to access water

  The members agreed that the system has reduced their labour component when the solar component is working but when it is down due to inadequate irradiance, they labour rather more. This was because the manual component that operates in default is new and they are now adapting to its operations.

Zorbisi

- Water usage changes (from drinking to flushing toilets)

  The community were in consensus that they do not have water closets and so do not use the water for flushing. Some members said they practiced free-range in the disposal of faecal matter while others said they use latrines they constructed.

- Change in water use (number of buckets of water now fetched because of the investment).

  Under this the discussants about 60% of them agreed that they now take more water home as compared to the time the facility was not installed. Thirty per cent of them said they had gone to the borehole on several occasions and found the reservoir dry and they had to resort to the use of the manual winding which they found difficult because the process was ergonomically not friendly to them. In other words, the process was new and not comfortable. The remainder also said that they still fetched majority of their water from the hand-dug-well they previously used because the reservoir was mostly empty in the evening and they are not comfortable with the manual system.

  From my observation, it is true that majority are not comfortable with the manual design and they will need training and time to adjust.

- Time spent in fetching water

  The discussants agreed that they now spend less time in the borehole because the taps run faster when the reservoir is full but that the manual process is difficult to operate. When asked to estimate the time spent in manually filling the same bucket and how much time the system use to do the same a participant indicated that the 6 and 3 minutes respectively.

- Changes (Improvement or decline) in access to cleaner water

  The group were in a consensus under this. A member intimated that the hand-dug-well from which they accessed water was open and allowed all manner of waste to fall into it contaminating the water as compared to the borehole which is designed to be watertight and does allow even waste water from the floor to enter the borehole. In sum, in terms of cleanliness/potability of the water, it was generally agreed that water from the system is of a higher quality than the hand-dug-well they formally accessed drinking water from. They added that, the open nature of their well is even dangerous and is not child friendly as compared to the solar borehole system.

- Changes (Improvement or decline) in access to education

  The discussant were in consensus, as they all admitted that their children now spend little time to fetch water because drawing water from the tank is relatively faster, as the water flows under pressure.

- Labour input to access water

  The members agreed that the system has reduced their labour component when the solar component is working but when it is down due to inadequate irradiance, they labour rather more. This was because the manual component that operates in default is new and they are now adapting to its operations.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

It can be inferred from the data gathered and from literature reviewed that borehole depths to groundwater in the region is deeper than 20 m. The majority of the borehole depths range from 23-65 m with yield generally decreasing with increasing depth. Also, majority of the boreholes have mean yields less than 100 l/min although a sizable number of them have yields more than 100 l/min.

The average daily pump discharge when powered by solar for both sites were 3.72 m^3/ d and 3.64 m^3/d for the Zorbisi and Nayagnia sites respectively, although there are individual daily discharges higher than the averages within a sunshine duration of about seven and a half hours (7.5h).

The manual pumping with 4 and 5 people at Nayagnia and Zorbisi produced a daily discharge of 5.68m^3/d and 7.27m^3/d within 10 hours and 11.5 hours of pumping respectively.

This therefore indicates that with more powerful pumps, there would be higher discharges from the boreholes.

The per capita demand for Nayagnia and Zorbisi are 16.32 and 17.3 l/d respectively.

5.2 Recommendations

Inferring from the results of this study, the following recommendations are made:

- ✓ That the solar panel is doubled and the energy generated by the extra panel stored to power the pumps during sunless periods.
- ✓ The capped boreholes, especially those with fluoride concentration levels ranging from 1.6-2mg/l are within the standards allowed for agricultural purposes elsewhere; for example in South Africa and so these boreholes water should be harvested for agricultural use in the Upper East Region. But initial studies on small scale or pot experiment should be evaluated first.

REFERENCES

1. Agodzo, S. K. (1987). Methods and Techniques of Irrigation: Workshop Training Manual. Nairobi: African Inst. for Higher Technical Training & Research (AIHTTR).

2. Anayah, F. and Kaluarachchi J.J. (2009). Groundwater Resources of Northern Ghana: Initial Assessment of Data Availability. College of Engineering Utah State University. USA

3. Arthur, R. (2012). DSTC Workshop Presentation on Solar Pump Installation in Bolgatanga Polytechnic.

4. Blignaut, J. and Van Heerden, J. (2009). The impact of water scarcity on economic development initiatives. *Water SA* **35** (4) 415-420.

5. Burke, J., Siebert, S., Hoogeveen, J., Frenken, K., Steduto, P. and Faures, J.M. (2012). The demand for groundwater services in agriculture - implications of a global inventory. FAO, Italy & Institute of Crop Science and Resource Conservation, University of Bonn, Germany.

6. Carrier M. A., Aubut, R., Lefebvre, R., Racicot, J., Asare, E.B., Fontaine R. and Rivera, A. (2009). Hydrogeological assessment of northern Ghana, Interim Hydrological Atlas.

7. Carruthers, J., Rosegrent, M.W. and Sohkler, D. (1997). 'Irrigation and Food Security in the 21st Century' *Irrigation and Draining System*, 11, 83-101.

8. Cuenca, R. H. (1989). Irrigation System Design - An Engineering Approach. Prentice-Hall, Inc., Englewood Cliffs, NJ. 552 pp.

9. Department of Water Affairs and Forestry. (1996). South African Water Quality Guidelines (2nd edition). Vol. 4: Agricultural Use: Irrigation. Editor Holmes, S.

10. Dinye, R. D. and Ayitio, J. (2013). Irrigated agricultural production and poverty reduction in Northern Ghana: A case study of the Tono Irrigation Scheme in the Kassena Nankana District *Int. J. Water Res. Environ. Eng.* 5(2): 119-133.

11. Dojlido, J. and Zerbe J. (1998). Instrumental methods for testing water and wastewater. *Arkady* (in Polish) [Is this a journal article? If so, please give vol and page numbers, if a book, please give publisher and addresss]

12. Dzokoto, S.T.K. (2000). Installation and Evaluation of a Solar Photovoltaic Water Pumping System. KNUST, MSc. Thesis, 2000.

13. Foster, S., Hirata, R., Misra, S. and Garduno, H. (2010). "Urban Groundwater Use Policy: Balancing the Benefits and Risks in Developing Nations." Strategic Overview Series No. 3. GW-MATE. World Bank, Washington, DC.

14. Ghana Statistical Service. (2011). Ghana 2010 Population and Housing Census Provisional Results, Accra, Ghana.

15. Greenwood, D. A. (1956). Some Effects of Inorganic Fluoride on Plants, Animals and Man. *USU Faculty Honor Lectures.* Paper 41. Available at http://digitalcommons.usu.edu/honor_lectures/41. Date accessed June 15th, 2012

16. Groundfus. (2012). Solar Pump Installation training Manual

17. Hussain, I., Giordano, M., and Hanjira, M. A. (2003). "Agricultural Water and Poverty Linkages: Case Studies on Large and Small Systems", in *Water and*

Poverty – A Collection of Case Studies: Experiences from the Field. Asian Development Bank, 2003.

18. IAH. (2006). Groundwater for life and livelihoods – the framework for sustainable use, 4th World Water Forum.

19. IFAD. (2012). Ghana Country Programme Evaluation Report No. 2433-GH.

20. International Programme for Technology and Research in Irrigation and Drainage (IPTRID) (1999). *Poverty Reduction and Irrigated Agriculture*. FAO.www.fao.org. Date accessed: November 10, 2012.

21. Jacobsen, M., Webster, M. and Vairavamoorthy, K. (eds). (2012). *the Future of Water in African Cities: Why Waste Water?* Directions in Development. Washington, DC: World Bank. Doi: 10.1596/978-0-8213-9721-3.

22. Kyei-Baffour, N. and Ofori, E. (2006). Irrigation development and management in Ghana: Prospects and challenges. J. Sci. Technol. (Ghana) 26(2):148-159.

23. Lipton, M., J. Litchfield, Blackman, R., De Zoysa, D., Qureshy, L. and Waddington, A. (2003). *Preliminary Review of the Impact of Irrigation on Poverty,With Special Emphasis on Asia*. FAOwww.fao.org. Date accessed:April 19, 2012.

24. MacDonald, A. M., Bonsor, H. C., Dochartaigh, B. E.O. and Taylor, R. G. (2012). Quantitative maps of groundwater resources in Africa. *Environ. Res. Lett.* **7**. 024009

25. Mono Pumps. (2004). Installation, Operation and Maintenance Instructions

26. Moyo, S. (2006). “Africa’s Agrarian Transformation: The Efficacy of the NEPAD Agricultural Strategy” in *Africa and Development: Challenges in the New Millenium, The New Debate*. Adesina, J. O., Berg, E and A. Olukoshi

(Eds). (2006). CODESRIA, Dakar, in Association with Zed Books, London, New York, and Unisa Press, Pretoria.

27. Namara, R. E., Awuni, J. A., Barry, B., Giordano, M., Hope, L., Owusu, E. S. and Forkuor, G. (2011). Smallholder shallow groundwater irrigation development in the upper east region of Ghana. Colombo, Sri Lanka:International Water Management Institute. 35p. (IWMI Research Report 143). doi: 10.5337/2011.214

28. NRC (National Research Council). (1993). Guidelines for Developing Community Emergency Exposure Levels for Hazardous Substances. Washington, DC: National Academy Press.

29. Obuobie E. and Barry B. (2010). Groundwater in sub-Saharan Africa: Implications for food security and livelihoods Ghana Country Status on Groundwater, Final Report.

30. Opoku-Agyemang, M. (2005). African Water Laws: Plural Legislative Frameworks for Rural Water Management in Africa, Johannesburg, South Africa

31. Patel, M. R. (199). Wind and Solar Power System. CRC Press. Washington DC.

32. Pielou, E. C. (1998). Fresh Water University of Chicago Press. Chicago. USA.

33. Rangwala, K. S. (2011). Water Supply and Sanitary Engineering (Environmental Engineering). 25th Edition, Charotar Publishing House PVT. Ltd. Gujarat, India.

34. Ratajkiewicz, H. (2007). An influence of quality of water on the selected properties of tank mixes. *Prog. Plant Prot.* **47** (1): 115-118.

35. RWSN. (2010). Code of Practice for Cost Effective Boreholes, Rural Water Supply Network. Available from http://www.rwsn.ch/documentation/skatdocumentation.2010-08-23.4523209156.

36. Rydzewski, J. R. (Ed.). (1987). Irrigation Development Planning: An Introduction for Engineers. John Wiley and Sons, Chichester.

37. Sahasrabudhe, S. R. (2010). Irrigation Engineering. Katson Books, New Delhi

38. Sahasrabudhe, S. S. (2012). Irrigation Engineering. S. K. Kataria & Sons, New Delhi.

39. Sandwidi, W.J.P. (2007). Groundwater potential to supply population demand within the Kompienga dam basin in Burkina faso. Ecology and Development Series Bd.55.

40. Shah, M. (2008). "Irrigation, Agricultural Productivity and Poverty Alleviation – A Case Study of Stage II, Chashma Right Bank Canal (CRBC), Dera Ismail Khan, NWFP, Pakistan". *Gomal University Journal of Research, Vol. 24.*

41. Sirte, T. (2008). High-Level Conference on Water for Agriculture and Energy in Africa; the Challenges of Climate Change. Libyan Arab Jamahiriya.

42. Thoreau, H. D. (1854).Walden, or, A Life in the Woods. Ticknor and Fields. Boston.

43. Upton, M. (1996). The Economics of Tropical Farming Systems, Cambridge University Press, Great Britain.

44. van den Berg, J. (2008). Exploring shallow groundwater irrigation: current status and future application. A case study in the Atankwidi catchment, Ghana MSc Thesis final report. Delft University of Technology.

45. Yilma, T., Berg, E., and Berger, T. (2005). Empowering African Women through Agricultural Technologies: the Case of Irrigation Technology in Northern Ghana, http://www.glowa-volta.de/fileadmin/template/glowa/downloads/. Date accessed: July 10, 2012.

46. WHO, (2006). Guidelines for Drinking Water Quality, Vol. 1, first Addendum to the third edition, Recommendations. Geneva: WHO Publication.

47. WHO/UNICEF. (2010). *Joint Monitoring Programme (JMP) for Water Supply and Sanitation*, Available from:http://www.wssinfo.org [accessed 1st June 2012]

48. Woźnica, Z. and Waniorek, W. (2008). Importance of water conditioners for glyphosate efficacy. *Prog. Plant Prot.* **48** (1)

49. Wardrop-Acres, (1990). Small Scale Irrigation Development potential in northern Ghana. Final report.