UNIVERSITY FOR DEVELOPMENT STUDIES

SCHOOL OF ENGINEERING

ASSESSMENT OF THE DRAINAGE SYSTEMS IN THE LOWLAND OF BONTANGA IRRIGATION SCHEME OF GHANA

BY

MOHAMED JOSEPH SESAY

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BY

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(BSc. Agriculture and Food Sciences)

(UDS/MID/0010/19)

A THESIS SUBMITTED TO THE DEPARTMENT OF AGRICULTURAL ENGINEERING, SCHOOL OF ENGINEERING IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE IN IRRIGATION AND DRAINAGE ENGINEERING

NOVEMBER, 2021

DECLARATION

DECLARATION BY STUDENT

I hereby declare that this thesis is the result of my own original work and that no part of it has been presented for another degree in this University or elsewhere. The work of others, which served as sources of information for this study, has been duly acknowledged in the form of references.

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DECLARATION BY SUPERVISORS

I hereby declare that the preparation and presentation of the thesis was supervised in accordance with the guidelines on supervision of thesis laid down by the University for Development Studies, Ghana.

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ABSTRACT

The study assessed the drainage system in the lowland of Bontanga irrigation scheme in Ghana. The study specifically characterized the physico-chemical and hydraulic properties of the soils, assessed the drainage system using performance indicators, determined the drainage coefficients for the drainage system and examined farmers perception on drainage within the scheme. Laboratory analysis was done on the physico-chemical and hydraulic properties of the soil in the lowland of the irrigable area. Observation wells were used to measure the waterlogging intensity using SEW_{30} index. Drainage coefficients were computed using a water balance approach and interviews using semi-structured questionnaires were used to assess the farmers perception on drainage within the scheme. The study revealed that soils showed variations in their physical and chemical properties before planting and after harvesting. Mean soil bulk density ranged from 1.25 - 1.62 g/cm^3 before planting and 1.47 - 1.95 g/cm^3 after harvesting. Unsaturated hydraulic conductivity ranged from 2.75×10^{-4} to 5.25×10^{-4} cm/s. Soil infiltration values ranged from 9.97×10^{-4} to 1.05×10^{-3} cm/s. Both the unsaturated hydraulic conductivity and soil infiltration rates were within values referenced from other literatures of sandy loam soils. The mean soil pH ranged from 5.37 to 6.43 before planting and 5.1 to 5.45 after harvesting. Mean soil electrical conductivity ranged from 0.025 - 0.039 dS/m before planting and 0.065 - 0.098 dS/m after harvesting. Mean exchangeable sodium percentage ranged from 5.31 - 6.68 % before planting and 6.53 - 10.98 % after harvesting. Farmers' practice of not embarking on adequate drainage might have influenced the changes in the physico-chemical and hydraulic properties of the soils. The salinity and sodicity levels of the soil were within the threshold for crop production. Waterlogging intensity in the area was moderately drained with values ranging from 140 - 240 cm.days. Drainage coefficients were found to range from 5.1 - 5.7 mm day^{-1} for April and 12.4 – 14.0 mm day^{-1} for May. Farmers perceived poor drainage to be the major factor contributing to salinity, sodicity and waterlogging and that the waterlogging was rated highest with a Problem Confrontation Index value of 468 as the consequences of drainage. Most of the farmers do not have access to information on drainage practices. Proper management actions are necessary for preventing drainage problems within the scheme. The management of the irrigation scheme should collaborate with the water users' associations to enforce byelaws on the maintenance of the drains. Government through GIDA should ensure equal or parallel investments of resources in drainage systems and GIDA should continuously embark on site-specific investigations of drainage problems in order to inform actions, interventions and strategies within the irrigation schemes in Ghana.

DEDICATION

This work is warm-heartedly dedicated to my beloved wife, Mrs. Fatima Sesay.

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LIST OF ACRONYM AND ABBREVIATIONS

AWM	Agricultural Water Management
CEC	Cation Exchange Capacity
DC	Drainage Coefficient
DOM	Dissolved Organic Matter
EC	Electrical Conductivity
EIA	Environmental Impact Assessment
ESP	Exchangeable Sodium Percentage
ETc	Crop Evapotranspiration
FAO	Food and Agricultural Organization
GIDA	Ghana Irrigation Development Authority
MAD	Management Allowable Depletion
MDI	Mini Disc Infiltrometer
MOFA	Ministry of Food and Agriculture
PCI	Problem Confrontation Index
RAM	Readily Available Moisture
SARI	Savannah Agricultural Research Institute
SEW	Sum of Excess Water
SII	Shortest Irrigation Interval
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
WUAs	Water Users Associations

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CHAPTER ONE

INTRODUCTION

1.1 Background

The global population increases steadily at a rate of 1.1 % per year and it is expected to reach about 9.80 billion people by the year 2050 and about 11.20 billion in year 2100 (UN-DESA, 2017). The productivity of the presently cultivated land must be improved in order to produce food for the increasing population. (FAO, 2012). Chihombori *et al.* (2013) stated that, the contribution of irrigation to enhancing food production is critical, especially, in areas that are dry such as arid, semi-arid and other areas that are scarce of water in the world.

Irrigation intensifies landuse by increasing crop yield and has been used to reduce water stress in crops during drought, by compensating for low rainfall. Irrigation also increases crop intensification, that is, cropping more than once in a year (Siebert *et al.,* 2015). FAO (2016) estimated that irrigation contributes 40 % to the supply of food in the world out of the 20 % of the worldwide equipped irrigated area, and it is estimated to be the largest anthropogenic global water use of about 60 % of the total water withdrawals (Siebert *et al.,* 2015).

Limiting the natural passages of water due to insufficient drainage or higher water levels at the outfalls will result in stagnation of water in depressed lands and this causes waterlogging, salinity and sodicity which exposes valuable agricultural lands to serious risks (Kumar *et al.,* 2014). Excess water in the soil has an effect on the growth of the crop and timely execution of pre-planting, planting and post-planting agronomic practices such as tillage, seeding, cultivation and harvesting. Poor drainage aids the buildup of salts in the soils (Wiangsamut *et al.,* 2013).

Drainage in the management of groundwater levels performs a significant role in sustaining the yields by preventing a reduction in the area of production which may be as a result of a rise in watertables and salt accumulation in the rootzone and reclaiming waterlogged and saline soils (Kumar *et al.,* 2014). The drainage problems are worsened by numerous factors including but not limited to inadequate drainage, lack of adequate knowledge by farmers on the role of drainage and making incorrect decisions in the management of the scheme, poor (Miniotti, 2016).

An effective solution for soils in rice fields to control waterlogging and salinity without destroying and causing any significant variation in the soil structure is the use of artificial drainage. The presence of drainage in some settings is considered as being crucial (Yazdani, 2007). The application of adaptable drainage system permits all year-round production in paddy fields. The drainage system in paddy fields becomes different from the conventional drainage of soil due to specific soil structures and layers in paddy fields (Rahimi *et al.,* 2017). FAO (2011) stated that, due to poor drainage, about 34 million hectares of land in the world are salinized and about 250,000 to 500,000 hectares of productive land for agriculture is lost yearly, which has contributed to reducing crop production potential. This situation is predominant in irrigated lands of semi-arid and arid zones (FAO, 2011), where it is irrigation-induced. Poor drainage manifests in increased waterlogging and salinization in the root zone of plants; these are two phenomena that unavoidably co-exist in regions that are scarce of water (Madramootoo *et al.,* 1997).

While the supply of oxygen in the crop rootzone is a necessity for optimum production of crops in upland, rice plant which can efficiently carry oxygen from the shoot to the root system can also flourish in shallow ponded water (Yazdani, 2007). It is however misleading to have this unique characteristic being misinterpreted that, drainage is not a necessity in the cultivation of rice. Ritzema (2016) stated that irrigation systems that have been developed without recognizing properly the role of drainage in the production of rice are suffering the negative consequences of inadequate drainage. The production of rice in wetlands needs adequate control of water for which the provision of adequate drainage remains an part to remove excess water from rainfall or the irrigation source (Ritzema, 2016).

Soil salinization and waterlogging in the rootzone of crops hampers the growth of plant and results in reduction of yields. To reduce waterlogging and salinization, artificial drainage on agricultural fields that are poorly drained is needed, ensuring that, the conditions in the rootzone of crops have optimum air, water and salt (Madramootoo *et al.,* 1997). In essence, drainage in agriculture is an important practice in the management of water that performs a valuable function in the efficient and sustainable agricultural production systems (Martinez-Beltran *et al.,* 2007).

Air, moisture and nutrients are required by plants in the rootzone. When there is excess water from rainfall, irrigation resulting in the rise of watertable, thereby disturbing aeration and ultimately hinders plant growth. Poor natural drainage conditions result to waterlogging and salinization of the soil, due to rise in the watertables in arid and semi-arid irrigated regions.

Deficiency in moisture content happen during most part of the cropping season as a result of uncertainty/low rainfall patterns in these areas. In this situation, irrigation is a necessity to improve crop production, but farmers are likely to over-irrigate when canals are available. In flat lands with little or no natural drainage, there is a possibility of watertables to rise and will often lead to waterlogging and salinity development (Pali, 2015).

The soil system and its associated processes are complex and non-linear. The saturated hydraulic conductivity of a soil varies temporarily and spatially (Ali, 2011). There is the need to optimally understand these processes as they affect crop production so as to be able to effectively manage agricultural water systems. The physical, chemical and biological characteristics of soils can vary spatially within few meters. Identifying these changes and distributions is very important in crop production (Jiang *et al.,* 2006).

Hence, undertaking a detailed study on the performance of existing drainage systems and bring out problems emanating from these systems in rice fields is very appropriate. These results would be useful to develop appropriate models for the design of sustainable drainage systems in paddy fields in the study area and other irrigation schemes with similar soil and drainage characteristics.

1.2 Problem Statement and Justification

The practice of irrigation makes households to earn more income, increase their resilience and transform their livelihood opportunities in some cases (Singh, 2018a). Irrigation, when managed properly and efficient irrigation methods employed will result in increased agricultural growth and reduction of poverty by embarking on intensification and diversification of crops; hence, increased outputs and income by farmers, increasing employment in the agricultural sector and reducing local food prices (Miniotti, 2016).

Agricultural production is mostly done by smallholder farmers who are dependent on unreliable rainfall pattern. Crop failure as a result of insufficient rainfall, climate change and occasionally uncontrolled floods affects the livelihood of people in a more serious manner (Singh, 2018a). As a result, the population has to contend with low productivity, and subsequently food insecurity threatens each year. United Nations (2017) stated that, there is an increasing rise in global population and it is expected to reach 9 – 10 billion from the present 7.6 billion by 2050. This suggests that more food is required to meet demand.

Although adequate supply of water is required for the production of crops, too much of it will cause negative consequences to the crop and will disturb the growth of the plant which will subsequently result to reduction in yield. Yields of crops are greatly reduced on soils that are poorly drained and, in some situations, where there are extended conditions of submerged rootzone, plants ultimately die as a result of deficiency of oxygen in the rootzone (Singh, 2018a).

Poor drainage and its related problems represent serious threats in sustaining the production of crops under irrigation especially in regions where there is scarcity of water (Singh, 2018b). Therefore, in order to sustainably produce food for the growing population, adequate and timely supply of water to crops is of essence (Singh, 2018c). Waterlogging and salinization in the root zone of plants are the two most prevalent phenomena that inevitably co-exist in semi-arid and arid regions due to poor drainage systems. FAO (2011) indicated that globally, 250,000 to 500,000 hectares of productive agricultural land is lost yearly due to poor drainage systems which ultimately has the tendency of reducing crop production potential.

According to Asafo-Adjei and Buabeng (2016), farmers in Ghana have been challenged by so many factors which they grouped into managerial, technological, marketing, health and extension services. These challenges associated with rainfed agriculture have compelled successive governments to place emphasis on irrigation development. Problems of excess water due to over-irrigation and canal seepage hinder the production of crops within the irrigable areas of the scheme, despite the development of these facilities, of which Bontanga is not an exception.

Muche *et al.* (2015) indicated that, an understanding of the physico-chemical properties of any soil is vital for effective management of agricultural resources. They further stated that, soil acidity could be one of the foremost reasons for the depletion of soil nutrients causing a decline in soil fertility which obviously affects plant growth. So many factors contribute to waterlogging, sodicity and problems of salinity; and these have a direct relationship with the physico-chemical properties of the soil. These among others include absence of sufficient drainage, uncontrolled drainage, unsuitable cropping patterns, inaccurate construction and rehabilitation of drainage systems, torrential rains and floods, increasing the levels of irrigation without due consideration on the negative effects on the quality of soil and water resources (Muhammed, 2014).

The socio-economic and technical circumstances in which drainage systems are operated exist in different levels. In using performance indicators, failure of services in the irrigation sector are easy to identify while those pertaining to drainage cannot be clearly seen (Smedema, 1996).

Vincent *et al*. (2007) further stated that, in water scarce areas where drainage systems have been installed recently, performance assessment in those countries have generally not started. A case in point is Ghana where this study is currently being carried out.

Vincent *et al.* (2007) stated that, the image of drainage to farmers is seen to be undesirable since *"it takes away water from the soil"* and its consequences are not seen desirable as those of irrigation. Predicting a change in direction of farmers' view towards need, benefits and problems of drainage could only be possible after farmers' perceptions, strategies, practices and the relation between the physical environment and their farming systems are revealed (Dolo *et al.,* 2017). Therefore, an understanding of farmers' perceptions on drainage and the consequences on the productivity of crops is necessary in the promotion of management practices relating to soil and water conservation; hence, farmers should serve as key stakeholders in developing programmes that will help salvage the many problems happening in their fields (Wickham *et al.,* 2006).

This study revealed the state of installed drainage system and its level of functioning as designed. It also revealed problems that are peculiar to drainage systems in rice irrigation schemes and thus attempted to bring out strategies to develop drainage water management systems. This has the potential of preventing economic and agricultural losses from water logging, salinization and water quality degradation.

1.3 Objectives of the Study

1.3.1 Overall Objective

The overall objective of the study was to assess the drainage system in the lowland of Bontanga irrigation scheme in the Kumbungu District in Northern Region of Ghana.

1.3.2 Specific Objectives

The specific objectives of the study were:

1. To characterize the soil for physico-chemical properties that affect soil internal drainage in the Bontanga irrigation scheme.
2. To assess the performance of the drainage system of the irrigation scheme using drainage performance indicators.
3. To determine drainage coefficient for surface drainage in the irrigation scheme.

4. To assess farmers' perception on the need, benefits and problems of drainage in the irrigation scheme.

1.4 Hypotheses of the Study

To guide the study, the specific objectives were used to formulate the hypotheses.

Null Hypothesis (H_0)

a. Drainage systems in the Bontanga irrigation scheme do not affect soil physico-chemical properties.
b. The drainage system in the irrigation scheme is not functioning efficiently.
c. Drainage coefficients for the drainage systems in the irrigation scheme cannot be determined under irrigated ecologies.
d. Farmers have a negative perception towards the need, benefits and problems of drainage in the irrigation scheme.

Alternate Hypothesis (H_1)

a. Drainage systems in the Bontanga irrigation scheme affect soil physico-chemical properties.
b. The drainage system in the irrigation scheme is functioning efficiently.
c. Drainage coefficients for the drainage systems in the irrigation scheme can be determined under irrigated ecologies.
d. Farmers have a positive perception towards the need, benefits and problems of drainage in the irrigation scheme.

1.5 Structure of the Thesis

This thesis has five (5) chapters. Chapter 1 presents a general introduction, problem statement and justification, overall objective and specific objectives of the study and hypothesis relating to the research.

The literature review (Chapter 2) explored the relevant theories and research work that has been published with specific focus on overview on drainage of agricultural lands, need and benefit of drainage on crop production, factors related to drainage, drainage policies in some parts of the world, physico-chemical properties of soil and drainage, indicators for sustainable drainage system management, drainage coefficients and farmers' perception on the need and benefits of drainage systems in irrigated ecologies.

Chapter 3 presents the area of study, materials and methods used in collecting, preparing and analyzing data.

Chapter 4 presents the results and discussion. Finally, the general conclusions and policy implications of the study as well as the recommendations for future research are presented in Chapter 5.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of Drainage on Agricultural Lands

2.1.1 Definition of Agricultural Drainage

Literally, the word ‘drainage’ means the process of removing a liquid. Land drainage is the process of removing surplus water through open channels, vertical drains or through creation of ditches and pumping the water out from embarked areas. Land drainage allows bringing low productive areas such as marches and waterlogged territories into agricultural use and to enhance efficiency of farming (Valipour *et al*., 2020).

FAO (1996) defined drainage as the process of removing surplus water and dissolved salts from the surface and sub-surface of the soil to support plant growth. Gurovich and Oyarce (2015) defined agricultural land drainage as a set of technical strategies and hydraulic structures allowing the removal of water and/or salt excesses present in the soil volume occupied by crop roots, to provide an adequately oxygenated environment suitable for root normal development, keeping adequate water and air relative proportions according to crop physiological needs, to enable soil sustainability for crop productive conditions.

A blend of surface and sub-surface drainage systems placed within agricultural lands are systems designed to drain water from these lands. In areas of crop production, surface drainage removes surplus water from the superficial layer of the soil. In sub-surface or tile drainage, surplus water is being removed from the rootzone of the plant thereby lowering the water table (Ritter and Shirmohammadi, 2001).

2.1.2 Types of Drainage Systems

Surface and sub-surface drainage are the two (2) main drainage systems that can be used in an agricultural field. Kleinman *et al.* (2015) stated that, the kind of drainage applied in an agricultural field is reliant on factors such as soil characteristics, topography, crop species, and suitable outlets. Surface drainage refers to the process of removing surplus water from the topmost area of the soil by constructing open drains and channels. Nangia *et al.* (2013) stressed that the oldest and easiest method that can be chosen by farmers is surface drainage. Schultz *et al.* (2007) described surface drainage as the process of removing excess water from the superficial layer of the land through the use of channels and/or shaping the land.

Sub-surface or tile drainage refers to the installation of perforated plastic pipes of different sizes, spacing and depths depending on the seriousness of the drainage situation. The drainage depth is normally less than 1 m if the flow is only at certain periods within the year and goes deeper if the flow is throughout the year (Kleinman *et al.,* 2015). Unlike surface drainage, Kamiri *et al*. (2013) emphasized that infiltration increases within the soil strata in sub-surface drainage since pipes are positioned underground and require water to percolate through soil before collection.

Xian *et al.* (2017) stated that in surface drainage, excess water is removed from the outer layer of the soil before it goes into the rootzone while the ground watertable is lowered by sub-surface drainage and makes provision for a good environment within the rootzone. Sub-surface drainage therefore is generally used in most parts of the world for removing surplus water in the rootzone of plants (Kennedy *et al.,* 2012).

2.1.3 Agricultural Drainage in the Global Context

Globally, millions of productive agricultural lands are lost yearly due to poor drainage (FAO, 2014). FAO (2011) reported that about 0.25 to 0.5 million hectares of valuable land in agriculture is degraded resulting in a decrease in the production potential of crops. Waterlogging and salinization are major problems of poor drainage. Sources of excess water in the soil include precipitation, over-irrigation, over-land flow and groundwater flow. Among these, Reinders *et al.* (2016) reported that, irrigation is a key source of watertables rising to the upper layer of the soil(waterlogging) and the accumulation of salts within the upper layers of the soil (salinization) in semiarid climates when the rainfall is inadequate to satisfy the crop water demands.

In agricultural lands, drainage problems are common especially when there are inadequately self-draining natural means. The extremes of drainage problems involve abandoning the land; a case in point is the deserted lands of historic Chaldea, Tigris valley and Euphrates Rivers in Mesopotamia (Malota, 2012). Ideally, an irrigation system should accurately supply the amount of water needed for plant growth and remove the excess to enable an ideal soil-water conditions for the development of plants as well as productive and sustainable agriculture (McCarthy *et al.,* 2016).

In Israel, the responsibilities for planning of water development, drainage etc. gave rise to the establishment of a public corporate body in 1952. In 1959, the Israel Water Law was passed which focus was to make water a public resource and controlling its abuse, allocation and avoidance of contamination and water preservation (Shevah, 1999). There have been some developments in the country aiming at the expansion of core distribution systems, runoff interceptions, recovery of wastelands and expanding operational productivity of water dissemination systems. Major investments were done by the government to drain flooded areas like swamps which were inundated in the winter, thus many agricultural lands were redeemed. This was then followed by expanding the regional operations into a large scale to control drainage basins. The emphasis was on improvement of poorly drained soils, flood protection, swamp drainage, diversion of runoff water from agricultural land by embarking on good drainage management strategies (Shevah, 1999).

2.1.4 Agricultural Drainage in the African Context

In East Africa, Ethiopia as an example, management of water in irrigated agriculture is hindered by challenges relating to policy, institutional capacity, technologies, infrastructure and markets notwithstanding the important contributions of government and other actors (Awulachew *et al.,* 2010). Challenges are more extensive in irrigation systems that are sustainable especially in water scarce areas in which large areas of crop production are affected by inadequate drainage systems causing soil salinity and waterlogging (Wichelns and Qadir, 2015). Whilst the potential benefits of irrigated agriculture are awesome, the real accomplishments in many irrigated zones within the country is significantly less than the potential due to inefficient water management strategies leading to waterlogging, salinization and other related problems (Hordofa *et al.*, 2008).

Shallow groundwater tables and natural saline seeps are the main causes of salinity. Lack of effective irrigation water management strategies and poor drainage are also factors that promote secondary salinization (Abebe *et al.,* 2015). Irrigation projects that are not properly planned and supported by improved management technologies had resulted to serious land degradation as a result of salinity and sodicity issues in the Awash basin which accounts for about one-third of total irrigated area of Ethiopia (Dubale *et al.,* 2002; Ruffeis *et al.,* 2007).

Drainage in North Africa is used as an approach to enable farmers cope with inadequate and/or unpredictable rainfall and to protect development projects in irrigation by eliminating the surplus water and salts brought in by the irrigation water (Ritzema, 2016). Drainage improves the capacity of the soil to act as a storage room, especially when there are possibilities for operational control to maintain the water table at a higher level. Water balance studies done in Egypt indicated that irrigation efficiencies can be improved through the use of controlled drainage.

South Africa which lies in the semi-arid zone is prone to irrigation-induced salinization and waterlogging (Reinders *et al.,* 2016). About 15 to 18 % of the total land under irrigation in South Africa is constrained with waterlogging and salinization with the cost of drainage making the problem to be worse (Malota and Senzanje, 2015). The severity of drainage problems has been emphasized by Reinders *et al.* (2016) that some of the agricultural lands in South Africa have been rendered invaluable, unproductive and therefore abandoned due to these problems.

Namara *et al.* (2010) indicated that, in West Africa about 1 Mha of land are into irrigation, with over 60 % equipped for full-control irrigation and 40 % in lowlands. Irrigation potential is estimated at 9.1 Mha with 55 % in just three (3) countries i.e., Nigeria, Ghana and Sierra Leone. A report by Africa Union (2020) stated that, poor drainage, waterlogging, eutrophication, soil salinity and acidity are common problems with Agricultural Water Management (AWM) schemes. It indicated further that, if not controlled, this can result to irrigation system failure, making land unsuitable for crop production and associated loss of investments.

2.2 Benefits of Drainage on Crop Production

Soils are natural resources that are ultimately required for the production of crops. FAO (2011) reported that close to 34 million hectares are salinized and approximately between 250,000 and 500,000 hectares of valuable agricultural soils are lost yearly because of poor drainage resulting in waterlogging and salinity. The consequences of salinity and waterlogging on farm economics are unfavourable because they can result in abandoning the land leaving it unproductive, hence, significant yield depressions. The choice of crops, intensification and diversification can be severely limited by saline and waterlogged conditions which can seriously affect the yield of crop thus making soils hard to work on.

Singh (2019) reported that, an effective artificial drainage system is an important component in providing good rootzone aeration on poorly drained soils, maintain soil moisture and improving the production of crops. Drainage is a means of protecting the lives of people and assets against flooding. Areas with good drainage network serve as a buffer for high rainfall. The hydrology of the soils has been altered in humid tropics by irrigation where monsoon flooding and waterlogging as natural conditions have aggravated the problem. Huge losses of human lives and damage to resources happen intermittently through uncontrolled floods, prominent examples could be seen in India and Bangladesh.

FAO (1997) assessed that, five (5) million individuals lose their lives yearly from illnesses relating to water such as malaria, schistosomiasis, lymphatic filariasis, guinea worm infection, water-borne diseases that are of gastrointestinal nature caused by faecal matter, and orally transmitted, as well as diseases related to the transmission of pesticides and pesticide residues in drainage water (non-communicable). Drains that are ineffectively maintained and silted-up drains due to stagnant water on inadequately drained land contribute to the spread of diseases and intensifies their incidence, causing human suffering, health costs, and countless costs in terms of unavailable or weak labour forces.

The advantages of tile drainage are being classified by Irwin (1981) into four (4). Categorizes: first, improved drainage may lead to landuse changes; second, there may be intensive utilization of the land resulting to an increase in crop yields and quality, increased fertilizer usage and improved crop rotations; third, there may be a reduction in production costs as a result of improved drainage. The time to cover the field is reduced and may result in the use of smaller, energy efficient tractors and finally, resource allocation on the farm would be improved with the use of tile drainage. Minimizing the number of wet areas or wet fields on a farm, presents a greater flexibility in crop placement amongst crop fields and may even be able to change the type of farming operation (Irwin, 1981).

Muma *et al.* (2017) stated that, installation of a drainage system in any agricultural field has got many consequences of which some are direct while others are indirect. The direct consequences include the decrease in the volume of water stored in or on the soil and removal of water from the agricultural fields. However, the direct effects are generally not the key aims of drainage. The indirect effects include providing the rootzone with better aeration for improved crop production (Nousiainen *et al.,* 2015), better fertilizer use, less weed growth, less denitrification, and less restriction on crop choices. Leaching of salts through drainage prevents further salinization of the rootzone and make irrigated land sustainable for the long-term (Jafari-Talukolaee *et al.,* 2015).

Alakukku *et al.* (2010) added that drainage promotes better land accessibility, makes the soil easy to work on, improves the structure of the soil, improved land bearing capacity and increased activities of micro-fauna by making soil drier and thus facilitates effective crop growth. Fraser and Fleming (2001) also asserted from their review of the environmental benefits of tile drainage that peak flow volumes diminished in waterways related to artificially drained land and that the total runoff was spread out more over time with a possible reduction in surface runoff.

2.3 Factors Affecting Drainage Systems

The natural conditions of an area can change over time when irrigation is introduced into an area and may require a drainage system. In order to forecast the consequences of the changes that will occur, factors relating to the soil and hydrology in the area where the drainage has to be installed need careful consideration. The main factors include some of the following;

2.3.1 Drainage Requirement

Drainage requirements include design and construction criteria, and this if followed with caution, will lead to an outcome of having reliable drainage systems for irrigated ecologies and man's potential agricultural use of the physical aspect and conditions of lands will affect the ultimate drainage requirement (ILRI, 1994). FAO (1996) highlighted the drainage requirement has to be identified in the design of a drainage system. This is the water that must be removed from a given location within a specified time frame in order to prevent an undesirable rise in groundwater or surface water levels. Removing the drainable surplus has two (2) benefits; it reduces waterlogging by artificially maintaining a sufficiently deep watertable. It eliminates enough water from the crop rootzone to ensure that any salt introduced by irrigation do not reach a concentration that is damaging to the crops (FAO, 1996).

The amount of data needed for a drainage problem is dependent on the particular problem and the significance of the investigations or report being created. The fundamental data must be sufficiently representative to allow for the selection of a good drainage plan from which to design and construct a functionally sound drainage system. For the purposes at hand, cost estimates must be established that are reasonably accurate. When it comes to evaluating drainage requirements and cost projections, having insufficient or incorrect data poses a severe danger (ILRI, 1994).

2.3.2 Watertable

The upper barrier of the groundwater is referred to as the watertable. It is the position where the pressure in the groundwater equals the pressure in the atmosphere. The watertable varies with time. It rises abruptly after irrigation or rainfall, then gradually falls as a result of the movement of water into the drainage system.

The control of watertable is done to enhance soil environment for vegetative growth, manage water for irrigation and drainage, improve the quality of water, make more effective use of rainfall, reduce the demand for water for irrigation, reduce runoff of freshwater to saline nursery areas, and promotes leaching of saline and alkali soil (USDA – NRCS, 2003). A watertable close to the bottom of the rootzone may result in a change of the extraction pattern of the soil moisture, affecting deep percolation and drainage requirements (ILRI, 1994).

2.3.3 Depth to the Water Table

Observation wells or piezometers are used to determine the depth of the watertable. An observation well is a plastic conduit with a small diameter (> Ø 12 mm) that is buried in the soil (FAO, 1996). Holes are created at the bottom of the pipe across a length that the watertable is expected to fluctuate and a gravel is sometimes installed around the pipe to prevent tiny particles like clay and silt from clogging the perforations and obstructing the flow of water. An auger hole can be sufficient when there are heavy clay soils and no pipe is needed. The watertable is constantly changing as a result of the many recharge and outflow components that make up a groundwater system. The highest mean and the lowest mean positions of watertable as well as the mean depths of water table in a hydrological year, are crucial in any drainage investigation (ILRI, 1994).

2.3.4 Dissolved Salts in the Groundwater

Salts in solution are present in all groundwater. The kind of salts that would be present to a large extent depends on the geological environment, the source of the groundwater, and its movement. Irrigation also contributes to the salt content of the groundwater. It dissolves salts in the rootzone as well as adding salts to the soil. Water from the rootzone of irrigated land typically has concentrations of salts that are many times higher than the irrigation water that was originally delivered. ILRI (1994) posited that even though there are numerous causes that contribute to the development of saline soils, the majority of the soils become saline due to the consumption of capillary groundwater and irrigation water containing salts as well as the application of chemicals.

2.3.5 Hydraulic Conductivity

The hydraulic conductivity, often referred to as the K-value, measures the soil's ability to transmit water. According to FAO (1996), there are significant variances in the K-values of different soil types, which are mostly determined by their texture. Hydraulic conductivity is a measured feature of soil that determines how well water moves through it. Understanding and establishing this attribute is critical to diagnosing and resolving most sub-surface drainage issues (USDA – NRCS, 2003).

2.3.6 Topography

Excess water must be removed by gravity and information about the topography of a region with drainage problem is critical. Physical features such as natural and man-made which will have an effect on the drainage system design has to be shown on the topographic map because slight differences in the land surface elevation are of essence (FAO, 1996). Because of the prime importance attached to topographic maps in drainage studies, it has an impact on the general plan that should be made on the location of the outlet, sub-outlet and collector drains. The importance of topographic features can be recognized even before reaching the planning and designing stages of drainage. Topographic maps therefore indicate slopes of land, slope length, position and the course of the natural drainage and other distinct situations that affect drainage (ILRI, 1994).

2.3.7 Impermeable Layers

In the vertical direction, soils are mostly not always uniform or homogeneous. There will always be an impermeable layer at some depth below the soil surface. The watertable is free to rise and fall when the impermeable layer is deep and groundwater only partially fills the porous upper layer. In such a situation, the groundwater is said to be unconfined, or to be phreatic or to be below the watertable (FAO, 1996).

2.4. Drainage Policies in Some Countries in Africa

Most policies in developing countries with regards to drainage are linked to water resources management, irrigation and agriculture. Government's effort to promote food security by providing subsidies not only create a fiscal burden at the expense of water security, it similarly has an effect on the quality and volume of drainage effluent. Additionally, water resources management and drainage in some countries is still lacking the enabling legal atmosphere (Safwat *et al.,* 2004).

Irrigation is a strategy used by farmers in North Africa to deal with insufficient and irregular rainfall and farmers view drainage as a way to deal with unpredictable rainfall thereby protecting resources invested irrigation by removing surplus salts and water as a result of irrigation (Ritzema, 2016).

The National Drainage Programme in Egypt is an important aspect in the government agenda for Water Resources Development and this aims to promote the effectiveness of water resource use as well as improve the efficiency of the drainage systems (ADB, 2015). Other legal instruments used in Egypt in enhancing drainage policy include Law 12(1982) *"concerning the issue of the Law on Irrigation and Drainage",* Law 213 (1994) *"regarding farmer participation",* Law 48 (1982) *"concerning the protection of the River Nile and waterways from pollution"* and Law 4 (1994) *"law for the environment"*.

Various Parliamentary Acts exist in East Africa, including the National Environmental Act of Uganda (1995), the Environmental Act of Tanzania (2004), and the Environment Management and Coordination Act of Kenya (1999). Some Acts deal directly with water management issues than others which generalize environmental management issues while others define the topics that lead agencies must address. (Angwenyi, 2004).

Drainage issues in Kenya, for instance are embedded in policy instruments such as Environmental Management and Co-ordination Act, No. 8 of 1999 with 2015 amendments and the Environmental Impact Assessment and Audit Regulations, 2003 and enacted in 2009 Legal Notice No.101, the Water Act 2002, the Public Health Act Cap 242, the Physical Planning Act, the local Government Act Cap 265, the Agriculture Act, the Irrigation Act, and the World Bank guidelines on Environmental Impact Assessment (EIA) procedures (GoK, 2017).

Agricultural drainage interventions in South Africa play an important part in implementing several aspects of the country's water strategy. The National Water Policy (RSA, 1997), for example grants right to the people of South Africa for an environment that is safe and protected for the benefit of current and future generations. It stresses on water use that is efficient, effective and long-term. Agricultural drainage systems ensure the long-term productivity of both water and land resources. The Conservation of Agricultural Resources Act (CARA) N0. 43 of 1983 stipulates the building and maintenance of soil conservation works (e.g., drainage infrastructure) as a means of removing surplus surface and groundwater from farmlands to prevent waterlogging and salinization (CARA, 1983).

Pertinent themes on water resources protection and water conservation are being emphasized in the National Water Resource Strategy (NWRS) (DWAF, 2013). Artificial drainage attains both themes by methodically removing excess water from agricultural regions, avoiding the pollution of groundwater by deep percolation. The South African Irrigation Strategy (DAFF, 2015) emphasizes the necessity of surface and sub-surface drainage improvements. The policy aims to increase irrigated land by more than 50 % in South Africa, implying a corresponding increase in agricultural drainage requirements.

There have been numerous calls by the African Development Agenda (Agenda 2063) and other declarations by governments for an increase in interventions relating to irrigation development and sustainable Agricultural Water Management (AWM) in West Africa (AU, 2020). In Ghana for instance, the National Water Policy makes provision for an inclusive framework to sustain the development of water resources, grounded on the principles of Integrated Water Resources Management (IWRM) and recognizing the various cross sectoral issues related to water use and the role of agricultural water management in the country (MOFA, 2011). The policy recognizes water as a finite resource that requires an integrated approach to ensure its sustainable development and utilization.

The 1987 Irrigation Development Authority Regulation (L. I. 1350) outlines the procedures for managing irrigation projects, including water management. SMCD 85 established the Ghana Irrigation Development Authority (GIDA) under the Ministry of Food and Agriculture (MoFA) in 1977 to replace the irrigation department, which began as a water and soil conservation unit before expanding into irrigation and reclamation. GIDA is primarily concerned with water conservation and irrigation, and is in charge of developing the country's water resources for irrigated agriculture, fish culture among others in irrigation ponds and dams. Despite all these institutions and legal framework for AWM in the country, agricultural drainage still remains a problem despite the fact that AWM is an important factor in productivity, growth and poverty reduction, especially in the north of the country (Evans *et al.,* 2012).

2.5 Physico-chemical and Hydrological Properties of Soil and Drainage

The interaction between the environment, nutrient dynamics and soil parameters is complex in any environment during the cultivation of crops such as rice, maize, millet, etc. (Ololade *et al.,* 2010). Mamun *et al.* (2011) stated that the physical properties of soil impact the availability of oxygen, water transport into or through soils and root penetration. Soils, according to Delgado and Gomez (2016), provide support and serve as water and nutrient storage tank.

Proper drainage in addition to landuse and soil texture has been suggested as being significant factors influencing infiltration. Fischer *et al.* (2014) stated that, due to the significance of vegetation and the spatial differences of places that has been documented, values of infiltration within different places for various crops can be different from the reported values in various literature as shown in Table 2.1. Understanding of hydrological properties such as infiltration is becoming important in drainage studies since infiltration allows the soil to temporarily store water, making it available for use by plants. If the infiltration rate is too slow and without proper drainage system, it can result in ponding in level areas and surface runoff and erosion in sloping areas (USDA – NRCS, 2004).

Table 2.1 Summarized Literature Values of Stable Infiltration Rates, Based on Soils (Clay and Sand) and Crops (Rice and Maize)

Soil / Crop	Average (mm/h)	Minimum (mm/h)	Maximum (mm/h)
Clay	4	< 0.1	10
Sand	26	2	250
Rice	4	0.004	18
Maize	204	12	925

(Source: Adapted from Söderberg, 2015)

Habtamu (2011) stated that the absence or insufficiency of agricultural inputs, uncontrolled drainage, continuous practice of cultivation together with environmental factors worsens the degradation of soil physico-chemical properties. Parent rocks, vegetation, altitude, drainage, and the activities of man have an impact the physico-chemical properties of soil and water (Manga *et al.,* 2017).

Too much application of pesticides or fertilizers without due consideration is amongst the main problems in crop production especially without proper drainage (Seifi *et al.,* 2010). The physico-chemical properties of such waterbodies would have the tendency to change rendering the waters undesirable to the surrounding ecosystem (Tening *et al.,* 2013).

The potential for elements in soils and sediments to be mobilized/immobilized and be re-distributed depends on several factors such as organic matter, type and amount of clay, pH and the prevailing redox conditions; and pathways (Manga *et al.,* 2017). Studies conducted by Buri *et al.* (2012) revealed that, soils within the Bontanga irrigation scheme belong to the Lima series as shown in Figure 2.1. These soils are moderately drained and there is therefore a great need to investigate the impact of drainage on the physico-chemical properties of the soils.

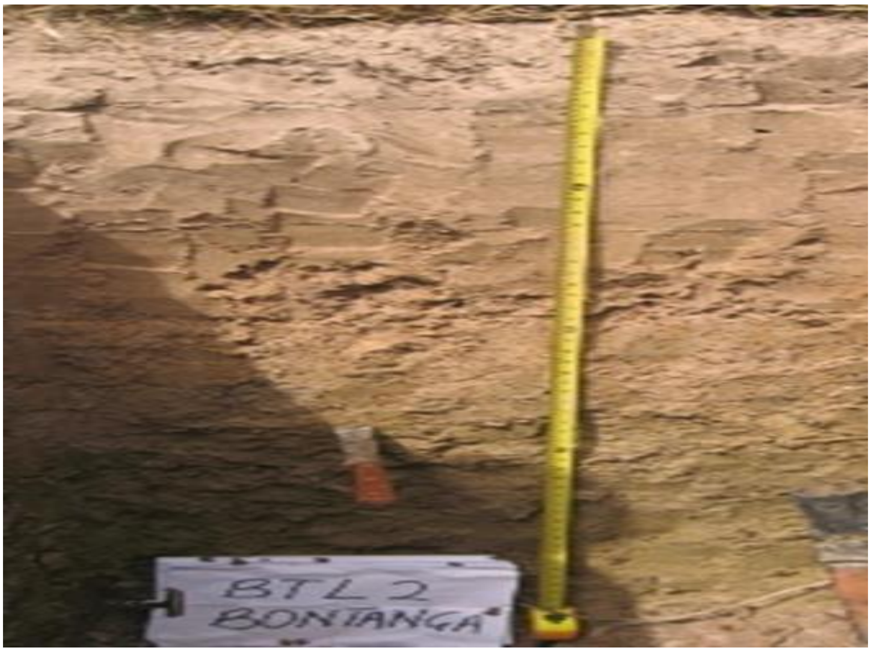

Figure 2.1: Typical Profile of Lima Soil Series (Source: Adapted from FAO/WRB: Endogleyi-Ferric Planosol in Buri *et al.,* 2012).

Studies conducted by Mohammad (2012) revealed that, vertical drainage will lessen the risk of failure, increase the efficiency of the drainage system, which has the tendency to prevent an increase in soil acidity in conditions that soil hydraulic conductivity is unstable and it may be essential over time. Brodshaug (2011) found out that drainage especially tile drainage can increase soil penetration resistance and improve trafficability. If the soil has greater penetration resistance, heavy machinery will be able to drive on it easily, thereby increasing the ease of planting, spraying, and harvesting and that soil penetration resistance is significantly higher with tile drainage, which means control structures should be in place to prevent the soil from becoming too dry and thereby increasing the soil penetration resistance. Kirnak *et al.* (2017) conducted a soil compaction experiment studying various soil characteristics such as bulk density, soil saturation, and nutrient levels. Results showed bulk density to be higher with more compaction. The study further demonstrated different irrigation treatments and findings indicated that application of more irrigation water could lead to significantly higher bulk density within the upper soil profile.

The stability of soil organic matter (SOM) is significant in the world carbon cycle and its relation to climate change since dissolved organic matter (DOM) play an important role in the binding and transport of nutrients and contaminants in the environment (Kaiser and Kalbitz, 2012). Thus, changes in organic matter in soils are associated with soil hydrology and drainage conditions during their formation (Kaiser and Kalbitz, 2012). The B horizon in poorly drained soils is water-saturated during most part of the year, and the organic matter is predominantly DOM derived (Lopes-Mazzetto *et al.,* 2018).

2.6 Performance Indicators for Sustainable Drainage System Management

2.6.1 Definition of Performance Assessment of Drainage System

Vincent *et al*. (2007) pointed out that performance assessment is an indispensable part of management and that each project ought to have objectives and means to achieve it and assess how the objectives are fulfilled (effectiveness) and how its means and resources are utilized (efficiency). Bos (1996) pointed out that, a variety of viewpoints could be used to define and assess performance; on the extent to which a company's products responds to the needs of their customers or the extent with which the company uses the resources at its disposal (both strategic and operational), or the level to which the systems conform with the design criteria (technical).

Operational performance when used in drainage studies is the system's level of agreement with its design criteria while strategic performance talks about the outputs, which do not merely mean only the result of the performance of the drainage system. Operational performance, at the field level is related to the removal of surface water after irrigation, rainfall, and/or with a proper control of the water table levels. At the system level, it is related to the proper removal of the water discharged from the fields (Vincent *et al*., 2007).

Strategic performance is connected to the various roles of drainage in increasing and regulating crop production. It includes the control of salts in the rootzone, contribution to rural development, and the effects on health and environment (Vincent *et al.,* 2007). The performance of the drainage system in an agricultural field cannot easily be separated from that of the irrigation system because in irrigated systems, it is doubtful whether the strategic performance can be seen as the performance of the drainage system alone.

2.6.2 Drainage System Performance Indicators

In order to assess performance of a system, a number of indicators associated with criteria and target levels has to be used. Criteria are established ranges of values of indicators used to categorize the indicator as satisfactory or not satisfactory (e.g., the salinity of soil can be regarded as non-saline, slightly saline, saline or severely saline). The target levels are being defined by a nominal value and a deviation from the range of acceptable values around the nominal value. Murray-Rust *et al.* (1994) made a distinction between indicator and parameter that an indicator is a variable that can be measured which can change over time while a parameter is a variable that is being measured at a specific time period.

Bos and Nugteren (1990) noted that, in order to facilitate international comparison of performance assessment studies, indicators should be formatted identically or analogously as much as possible. The nature of an indicator is a significant aspect that has to be considered in its selection; the indicator could be used to define a precise activity or may define the aggregate or transformation of a group of underlying activities. Smedema and Vlotman (1996) defined Performance Assessment (PA) as the process of determining the way the drainage system functions as against the already established design criteria and can be direct and/or indirect. Their research further explained that, PA consists of two (2) parts; the assessment of the way the drainage system functions and the analysis of the cause. Boss (1996) studied the performance indicators for drainage systems general features as:

$$\text{Sustainability of Irrigation Area} = \frac{\text{Current Irrigation Area}}{\text{Initial Total Irrigation Area}} \quad \text{Equation 2.1}$$

$$\text{Relative Groundwater Depth} = \frac{\text{Actual Groundwater Depth}}{\text{Critical Groundwater Depth}} \quad \text{Equation 2.2}$$

$$\text{Relative Salinity (EC)Ratio} = \frac{\text{Actual EC Value}}{\text{Critical EC Value}} \quad \text{Equation 2.3}$$

The critical value of any main parameter measures a physical process in which the concentration of a chemical restricts crop yield, or hampers health if that critical value is exceeded e.g., the salinity of irrigation water has a critical value that reduces crop yield if passed (Bos *et al.,* 2005).

Waterlogging intensity is one of the indicators used in the assessment of drainage system performance. Sieben (1964) assessed agricultural drainage system in Australia using the SEW_{30} index. The SEW_{30} is the summation of all values (in cm) for days by which water table is closer than 30 cm to the soil surface.

The SEW_{30} index assumes that linearly the waterlogging intensity increases with a rise in water table above 30 cm. Compiling available literature is sometimes difficult as different writers use different terms for the same indicator. However, Table 2.2 presents some performance assessment indicators as used by some authors.

Table 2.2: Drainage Performance Assessment Indicators

No	Indicator	Author(s)
1	Water table as function of time	Vincent *et al.* (2007); Bos *et al.* (2005)
2	Water table draw-down rate	Vincent *et al.* (2007); Bos *et al.* (2005)
3	Relative ground water depth (ICID)	Vincent *et al.* (2007); Bos *et al.* (2005)
4	Water table depth as function of the area	Molden *et al.* (1998); Bos *et al.* (2005); Vincent *et al.* (2007)
5	Change in hydraulic conductivity over time	Ijir and Burton (1998); Bos *et al.* (2005);
6	Sustainability of drained area (modified ICID for irrigable area)	Bos *et al.* (2005); Vincent *et al.* (2007)
7	Ratio of design discharge versus actual discharge over time	Bos *et al.* (2005); Vincent *et al.* (2007)
8	Relative change of soil salinity	Bos *et al.* (2005); Vincent *et al.* (2007)
9	Relative change of soil alkalinity (SAR or ESP)	Bos *et al.* (2005); Vincent *et al.* (2007)
10	Infiltration rate over time	Garcés (1983); Bos *et al.* (2005); Vincent *et al.* (2007);
11	Relative yield change	Bos *et al.* (2005); Vincent *et al.* (2007)
12	Relative cropped area change	Bos *et al.* (2005); Vincent *et al.* (2007)
13	Changes in cropping pattern	Molden *et al.* (1998); Bos *et al.* (2005); Vincent *et al.* (2007)
14	Workability	Bos *et al.* (2005); Vincent *et al.* (2007)
15	Waterlogging index	Garcés (1983); Bos *et al.* (2005); Vincent *et al.* (2007)

2.6.3 Properties of Performance Indicators

A precise performance indicator is made of a current value and a projected value that allows the assessment of the degree of variation. Additionally, it must contain information that is vital which can help the evaluator to find out if the difference is acceptable or not. Bos (1997) outlined some properties of performance indicators as follows:

i. Scientific basis: The indicator must have come from a systematically and statistically experienced essential model of the section of the system it refers to.

ii. Quantifiable: The information that is required to quantify the indicator should be accessible or reachable (quantifiable) with the available knowledge. The assessment should be replicable.

iii. Reference to a target value: Implies that the importance and the appropriateness of the projected value and acknowledgement for the indicator can be settled. The settled values together with their degree of differences must be connected to the prevailing technology and management practices.

iv. Provide unbiased information: Preferably, in the development of performance indicators, a narrow ethical standpoint should be avoided. Actually, this is not easy since even technical procedures have different ways of thinking.

v. Ease of use and cost effectiveness: Mainly for regular management, performance indicators must be strictly achievable, and readily used by the organization personnel considering their motivation and level of knowledge. Moreover, the implication of adopting the use of indicators in respect to equipment, investment, and human resources commitment, must fit within the organization's assets.

2.7 Drainage Coefficients

The capacity of a drainage system is largely determined by the drainage coefficient and therefore, its determination is of essence. More benefits are realized with increasing values of drainage coefficients which similarly result to additional cost. Choosing a coefficient for a drainage system requires the optimization of the expected benefits relative to the costs. Certain countries have accepted standard drainage coefficient values to be used under different conditions and some have adopted standard methods for the purpose of determining q-values. Drainage coefficients used in sub-surface drainage design for instance for water table control under rainfall recharge conditions vary primarily within the narrow range of 5 to 10 mm/day. These Values have been found to characterize a technical-economic optimum for pipe drainage under these conditions. Groundwater balance calculations and salt balance studies are necessary prerequisites in the determination of drainage coefficients in controlling water table in using sub-surface drainage system (Ochs and Bishay, 1992).

Murty and Jha (2011) stated that, the idea of drainage coefficients is a primary parameter for the design of hydraulic systems in agricultural drainage. In surface drainage networks, the rate at which open channels/drains ought to remove water from a drainage area depends on size of the drainage area, irrigation frequency/rainfall intensity, characteristics of the drainage area, nature of the crops grown and the degree of protection required from waterlogging.

2.7.1 Methods of Determining Drainage Coefficients

Several methods have been used for the determination of drainage coefficients. Some of the methods include Simplified Hydrologic Accounting method, Cypress Creek formula, Boston Society formula and

2.7.1.1 Cypress Creek Formula

Information from a huge number of watersheds within America have been utilized to create a relationship that is empirical which relates the frequency of drainage design at the outer end of the drainage basin and the catchment region. This relation is famously referred to as the Cypress Creek equation and is regarded effective for a mean watershed slope of 0.45 %. Consequently, Equation 2.4 which relates the runoff rate with the watershed area was obtained and cited by USDA – NRCS (2003) as follows:

$Q = C \times A^{P}$ ……………………………………………………………Equation 2.4

Where:

Q = Runoff rate (m^3/s),

A = Area of the watershed or agricultural land (km^2),

p = 5/6 (Approximate average value) and

C = Coefficient (0.2098 + 0.0074Y), where Y is the direct runoff volume (mm) estimated by the CN method.

The SCS-CN method since its origin has been implemented for various areas and for various landuses and climatic conditions and it has been applied to a wide variety of applications beyond its original scope including runoff estimation in large scale river basins and integration in long-term, daily time-step, hydrological models. It has been also the subject of many analyses on both practical and theoretical grounds and of several modifications, adaptation, and improvement attempts for over 60 years (Soulis, 2021).

Combining the water balance equation and proportional equality hypothesis, the NRCS – CN method is represented by the equation given by Mockus (1949):

$Q = \frac{(P-0.2S)^2}{(P+0.8S)}$ ……………………………………………………Equation 2.5

S is the retention parameter. This parameter changes spatially with changes in soils, landuse and slope and temporally due to in soil water content changes and is defined mathematically by Mockus (1949):

$$S = \left(\frac{25400}{CN}\right) - 254 \quad \text{.......................................Equation 2.6}$$

CN is a dimensionless number and a function of landuse antecedent soil moisture content and other factors affecting runoff and retention of watershed (Shi *et al.,* 2017).

2.7.1.2 Boston Society Formula

The Boston Society of Civil Engineers suggested the peak discharge for surface drains design and this was reported by Uppal and Sehgal (1965) as:

$$Q = C \times A^{0.5} \quad \text{.......................................Equation 2.7}$$

Where:

Q = Peak discharge in cusec (ft^3/s),

C = Coefficient (dimensionless) and

A = Peak catchment area in square miles.

2.7.1.3 Simplified Hydrologic Accounting Method

Simplified Hydrologic Accounting method as stated by Raadsma and Schulze (1974), uses information on crop tolerance and analyzes the rainfall data to estimate the time period in hours needed to eliminate surplus water. The data from the rainfall should be analyzed for duration-frequency. The duration-frequency of rainfall for a certain cropping season should be taken into consideration as drainage is planned with an attention on the crop. The excess of rainfall is computed and allowance for storage in the channel is being catered for.

Knowing the drainable surplus, the drainage system capacity required can be obtained (Murty and Jha, 2011).

The procedure involves a graphical method that is used to determine drainage coefficient with the help of rainfall depth-duration-frequency curve. The losses due to interception, infiltration and evapotranspiration are ignored in this procedure due to maximum saturated conditions of atmosphere and soil surface. A minimum surface ponding is permitted for a crop and water exceeding such limit is to be drained within the tolerance period of the crop (Ritzema, 1994).

2.7.2 Drainage Coefficients for Irrigated Areas

FAO (2002) has indicated that, drainage coefficients could be determined by analyzing the water balance and soil characteristics in an irrigated field. The Peak evapotranspiration (PeakET) should be estimated using appropriate model such as CropWat or manually. Field capacity, permanent wilting point and bulk density should then be analyzed in the laboratory. The Readily Available Moisture (RAM) of the soil would be estimated using appropriate relationship between soil depth, bulk density, field capacity and permanent wilting point. Net irrigation should then be calculated from the relationship between allowable soil moisture depletion, root zone depth, field capacity and permanent wilting point. The shortest irrigation interval is calculated from the equation:

$$SII = \frac{RAM}{ET_C} \quad \text{Equation 2.8}$$

Where:

SII = Shortest Irrigation Interval (days)

RAM = Readily Available Moisture (mm) and

$PeakET_c$ = Peak Evapotranspiration (mm day^{-1}).

Deep percolation and seepage are computed as percentages of water losses.

Leaching requirement are usually ignored because in systems that use surface irrigation, deep percolation is greater than leaching requirement so only the former is used in computation. It should be assumed that excess water going down the soil as a result of deep percolation can be used for leaching (FAO, 2002). If there is any rainfall during the growing period, the amount should be recorded and included in the simulation of the drainage coefficient for surface drainage under irrigated ecology.

Total water input into drains should be equal to the sum of deep percolation, seepage and rainfall (if any) as given in Equation 2.9

$$TW_d = D_p + S + R \qquad \text{Equation 2.9}$$

Where;

TW_d = Total water into drains (mm),

D_p = Deep percolation (mm day^{-1}),

S = Seepage (mm day^{-1}) and

R = Rainfall (if any) (mm).

Drainage coefficient would then be equal to total water input into drains divided by shortest irrigation interval as given by the equation below:

$$DC = \frac{TW_d}{SII} \qquad \text{Equation 2.10}$$

Where;

DC = Drainage Coefficient (mm day^{-1}),

TW_d = Total water input into drains (mm), and

SII = Shortest Irrigation Interval (days).

2.8 Farmers' Perception on the Need, Benefits and Problems of Drainage in Irrigated Ecologies

Chaponnière *et al.* (2012) stated that, in evaluating a system that is made of different stakeholders, there happens to be a diversity of conditions and viewpoints that when combined make up its reality. There are many faces of one reality, and each is specified by diverse set of situations that construct and shape their viewpoint through which each person looks at things. It is therefore critical to understand what composes each perception. This empowers evaluators to use coordinated efforts in doing joint assessments of the same system, using an all-encompassing approach that points to gather distinctive suppositions of the same environment.

Kolkman, *et al.* (2005) stated that, there are five (5) major perspectives that characterized the perception of those actors that are involved in water management processes i.e., technical, ethical, organizational, personal, and aesthetic. This concept is central for having an idea on the differences between actors when assessing an agricultural drainage system. Consequently, diverse judgments on the same topic can be viewed by stakeholders at different levels, resulting to clashes over the management of water. Nevertheless, the perception of farmers has been looked with a low interest and were not considered in the evaluation process leading to ineffective performances, knowing that farmers are primarily the main beneficiaries of any irrigation and drainage system. Many studies have proved that the perception of farmers towards issues of soil fertility, salinity, waterlogging, sodicity and pests vary from scientific assessments due to variations in objectives and methods on the topics (Pereira, 2009; Ferchichi, 2012).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of Study Area

The study was conducted at the Bontanga Irrigation Scheme which is located in the Kumbungu District, Northern Region of Ghana. This district was carved out of the then Tolon/Kumbungu district with Legislative Instrument (LI) 2062 of 2011 (KDA – MTDP, 2013). The geographical location of Bontanga irrigation scheme is latitude N 9° 57' and longitude W 1° 02'. The scheme is a large-scale gravity-fed scheme that covers a potential area of 800 ha. However, Braimah *et al.* (2014) reported that, out of this 800 ha, only about 450 ha is considered irrigable, of which 240 ha is used for rice cultivation and the remaining 210 ha is used for upland vegetable production.

The irrigation system in Bontanga is an earth fill dam of 12 m in height with a crest width of 5.0 m. The spillway is at an elevation of 5.8 m and a surface area at the spillway elevation of 770 ha with a reservoir capacity of 25 million m^3 (Sadick *et al.*, 2014). Rice (*Oryza sativa*) is the main crop that is grown in the scheme with some minor crops such as okra *(Hibiscus esculentus*), tomatoes (*Lycopersicon esculentum*), onion (*Allium cepa*), and pepper (*Capsicum frutescens*) (Adongo *et al.,* 2015).

Kranjac-Berisavljevic (1999) reported that, the Northern Region is unimodal having a normal rainy season in the region starts from May to October with the highest rainfall happening in August and September, while November through May consist of dry periods putting the competition for the scarce water resources at high levels within the basin. Abdul-Ganiyu (2011) reported that, the temperatures within the area are normally high with a yearly mean of 29^o C with evapotranspiration (ET_o) being estimated at over 1600 mm/y.

During the dry season, the relative humidity is generally low with average values of 50 % or below; while the velocities of the wind and temperatures are normally higher in the dry period. This prompted the development of irrigation schemes in the region to store runoff water in earth dams (Abdul-Ganiyu *et al*., 2015).

3.2 Data Collection Methods

3.2.1 Desk Review

A desk study which involved reviewing relevant literature including journals, articles, thesis and reports on irrigation drainage systems worldwide as well as work done in Ghana was carried out. Documents on the Water Users Association (WUA) which contained names of farmers in the scheme were also obtained from the scheme's manager.

3.2.2 Field Observation and Measurements

The drainage system in the irrigation scheme was assessed by field observation on the status of the field, lateral and main drains and measurements taken looking at drainage design parameters to check whether the drainage system is functioning in line with the design criteria.

3.2.2.1 Characterisation of Physico-chemical Properties of Soil in the Irrigable Area of the Scheme

The lowland area of the irrigation scheme was divided into three (3) zones; upstream (US), midstream (MS) and downstream (DS). Six (6) farmers whose farms were used to collect field data were selected randomly, 2 from each zone. Zone based sampling was employed in doing the sample collection. In zone-based strategies, the goal was to collect samples that represent the average soil within each zone. Three (3) composite soil samples (1 from each zone) were taken 2 times during the cropping season (one before the start of the cropping activities and one after harvest). Samples were collected at depths of 0 – 20 cm, 20 – 40 cm, 40 – 60 cm (Plate 3.1). These sampling depths were chosen based on the maximum effective rooting depth of rice of up to 60 cm as reported by FAO (1998). The sampling unit consisted of locating one sub-plot for each farmer measuring 10 m × 10 m, making four (4) sampling points in each zone. These points were referenced using field measurement or global positioning system coordinates as indicated in Table 3.1 and then collecting soil samples/cores.

In each zone, three (3) undisturbed soil samples giving a total of nine (9) undisturbed samples for the three (3) zones were taken at the different depths mentioned above for bulk density determination. Baseline samples were collected from four (4) points that were drawn from each zone as sub-samples for each depth. Nine (9) sub-samples were collected for the three (3) zones as composite samples for laboratory analysis. The nine (9) composite samples from the three (3) zones that are for the analysis of physico-chemical properties were transferred into sampling bags, tied and labelled. Soil infiltration test was conducted as shown in Plate 3.1 using mini-disc infiltrometer to determine the rate of infiltration and the soils hydraulic conductivity.

Particle size distribution, soil organic matter, soil electrical conductivity, soil pH, field capacity and permanent wilting point were determined at the Soil Science Laboratory of the University for Development Studies whilst Cation Exchange Capacity (CEC), Exchangeable Sodium Percentage (ESP), and total nitrogen (N), were also determined at the Soil Science Laboratory of Savannah Agricultural Research Institute in Nyankpala.

Table 3.1: Soil Sampling Points in the Irrigable Areas of the Bontanga Irrigation Scheme

Location	Latitude (º)	Longitude (º)	Altitude (m)
Upstream	N09.579112	W001.034433	145
	N09.578950	W001.034317	143
	N09.581100	W001.023595	140
	N09.581105	W001.023654	140
Midstream	N09.598184	W001.039307	139
	N09.598405	W001.039126	139
	N09.608847	W001.040794	138
	N09.608745	W001.041216	136
Downstream	N09.600521	W001.029387	134
	N09.600395	W001.029071	134
	N09.613952	W001.028408	133
	N09.613894	W001.028196	133

Plate 3.1: Field Soil Sampling using Auger

The unsaturated hydraulic conductivity was measured using a mini disk infiltrometer (MDI, Decagon Devices Inc., Pullman, Washington, USA). It consists of two (2) chambers (water reservoir and bubble chamber), connected via a Mariette tube to provide a constant water pressure head of − 0.5 to − 7 cm (equivalent to − 0.05 to − 0.7 kPa). Suction rate of – 2 cm, was chosen for this study (Al-Dosary *et al.,* 2019). The infiltration tests were conducted without any addition of water or modification of the soil surface and these were taken 5 times for each zone (downstream, midstream and upstream) and average values used.

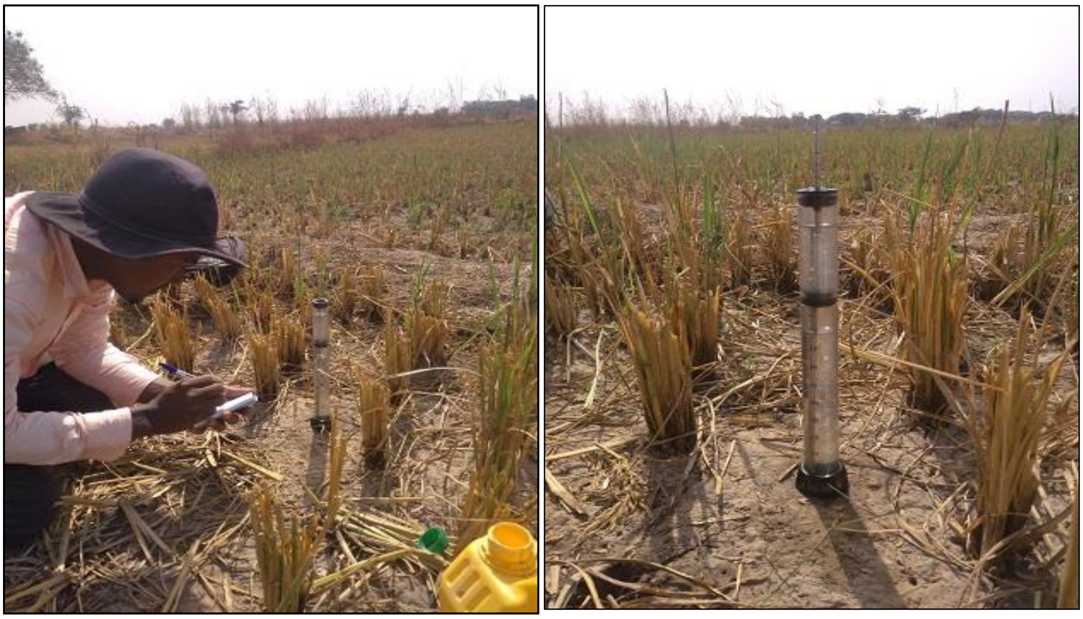

Plate 3.2: Conducting Infiltration Test Using Mini-disc Infiltrometer

The determination of particle size distribution was done using the hydrometer method and soil reaction (pH) was determined in 1:2.5 soil-water suspension as described by Kacar (1997). Cation exchange capacity (CEC) was determined by saturating the samples with sodium acetate; electrical conductivity (EC) in 1:2.5 soil-water saturation and organic matter using Walkley-Black method. The Exchangeable Sodium Percentage (ESP) procedure was used to determine sodicity levels in the soils (Senon *et al.,* 2012). Field capacity and wilting point water content were determined using pressure plate and pressure membrane apparatus. Total nitrogen was determined using Kjheldal method (Bremner and Mulvaney, 1982).

The method proposed by Zhang (1997) is quite simple, and works well for measurements of infiltration into dry soil. The method requires measuring cumulative infiltration versus time and fitting the results with the function. Infiltration was computed using Equation 3.1 from the cumulative infiltration records versus time following Zhang (1997), Carsel and Parrish (1988), and Decagon Devices Inc. (2012) recommendations.

$$I = C_1 t + C_2\sqrt{t} \qquad \text{Equation 3.1}$$

Where:

C_1 (cm.s^{-1}) and C_2(cm.(s^{-1})$^{-0.5}$) are parameters.

C_1 is related to hydraulic conductivity, and C_2 is the soil sorptivity.

The hydraulic conductivity for the soil (k) is then computed using Equation 3.2.

$$k = \frac{C_1}{A} \qquad \text{Equation 3.2}$$

Where:

C_1 is the slope of the curve of the cumulative infiltration versus the square root of time (cm.s^{-1})

A is a value relating the van Genuchten parameters for a given soil type to the suction rate and radius of the infiltrometer disk.

The values of ‘A’ in Table 3.2 can be calculated using Equations 3.3 and 3.4 (Carsel and Parrish, 1988).

$$A = \frac{11.65(n^{0.1} - 1)\exp[2.92(n - 1.9) \propto h_0]}{(\propto r_0)^{0.91}} \quad (n \geq 1.9) \qquad \text{Equation 3.3}$$

$$A = \frac{11.65(n^{0.1} - 1)\exp[7.5(n - 1.9) \propto h_0]}{(\propto r_0)^{0.91}} \quad (n < 1.9) \qquad \text{Equation 3.4}$$

Where;

n and α are the Van Genuchten parameters for the soil,

r_o is the disk radius and

h_o is the suction at the disk surface.

Table 3.2: Van Denuchten Parameters for 12 Soil Texture Classes and Values of A for a 2.25 cm Disk Radius and Suction Values From 0.5 to 6 cm.

Texture	A	n(h)	A						
			-0.5	-1	-2	-3	-4	-5	-6
Sand	0.145	2.68	2.9	2.5	1.8	3	0.9	0.7	0.5
Loamy Sand	0.124	2.28	3	2.8	2.5	2.2	1.9	1.6	1.4
Sandy Loam	0.075	1.89	4	4	4	4	4	4.1	4.1
Loam	0.036	1.56	5.6	5.8	6.4	7	7.7	8.4	9.2
Silt	0.016	1.37	8.1	8.3	8.9	9.5	10.1	10.8	11.5
Silt Loam	0.02	1.41	7.2	7.5	8.1	8.7	9.4	10.1	10.9
Sandy Clay Loam	0.059	1.48	3.3	3.6	4.3	5.2	6.3	7.6	9.1
Clay Loam	0.019	1.31	6	6.2	6.8	7.4	8	8.7	9.5
Silty Clay Loam	0.010	1.23	8.1	8.3	8.7	9.1	9.6	10.1	10.6
Sandy Clay	0.027	1.23	3.4	3.6	4.2	4.8	5.5	6.3	7.2
Silty Clay	0.005	1.09	6.2	6.3	6.5	6.7	6.9	7.1	7.3
Clay	0.008	1.09	4.1	4.2	4.4	4.6	4.8	5.1	5.3

Source: MDI-Decagon Devices (2012

3.2.3 Drainage Performance Indicators Used at the Bontanga Irrigation Scheme

The current drainage network was identified using GPS coordinates and plotted using GIS for comparison with the standard component of a drainage system as stated by FAO.

Data on soil electrical conductivity and exchangeable sodium percentage was used for the analysis of salinity and sodicity indicators respectively using the Equations 3.5 from International Committee on Irrigation and Drainage (Bos *et al.,* 2005).

$$\text{Relative Change of EC} = \frac{\text{EC Value after Harvest-Baseline EC}}{\text{EC Value after Harvest}} \quad \text{……………Equation 3.5}$$

Waterlogging intensity in the study area was assessed using SEW_{30} as an indicator. Sieben (1964) after conducting drainage experiments in The Netherlands used the SEW_{30} concept to quantify the waterlogging situation. Observation wells made of 2" PVC pipes were installed in the upstream, midstream and downstream of the field. The pipes were punched with holes over a length that the water table is expected to fluctuate. A gravel filter was then placed around the pipe to ease the flow of water and to prevent the holes from being clogged with clay and silt particles. To collect the SEW_{30} values, 6 observation wells were installed across the selected plots in the study area to record fluctuations in the water table elevations during the cropping season as shown in Plate 3.3. The wetted tape method was used to measure the level of water table depth. In this method, a steel tape (calibrated in millimeters), with a weight attached to it, was lowered into the pipe below the water level.

Soil salinity as an indicator was determined by using electrical conductivity (EC) procedure of a solution extracted from a soil wetted to a saturation paste as stated by Senon *et al.* (2012) and values were compared to Table 3.3.

Table 3.3: Classes of Soil Salinity with respect to Electrical Conductivity

Electrical Conductivity (dS/m)	Salinity Class
0 < 2	Non – saline
2 < 4	Very slightly saline
4 < 8	Slightly saline
8 < 16	Moderately saline
≥ 16	Strongly saline

Source: Adapted from USDA – NCRS Survey Book (2004)

SEW_{30} was then used to calculate the sum of excess water by which water tables are closer than 30 cm. The concept is given by Sieben (1964) as:

$SEW_{30} = \sum_{i=1}^{N} (30\text{-}WTD_i)$ ……………………………………………………Equation 3.7

Where WTD is the daily water table depth or day (i) and N is the number of days.

These values were then compared with the index values as presented in Table 3.4 to check the waterlogging situation in the research area.

Table 3.4: Waterlogging Classes Using SEW30 Index

Waterlogging Class (in terms of Drainage)	SEW_{30} Index (cm.days in an Average Growing Season)
Well drained	<30
Moderately well drained	30–100
Moderately drained	100–250
Imperfectly drained	250–500
Moderately poorly drained	500–1200
Poorly drained	1200–2500
Very poorly drained	>2500

Source: Adapted from Moore (2001)

Water levels were determined manually by taking discrete measurements with time. Weekly observations were taken and the water table depth plotted against time. These weekly observations were also used to assess water table as function of time as key performance indicators for the drainage system as stated by Bos *et al.* (2005).

Plate 3.3: Installation of Observation Wells in the Irrigable Area

3.2.4 Determination of Surface Drainage Coefficient Using Water Balance Approach

The water balance approach was used in the computation of the drainage coefficients as cropping is done in the study area under both rainfed and irrigation. Under the irrigated system, soil properties such as moisture content at saturation, field capacity, permanent wilting point and bulk density were analyzed in the laboratory before sowing. Rice root zone depth of 300 mm (FAO, 1998) and Management Allowable Depletion (MAD) of 20 % (Allen *et al.,* 1998) were adopted based on the irrigation system (surface) practiced in the scheme.

Peak evapotranspiration (PeakET) values for the months of March (5.36 mm day^{-1}), April (5.56 mm day^{-1}), and May (3.64 mm day^{-1}), were referenced from works done earlier within the scheme (Sadick *et al.,* 2014). PeakET for June was computed from the relationship between reference crop evapotranspiration (ET_0) and crop coefficient value (K_c) using Equation 3.8:

$ET_c = ET_o \times K_c$ ……………………………………………………..…………Equation 3.8

Where:

ET_c = Crop Water Requirement,

ET_o = Reference Crop Evapotranspiration and

K_c = Crop coefficient

Water conveyance and seepage were sought from previous works that have been done in the scheme by Abdul-Ganiyu *et al.* (2015). Rainfall data for the study area during the research period was sought from SARI weather station and have been added into the simulation.

Readily available moisture (RAM), net irrigation and shortest irrigation interval were determined using empirical relationships developed by FAO (1996) as:

$$RAM = (\theta_m FC - \theta_m PWP) \times \rho b \times P \times RZD \quad \text{Equation 3.9}$$

Where:

$\Theta_m FC$ = Field capacity (%),

$\Theta_m PWP$ = Permanent wilting point (%),

ρb = bulk density (g/cm^3),

RZD = Root zone depth (cm) and

P = allowable soil moisture depletion (%).

The shortest irrigation interval was calculated from the equation given by FAO, (1996):

$$SII = \frac{RAM}{ET_C} \quad \text{Equation 3.10}$$

Where:

SII = Shortest irrigation interval (days),

RAM = Readily available moisture (mm) and

PeakET$_c$ = Peak evapotranspiration (mm day^{-1}).

Total water input into drains was calculated by summing deep percolation, seepage and rainfall using the equation as presented by FAO (1996).

$$TW_d = D_p + S + R \quad \text{Equation 3.11}$$

Where:

TW_d = Total water into drains (mm),

D_p = Deep percolation (mm),

S = Seepage (mm), and

R = Rainfall (mm) (if any).

Because the drainage coefficients are being computed under irrigated ecology, the amount of irrigation as input and crop evapotranspiration as output are being added to Equation 3.12 to give a modified equation for a complete water balance approach as:

$$TW_d = I + R + C - (SP + ET_C) \qquad \text{Equation 3.12}$$

Where:

I = Irrigation water (mm),

R = Rainfall (mm),

C = Capillary rise (mm day^{-1}),

SP = Seepage and percolation (mm day^{-1}) and

ETc = Crop evapotranspiration (mm day^{-1})

Seepage and percolation values have been computed for the scheme as being equal to 3.31 cm/day (Abdul-Ganiyu *et al.,* 2015). This value was used in the computation.

In flooded rice areas, since there is a nonstop downward flow of water from the puddled layer to below the plow pan, that fundamentally prevents capillary rise into the rootzone, capillary rise is therefore normally neglected in the water balance of paddies (Bouman *et al.,* 2007).

Six (6) farms, two (2) from each zone were selected randomly for the computation of drainage coefficients. Each farm was identified as a system. Water for irrigation into the respective fields was delivered from an earthen dam by means of gravity into the canals and laterals. When water is opened and flows through the canal, the farmers open their lateral gates in rotation defined by the WUA. These canals and laterals are lined with concrete to reduce the amount of delivery losses. Each farmer opens the gate in order to siphon the water needed for his/her field. The flow of water to the farmers field was measured using a graduated cylinder of 0.04 m^3 (40 liters). Measurements were taken for each irrigation event and average time taken to fill the cylinder was recorded in seconds. This was extrapolated to the amount of water applied per unit area of the basin with respect to the time taken per irrigation event.

Drainage Coefficients therefore were computed by dividing the total water into the drains by shortest irrigation interval using Equation 3.13 as given by FAO (1996)

$$DC = \frac{TW_d}{SII} \quad \text{.........Equation 3.13}$$

Where:

DC = Drainage Coefficient (mm day^{-1}),

TW_d = Total water input into drains (mm) and

SII = Shortest Irrigation Interval (days).

3.2.5 Assessing Farmers' Perception on Drainage in the Bontanga Irrigation Scheme

The respondents comprised farmers who are cultivating rice in the right bank of the Bontanga irrigation scheme. The total number of farmers in the right bank of the scheme was given as 300 from the scheme's office and thus constituted the sample frame. The sample size was determined by a scientific formula given by Miller and Brewer (2003) as:

$$n = \frac{N}{1+N(\propto)^2} \quad \text{.........Equation 3.14}$$

Where:

N = Sample frame,

n = Sample size and

α = Margin of error (fixed at 5 %).

Therefore, from equation 3.15, the sample size is shown below:

$$n = \frac{300}{1+300\,(0.05)^2} \quad \text{.......... Equation 3.15}$$

n = 171 rice farmers

The right bank canal has fourteen (14) laterals and each lateral was assigned twelve (12) respondents to be interviewed randomly with the exception of laterals one (1), seven (7) and fourteen (14) which had thirteen (13) respondents each. A simple random sampling was employed in the selection of the farmers who were interviewed.

A semi-structured pretested questionnaire was then used to collect data (Plate 3.4) on farmers' socio-demographic characteristics, their perception on the need for drainage systems, the benefits associated with the effective use of the drainage systems and the problems emanating from the non-compliance on the use of drainage.

Plate 3.4: Questionnaire Administration to Farmers

Data from the questionnaire was processed and analyzed based on the understanding of the perception of farmers on the need, benefits and problems emanating from the non-compliance on the use of drainage. SPSS version 20 was used as a statistical package to analyze the data that was collected. The data was cleaned and coded. In the editing, the information collected was cross-checked for completeness, precision and consistency. Deductive and inductive coding were utilized. With the deductive coding, responses were classified into pre-established categories, as in the case with closed-ended questions.

Tables, charts, percentages and graphs were used to represent the data quantitatively, while description of tables and graphs were used in the case of the qualitative analysis.

The perceived constraints on the consequences of drainage and factors contributing to salinity, sodicity and waterlogging/ponding were evaluated and grouped into categories as “very serious problem”, “serious problem”, “problem” “no problem” and “don’t know” as it relates to the effects on the production of rice in the study area, and a ranking was conducted using the Problem Confrontation Index (PCI) as suggested by Ndamani and Watanabe (2015). The values of PCI were estimated using Equation 3.16:

$$PCI = P_{np} \times 0 + P_p \times 1 + P_{sp} \times 2 + P_{vsp} \times 3 \qquad \text{Equation 3.16}$$

Where:

PCI = Problem Confrontation Index,

P_{np} = Number of respondents who said “no problem”,

P_p = Number of respondents who said “a problem”,

P_{sp} = Number of respondents who said “a serious problem” and

P_{vsp} = Number of respondents who said “a very serious problem”.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Physico-chemical and Hydraulic Properties of Soil in Lowlands of the Scheme's Irrigable Area

4.1.1 Soil Textural Classification

The results of the textural classification at different locations at three (3) different depths of a soil profile in the lowland of the irrigable area of the Bontanga irrigation scheme are presented in Table 4.1.

Table 4.1 Textural Classification of Soils at the Bontanga Irrigation Scheme at Different Depths of Soil Profile

Location	Soil Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Soil Class
Upstream (US)	0 – 20	73.28	14.00	12.72	Sandy loam
	20 – 40	70.28	10.96	18.76	Sandy clay loam
	40 – 60	60.00	9.28	30.72	Sandy clay loam
Midstream (MS)	0 – 20	72.00	12.76	15.24	Sandy loam
	20 – 40	64.00	22.72	13.28	Sandy clay loam
	40 – 60	50.00	33.84	16.16	Sandy clay loam
Downstream (DS)	0 – 20	72.00	16.20	11.80	Sandy loam
	20 – 40	56.00	16.20	27.80	Sandy clay loam
	40 – 60	46.00	12.20	41.80	Sandy clay

As presented in Table 4.1, soils within 0 – 20 cm and 20 - 40 cm were classified as sandy loam and sandy clay loam respectively for all zones based on composition of sand, silt and clay. It was noted that, the percentage of clay increased with an increase in soil depth. Soil texture affects the rate at which water moves through the soil and the pattern of water movement. In sandy soils for instance, water will move straight down whereas it will show some lateral movement in soils with clay content. Senjobi and Ogunkunle (2011) noted that, soil texture influences water retention capabilities of soils at different locations, as soils with high clay content tend to have high water holding capacity and that, the soil texture and crop rooting depth affect total amount of water stored in the soil within the plants rooting zone. The results of this study agreed with that of Buri *et al.* (2012) who reported that, the topsoil textures of savannah agro-ecological zones are loam, silt loam or sandy loam and the underlying subsoil textures ranged from sandy clay loams to clays. These soils, they further stated belong to the category of Lima soils which are deep (> 140 cm) and imperfectly to poorly drained.

4.1.2 Soil Bulk Density

The results of the soil bulk density for the three (3) locations (zones) i.e., upstream, midstream and downstream of the Bontanga irrigable area are presented in Figure 4.1.

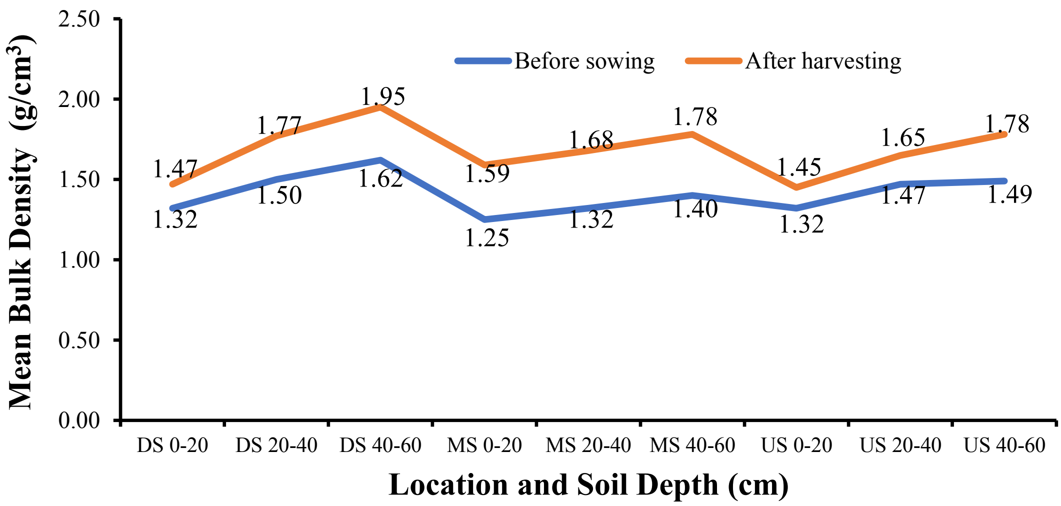

Figure 4.1: Mean Levels of Soil Bulk Density in the Different Zones of Bontanga Irrigation Scheme

As presented in Figure 4.1, the mean dry bulk densities of the lowland of the Bontanga irrigation scheme ranged from 1.25 to 1.62 g/cm^3 before planting of rice and 1.47 to 1.95 g/cm^3 after harvesting of rice. The T-test demonstrated that, soil depths within the zones showed significant differences in their bulk densities before sowing and after harvesting ($p = 0.021$ for downstream, $p = 0.0005$ for midstream and $p = 0.025$ for upstream). In all the zones, bulk density increased with depth. Landsberg *et al.* (2003) reported that, bulk density typically increases with depth because of changes in soil texture, gravel content and structure. Doerr *et al.* (2000) supported the assertion that, it could also be as a result of biological activity on surface soils with high organic matter content and vegetation residues which decreases down the soil profile. USDA (2004) also postulated that, reduced aggregation, root penetration and less pore space of the sub-surface layers compared to surface layers equally led to increase bulk density down the soil layers. This is consistent with the findings of Price *et al.* (2010) who discovered that, the mean bulk density of the upper layers was significantly ($p < 0.001$) lower than the lower layers.

From Figure 4.1, it can be seen that, in all the three (3) zones, the bulk density showed a regular increase with depth (i.e., higher bulk density at the lower soil layers). This agrees with the study conducted by Siltecho *et al.* (2010), who obtained similar findings of regular increase in bulk density down the soil profiles. The values of bulk density ranged from 0.5 to 3.0 g/cm^3 but most of them are between 0.8 and 1.8 g/cm^3 (Buol *et al.,* 1981). Soils with bulk density greater than 1.8 g/cm^3 are root limiting. It can be observed that, the values of bulk density in all the depths both before and after harvesting are consistent with the standard values for crop production.

Puddling is done in the study area by farmers and this leads to soil compaction. Bulk density is an indicator of soil compaction and soil health. This has the tendency to affect infiltration, soil porosity, plant nutrient availability, activities of microorganisms, which influence key soil processes and productivity. USDA – NCRS (2003) noted that, bulk density typically increases with soil depth since subsurface layers are more compacted and have less organic matter, less aggregation, and less root penetration compared to surface layers, therefore contain less pore space.

4.1.3 Soil Unsaturated Hydraulic Conductivity

The unsaturated hydraulic conductivity of the lowland soils of the Bontanga irrigable area as presented in Table 4.2 ranged from 2.75×10^{-4} to 5.25×10^{-4} cm/s. The upstream portion had a higher hydraulic conductivity compared to midstream and downstream portions. The downstream portion recorded the lowest hydraulic conductivity values. A good drainage system ensures an increase in soil fertility and porosity, thereby enabling plant roots to penetrate into the soil, which eventually increases the hydraulic conductivity (Chaudhry and Subhani, 2000).

The hydraulic conductivity parameter is one which is predominantly a function of the water content or the matric suction of the unsaturated soil. It is an important soil hydraulic property that affects water flow because it controls the movement of water (Fatehnia *et al.,* 2014) and therefore it is of great importance in drainage studies. Applying water at rates greater than the soil can take can also cause ponding, which increases the possibility of diseases, as well as runoff, which causes soil erosion and possible fertilizer loss. Johnson (1963) contended that, there are no particular values of infiltration rate for specific sort of sediment. This means that it is not easy to generalize infiltration rates by crop type or soil type given the range of values found in nature and detailed within existing literature.

Table 4.2: Unsaturated Hydraulic Conductivity of the Lowland of Bontanga Irrigable Soils

Location	C_1 (cm.s^{-1})	A	Suction Rate (cm)	$k_{(h)}$ (cm s^{-1})
Upstream	0.0021	4.0	2	5.25×10^{-4}
Midstream	0.0012	4.0	2	3.0×10^{-4}
Downstream	0.0011	4.0	2	2.75×10^{-4}

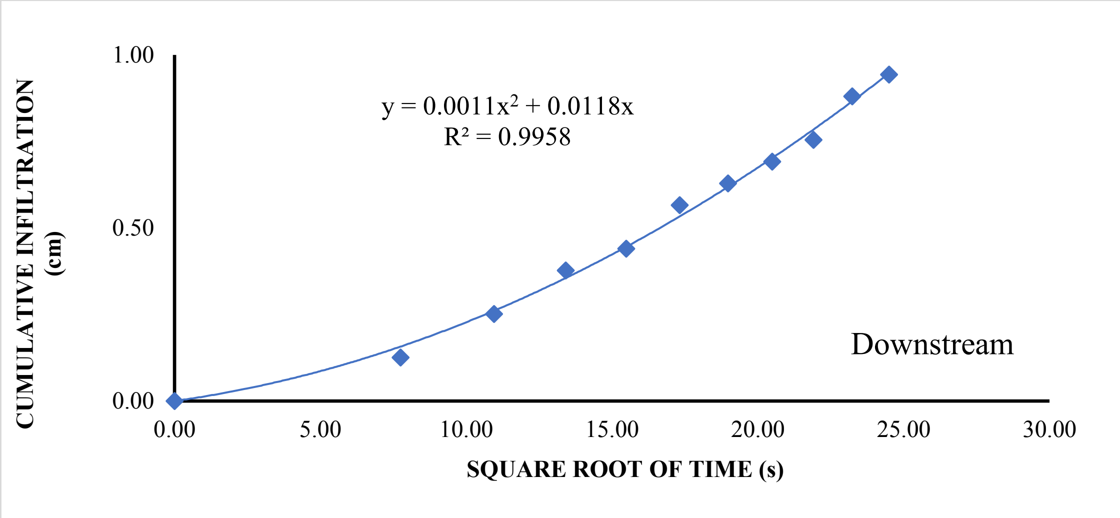

Figure 4.2a: Cumulative Infiltration Versus Square Root of Time for Downstream

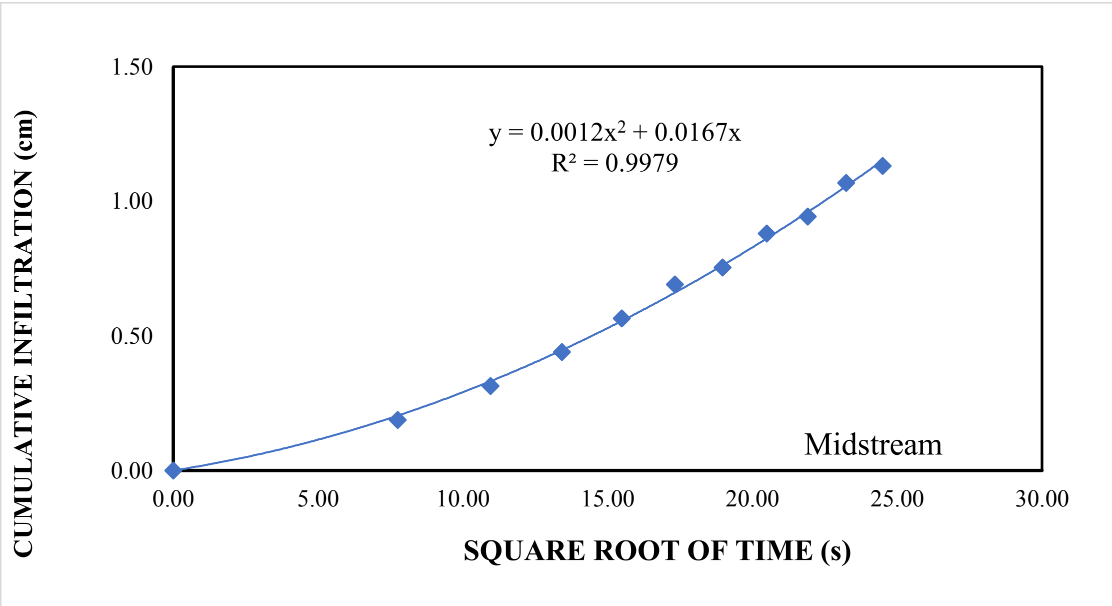

Figure 4.2b: Cumulative Infiltration Versus Square Root of Time for Midstream

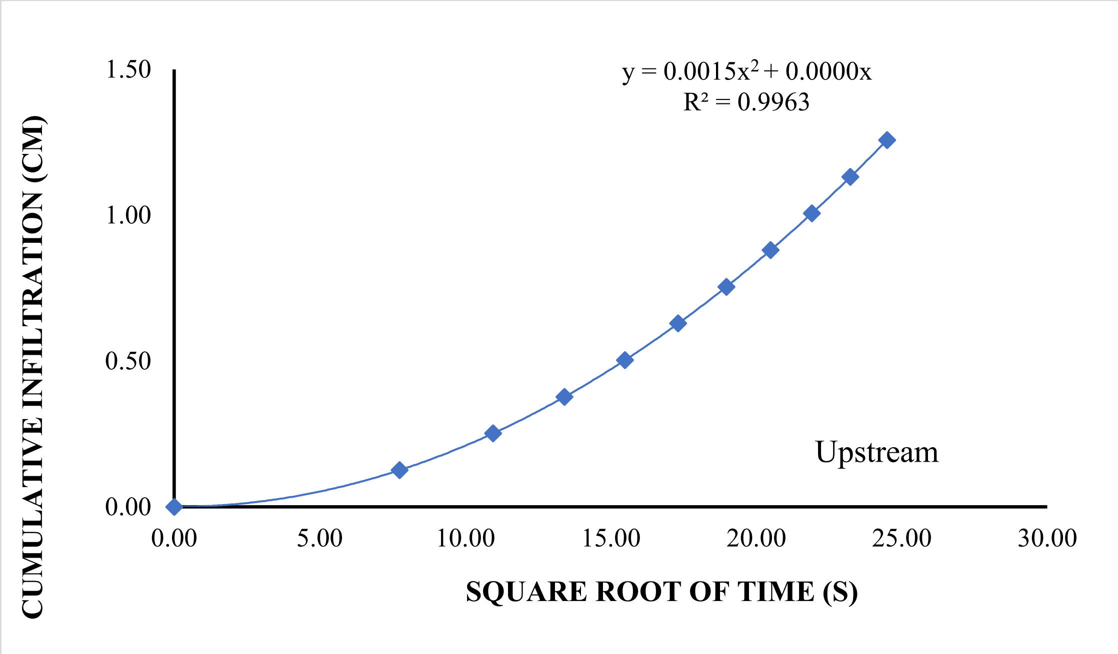

Figure 4.2c: Cumulative Infiltration Versus Square Root of Time for Upstream

4.2 Chemical Properties of Soil in the Lowland of Bontanga Irrigable Area

4.2.1 Soil pH

The pH of the soil in the study area is presented in Figure 4.3.

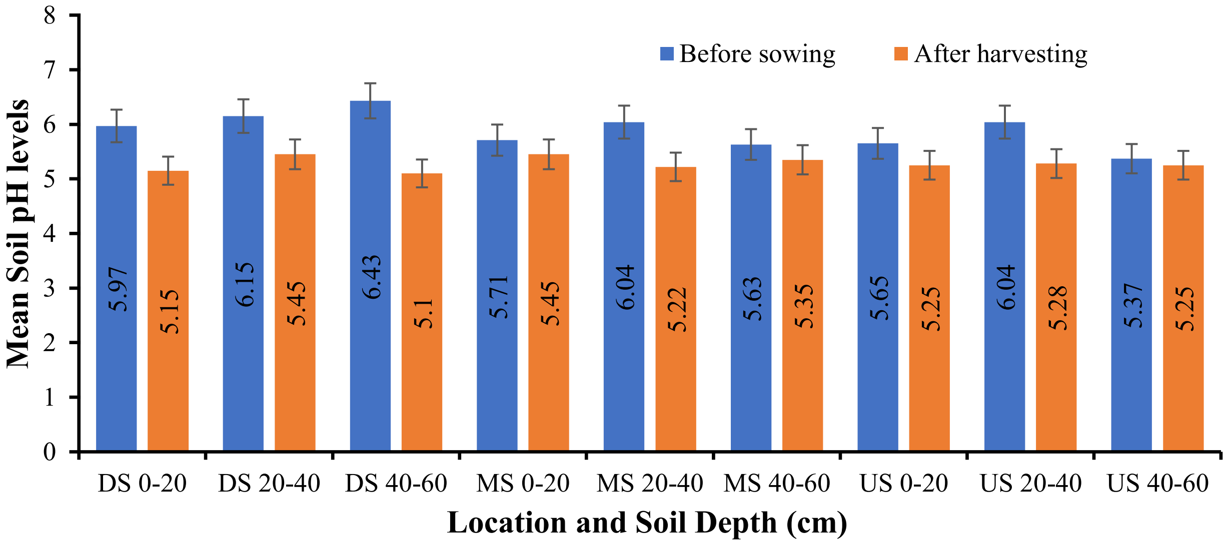

Figure 4.3: Mean Levels of Soil pH in the Lowland of Bontanga Irrigable Area

As presented in Figure 4.3, the pH of the soil in the lowland of the Bontanga irrigable area ranged from 5.37 to 6.43 before planting and 5.1 to 5.45 after harvesting. A T-Test performed on the pH values resulted in $p = 0.01$, $p = 0.06$ and $p = 0.07$ for the downstream, midstream and upstream respectively. Therefore, the pH for the downstream, midstream and upstream before planting and after harvesting were significantly different. All the pH values in the field indicate a general decrease at all depths between before planting and after harvesting. However, the decrease in all the various depths have average values of 5.1 – 5.45 which means they are slightly acidic.

This however, calls for careful management and close monitoring as soil pH relates to the solubility of various compounds and the suitability of soil conditions to microbial activity. Whiting *et al.* (2014) stated that acceptable pH for the growth and development of most crops range between 6.0 – 7.5; when pH is 4.6 or below, it is too acidic for most plants, pH of 5.5 tends to reduce microbial activities and for most plants a pH greater than 8.3 is seen to be too alkaline. The critical pH value for rice is 6 (Nur Sa'adah *et al.,* 2018).

According to Ilagan *et al*. (2014), a soil pH of 5.5 – 7.0 is best suitable for rice. This means that, the soils in the downstream, midstream and upstream of the lowland area of Bontanga irrigation scheme after harvesting should be a concern to the farmers and thus needing proper management decisions. The United States Department of Agriculture - USDA (2003) reported that, too high or too low pH leads to deficiency of many nutrients, decline in microbial activities, decrease in crop yield and deterioration of soil health. This is also supported by Agbeshie and Adjei (2019) that, soils with lower pH are as a result of leaching basic cations during seasonal flooding, inadequate drainage of wetland, addition of chemical fertilizers (e.g., Urea) and loss of organic matter through erosion and that sandy soils commonly have low organic matter content, resulting in a low buffering capacity, high rates of water percolation and infiltration making them more vulnerable to acidification.

4.2.2 Electrical Conductivity

The electrical conductivity (EC) of the soils in the study area was measured from soil samples collected within the three (3) zones of the scheme at different layers and presented in Figure 4.4.

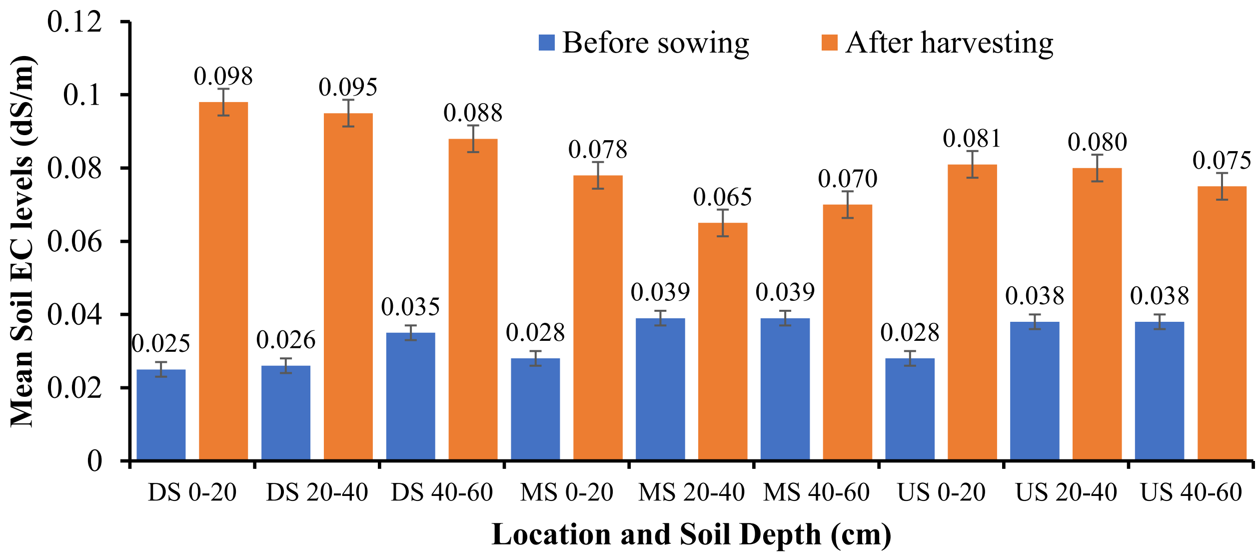

Figure 4.4 Mean Levels of Electrical Conductivity (EC) in the Lowland Soils of Bontanga Irrigable Area

As shown in Figure 4.4, the minimum and maximum values of EC in the downstream before planting and after harvesting were 0.025 and 0.035 dS/m and 0.088 and 0.098 dS/m respectively. Midstream recorded 0.028 and 0.039 dS/m as minimum and maximum values before planting while 0.065 and 0.078 dS/m were recorded as minimum and maximum values after harvesting. For the upstream, 0.028 and 0.038 dS/m were recorded as minimum and maximum values before planting while 0.075 and 0.081 dS/m were EC values after harvesting.

It was noted from the study that, the salinity levels of the soil before sowing and after harvesting in the upstream (US), midstream (MS) and downstream (DS) of the irrigable area were significantly different. A paired, one-tailed distribution T-Test performed showed very high significant differences in the downstream ($p < 0.004$), midstream ($p < 0.019$) and upstream ($p < 0005$). Thus, the electrical conductivity of the various depths within the irrigable area are statistically significant. Based on the standards set by the USDA for salinity levels, the soils in the lowland of Bontanga irrigable area can be classified as non-saline soils. Adongo *et al.* (2015) noted an EC of 20 µS/cm (0.020 dS/m) in the lowland soils of the Bontanga irrigable area. However, it is worth noting that since 2015 to 2021, there has been an increase in the EC values.

Changes in the chemical properties like electrical conductivity of soil happen due to the elimination of oxygen from the rhizosphere caused by waterlogging or flooding (Fagaria *et al.,* 2011). These changes are linked to physical processes between the soil and water and also due to the biological processes that happen as a result of excess water or oxygen deficiency (Fagaria *et al.,* 2011). Magdoff and Harold (2010) remarked that soil pH, redox potential and electrical conductivity are the most significant chemical changes that happen in soils with flooded or submerged rice.

From the results in Table 4.3, the relative change of ECs recorded were 71.4 %, 67.1 % and 64.3 % in the 0 – 20 cm of the upstream, midstream and downstream respectively. This could be as a result of fertilizers and chemicals applied by the famers without proper drainage. Seifi *et al.* (2010) indicated that excess application of pesticides or fertilizers without proper drainage is one of the major problems that increases salinity threshold and hence threatens plant. USDA-NCRS (2003) emphasized that management that leads to low organic matter, poor infiltration, poor drainage, saturated soil, or compaction can increase EC and the soil's ability to buffer EC.

Table 4.3: Relative Change of EC (%)

Soil Depth (cm)	Relative Change of EC (%)
US 0 – 20	71.4
US 20 - 40	51.3
US 40 - 60	41.5
MS 0 – 20	67.1
MS 20 - 40	48.7
MS 40 - 60	35.0
DS 0 – 20	64.3
DS 20 - 40	62.3
DS 40 - 60	35.2

4.2.3 Exchangeable Sodium Percentage

The Exchangeable Sodium Percentage (ESP) of the study area as sodicity indicator was determined and the results are presented in Figure 4.5.

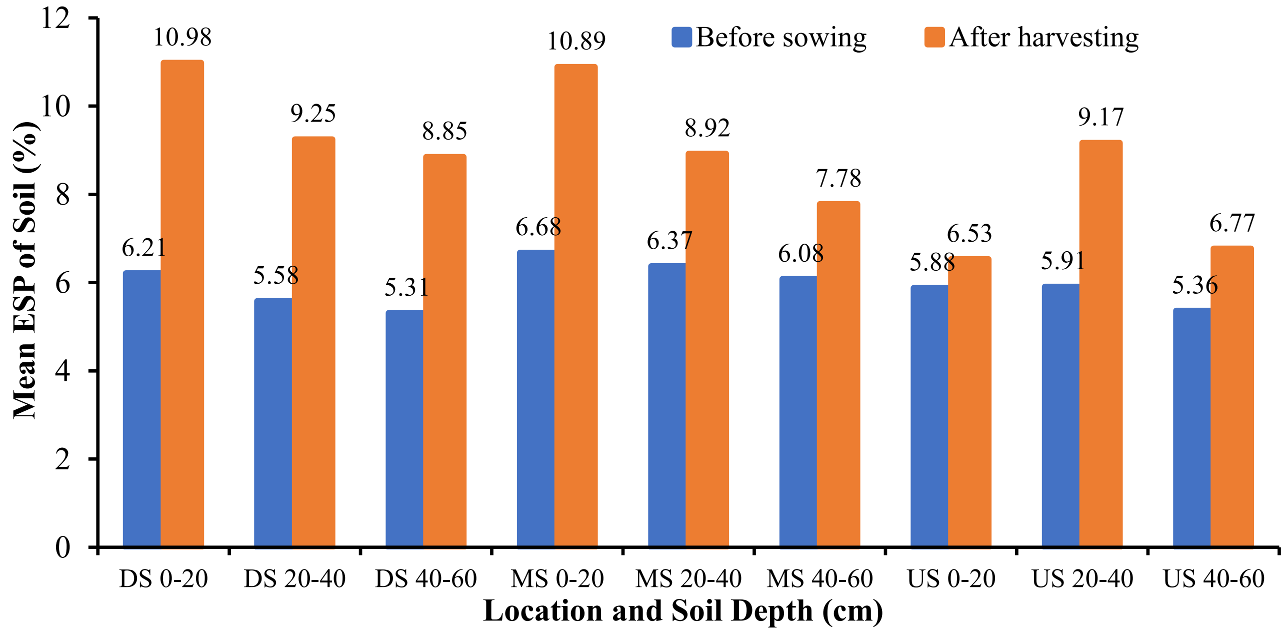

Figure 4.5: Mean Levels of Exchangeable Sodium Percentage (ESP) in the Lowland Soils of Bontanga Irrigable Area

From Figure 4.5, minimum values of ESP in the downstream before sowing were 5.31 and 6.21 % while after harvesting it was 8.85 and 10.98 % as minimum and maximum values respectively. In the midstream, 6.08 % (minimum) and 6.68 % (maximum) were recorded before sowing while 7.78 % (minimum) and 10.89 % maximum were recorded after harvesting. For the upstream, 5.36 % as minimum and 5.91 % as maximum were recorded before sowing while 6.53 % (minimum) and 9.17 % (maximum) were the ESP values after harvesting.

A paired, one-tailed distribution T-Test performed showed very high significant differences in the downstream ($p < 0.004$) and midstream ($p < 0.031$). However, the upstream ($p < 0.074$) did not show significant differences. Thus, the Exchangeable Sodium Percentage for the downstream and midstream were statistically significant while those in the upstream were not significantly different. A soil with an ESP of more than 15 % is classified as sodic soil (Quirk, 2001). This implies that sodium has more than 15 % of the soil's cation exchange capacity (CEC). Based on this classification, the soils in the lowland of Bontanga irrigable area can therefore be classified as non-sodic.

When sodium levels are high, there is competition with calcium, magnesium and potassium for uptake by the roots of plants. Too much sodium, hence, can lead to deficiencies of other cations and thus result in ion toxicity to crops that are sensitive (Akram *et al.,* 2007). High amounts of sodium in a soil can lead to dispersion and therefore has a strong impact on the soil in which it is found (Bleam, 2016).

4.2.4 Soil Organic Carbon

The results for organic carbon content in the lowland soils of Bontanga irrigable area are presented in Figure 4.6.

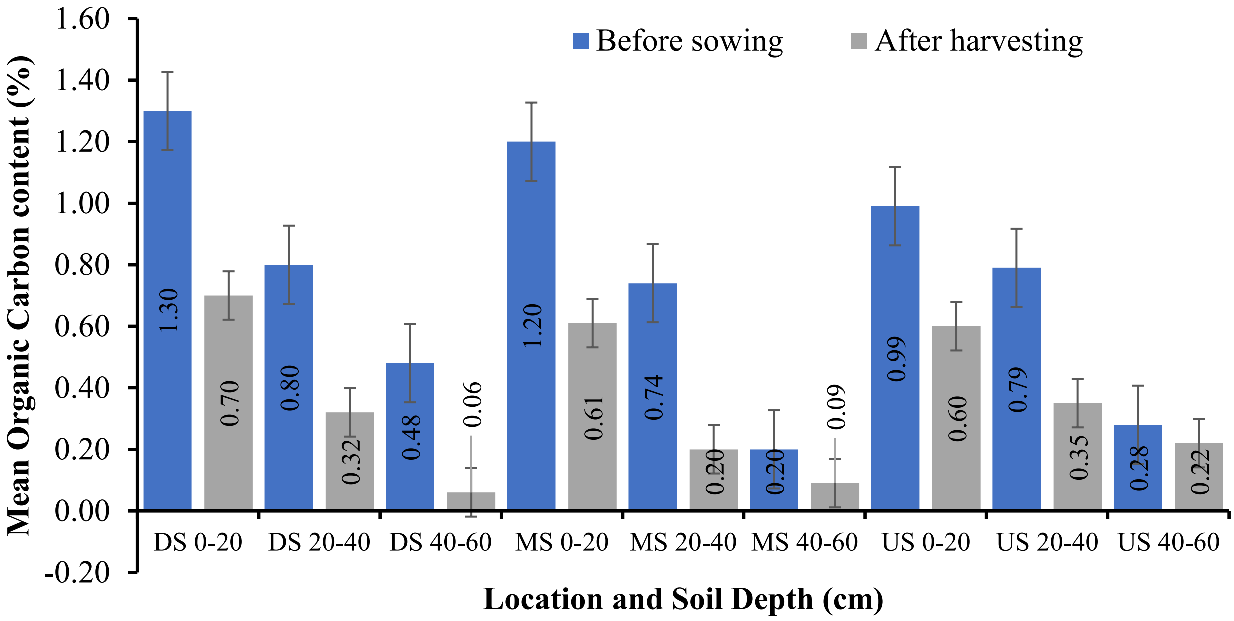

Figure 4.6: Mean Levels of Organic Carbon Content in Lowland Soils of Bontanga Irrigable Area

As presented in Figure 4.6, it was noted that, the SOC varied with soil depth. The soil layer at 0 - 20 cm depth in the downstream has high mean SOC content (1.30 %), followed by 0 – 20 cm depth in the midstream (1.20 %) and 0 – 20 cm depth in the upstream (0.99 %) before sowing. The mean organic carbon content after harvesting decreased to 0.70 % in the soil layer of 0 – 20 cm in the downstream, 0.61 % in the soil layer of 0 – 20 cm in the midstream and 0.60 % in the upstream.

However, the trend in Figure 4.6 shows a decrease in the mean SOC in deeper layers. The results from this study showed a significant difference (p=0.0003) among depths in the various zones. This however, agreed with the findings of Aondoakaa and Agbakwuru (2012) that, the organic carbon levels in all the zones are significantly different from each other and is significantly low compared to the standard organic carbon requirement for rice cultivation stated as 0.20 – 21.0 %.

SOC being the main component of soil organic matter (SOM) and indicators for soil health, plays a significant role in the production of food, mitigation and adaptation to climate change, and the achievement of the Sustainable Development Goals (FAO, 2017). The amount of SOC stored in a given soil is dependent on the equilibrium between the amount of carbon entering the soil and the amount of carbon leaving the soil as carbon-based respiration gases resulting from microbial mineralization and, to a lesser extent, leaching from the soil as dissolved organic carbon (FAO, 2017). Increasing the quantity and quality of soil organic carbon improves soil structure stability, water retention capacity, porosity and soil fertility (Bernoux and Chevallier, 2014).

Jackson (1964) suggested a conversion factor of 1.724 to estimate the soil organic matter from soil organic carbon determination. Using this factor, results of the study showed a decrease in trend in the mean SOM at deeper layers. These findings are aligned with those of Sellathurai *et al.* (2015) who investigated organic matter content of a lowland paddy soil as affected by plant growth and urea fertilization and found that SOM content in paddy field increased from the beginning and decreased after some time of cultivation.

The soils in the lowland of the irrigable area are very low in SOM as compared to the values stated by Aondoakaa and Agbakwuru (2012). This is similar to the findings of Buri *et al.* (2012) that, within the savannah agro-ecology of Ghana, organic matter levels are comparatively lower with general mean levels. Soils containing organic matter have a better structure that improves water infiltration, and reduces the soil's susceptibility to compaction, erosion, desertification and landslides. Maintaining soil organic matter levels and optimizing nutrient cycles are important aspects in ensuring sustainability in the production of agricultural systems.

4.2.6 Total Nitrogen

The results for total nitrogen in the lowland soils of Bontanga irrigable area are presented in Figure 4.7.

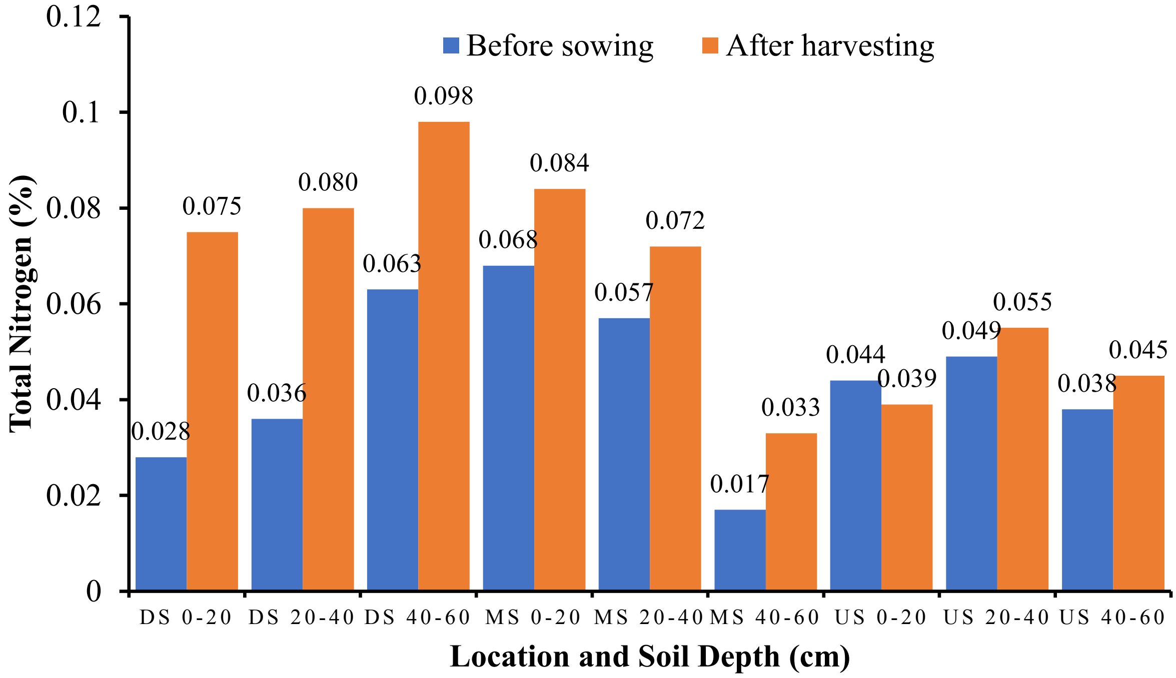

Figure 4.7: Mean Levels of Total Nitrogen in the Lowland Soils of Bontanga Irrigable Area

The minimum and maximum values for mean total nitrogen before sowing was 0.017 % and 0.068 % respectively whilst after harvesting 0.033 % and 0.098 % were recorded as minimum and maximum values respectively. The mean values for total nitrogen in the downstream and midstream showed a significant difference before sowing and after harvesting with $p = 0.003$ and 0.0002 respectively. The upstream however, did not show significant difference ($p = 0.279$).

The results of the findings revealed an increase in the nitrogen content after harvesting. This can be attributed to the application of nitrogenous fertilizers by the farmers during the cropping season. The findings of this study on total nitrogen conforms with those of Buri *et al.* (2012) who indicated that, the savannah zones have much lower levels of total nitrogen with much lower variability compared to other ecological zones. Kunda *et al*. (1996) indicated that, nitrogen is required in substantial amount as a macro-nutrient for quality as well as high yield production of rice. According to Skaggs *et al.* (2012), improvement in water management strategies in paddy fields that are well drained is possible through the implementation of adequate drainage management ensuring a decreasing in drainage intensity and saving irrigation water.

4.2.7 Cation Exchange Capacity

The results for cation exchange capacity (CEC) levels in the lowland soils of Bontanga irrigable area are presented in Figure 4.8.

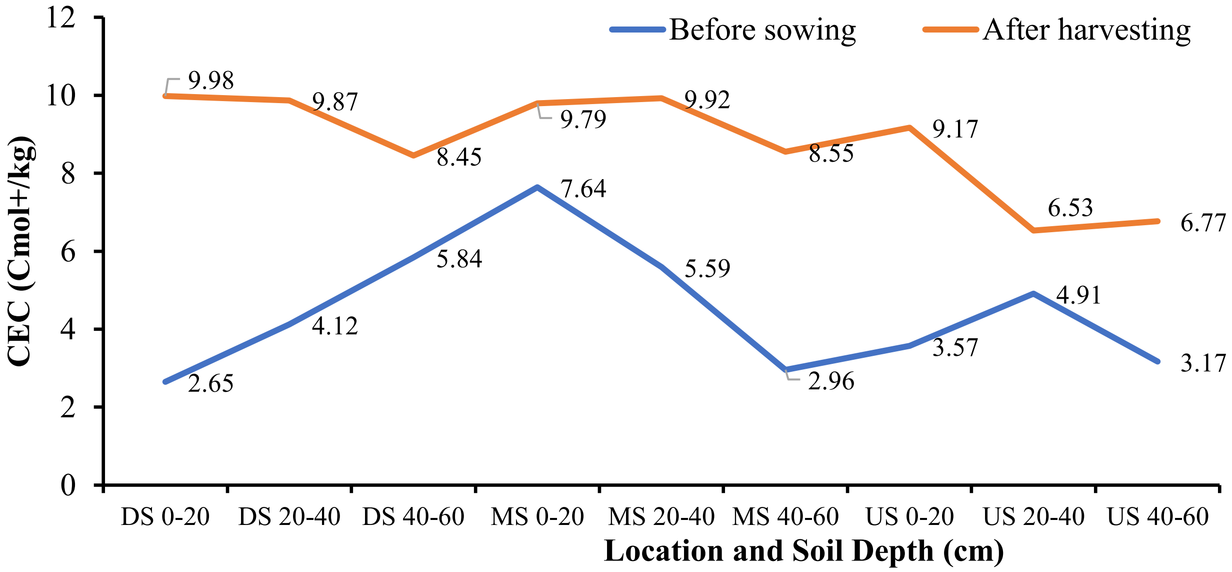

Figure 4.8: Mean Levels of Cation Exchange Capacity in Lowland Soils of Bontanga Irrigable Area

Cation exchange capacity represents the total amount of exchangeable cations that a soil can hold. A T-Test performed on the results of the findings in Figure 4.9 revealed that, the level of the CEC in the downstream, midstream and upstream before sowing have a significant difference ($p = 0.031$), ($p = 0.028$) and ($p = 0.005$) respectively, when compared to the CEC after harvesting but still fall within the range for rice cultivation (2.12 – 11.39 Cmol+/kg) as stated by Aondoakaa and Agbakwuru (2012). CEC is used as a measure of fertility, nutrient retention capacity, and the capacity to protect groundwater from cation contamination (Messiga *et al.,* 2013).

Cation Exchange Capacity (CEC) is also dependent on soil type with respect to the clay type and amount and organic matter content in the soil. As stated by Brady and Weil (2002), the soils in the research area are sandy loam, and are within the range of CEC for sandy loam soils.

The increase in the CEC after harvest can be attributed to the fertilizers applied by the farmers, as this was revealed by the total nitrogen in the soil. Equally, Cakmak *et al.* (2010) reported that, addition of fertilizers to soils influences the chemical composition of soil solution. In their experiment, nitrogen application as calcium ammonium nitrate fertilizer only or in combination with NPK complex fertilizers significantly increased soil CEC. The CEC of a soil is dependent upon the amounts and types of clay minerals and organic matter present. Soils with high CEC will generally have higher levels of clay and organic matter.

4.3 Evaluation of the Drainage System of the Lowland of the Bontanga Irrigable Area

4.3.1 Components of the Drainage System

The components of the drainage system within the right bank canal of the lowland of the Bontanga irrigable area is presented in Figure 4.9.

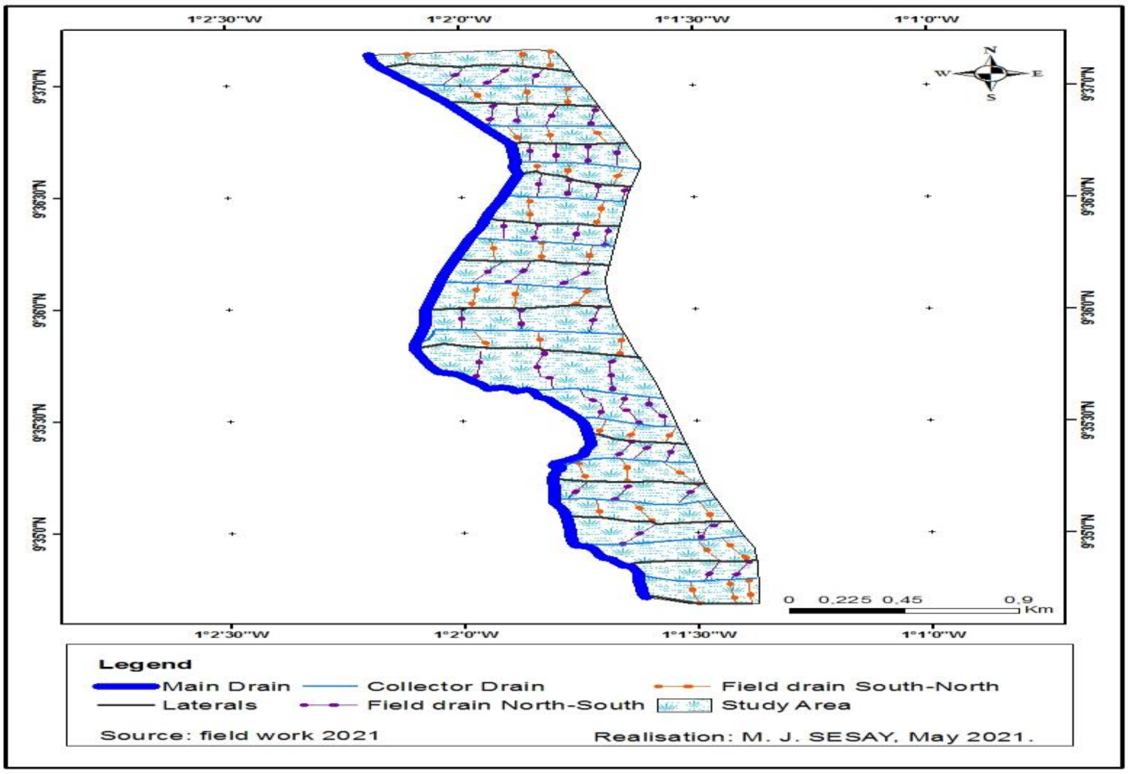

Figure 4.9: Components of the Bontanga Drainage System

The Bontanga irrigation scheme drainage system has a main drain, collector drains that lie between laterals and field drains within the farmers' fields. For a drainage system to orderly and timely remove surplus water from agricultural fields, the surface of the land has to be in a continuous gentle slope in order to maintain an overland flow of water to the collector drains and then to the main drain of the irrigation scheme for disposal. ICID (1982) indicated that, in order to prevent ponding in low areas, surface runoff from fields should be transported through field drains and collector drains towards the drainage outlet of the area.

FAO (1996) described the main drainage system as one that consists of a main drain, lateral or collector drains and field drains.

Observations within the irrigable area of the Bontanga irrigation scheme revealed that, most farmers cultivate in the collector/lateral drains and field drains as shown in Plates 4.1 and 4.2. Farmers who do not cultivate in the drains do not clean them, hence, the weeds obstruct the continuous flow of water within the drains.

Plate 4.1: Condition of Field Drains of Bontanga Irrigation Scheme

Plate 4.2: Condition of Lateral/Collector Drains of Bontanga Irrigation Scheme

4.3.2 Waterlogging Intensity

The waterlogging condition of the study area was monitored for two (2) months (April and May, 2021) during the growing season and the results presented in Figure 4.10. The study found that waterlogging was higher in the downstream with 235.5 cm.days for the month of April while May recorded 240 cm.days. The midstream recorded 210 cm.days for the month of April while the month of May recorded 200 cm.days. The upstream recorded the least values of 155 cm.days for April and 140 cm.days for May.

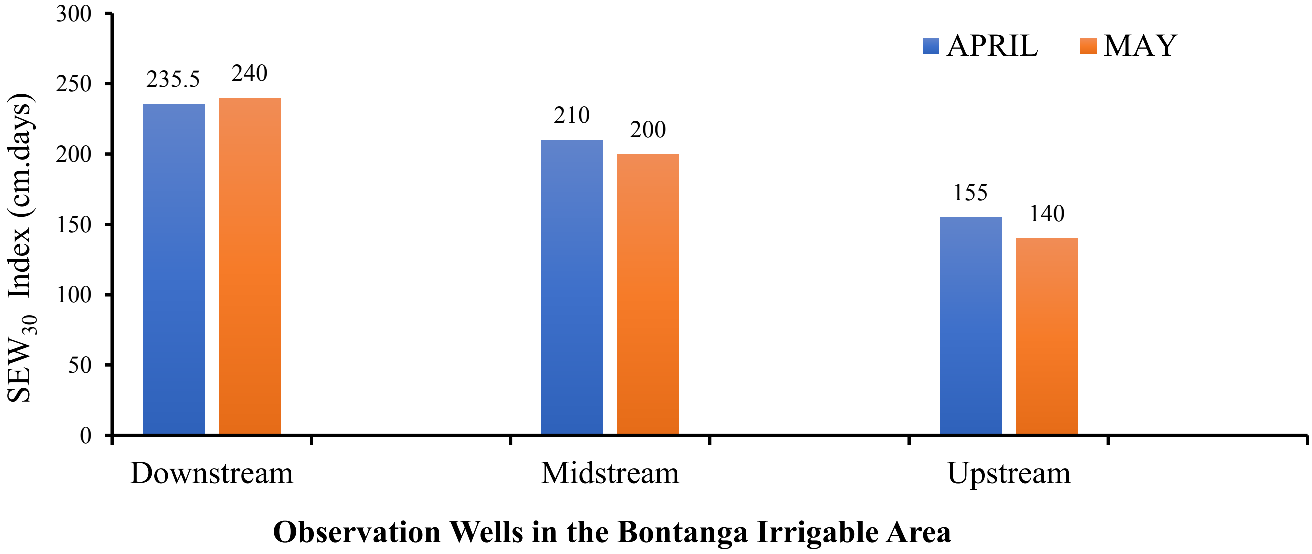

Figure 4.10: Waterlogging Intensity of the Lowland of Bontanga Irrigable Area

Ahmed *et al.* (2013) stated that, SEW_{30} index could be used as a direction on the possible effect of waterlogging on the growth; and development of plant but basic factors such as incidence of waterlogging, levels of nutrients in the soil, degree of salinity in the soil, temperature, flooding, etc. have an impact on the interaction between waterlogging and plant growth. Based on the classification in Table 3.4, the soils in the upstream, midstream and downstream of the study area are in the category of moderately drained. Moore (2001) remarked that; tolerance of plants to salinity is reduced when the plants are concurrently stressed by waterlogging. Some of the many effects of waterlogging on the growth of crops is such that, under saline conditions, waterlogging hinders the ability of roots to screen out salt at the root surface and continuous flooding of water in rice fields promotes anaerobic conditions that will negatively affect the environment by releasing greenhouse gas emissions particularly, methane (CH_4). (USDA – NRCS, 2003).

4.3.3 Relative Change of Depth of Groundwater

Weekly recordings of water table depths from April to June 2021 were done from the observation wells being installed in the study area. The results in Figure 4.11 indicated that, the water table fluctuated with time due to the basin irrigation system being practiced. The findings agreed with Yang *et al.* (2007) who reported that, due to the practice of continuous flooding, large amounts of percolating water have raised the shallow groundwater tables close to the surface. This condition is true in soils with heavy texture and poor subsoil drainage and in traditional irrigated rice fields where rice is grown under continuous flooded condition.

Most of the readings of the observation wells have fluctuated in a cyclical manner that can be correlated mainly with the irrigation events and partially with the precipitation that occurred during the growing season. The mean water table was 16.94 cm during April and 17.18 cm during May for the downstream, while the midstream recorded a mean of 20.33 cm during April and 20.26 cm during May. The upstream recorded a mean of 24.28 cm in April and 24.65 cm in May. The statistical summary of the daily water table depth is shown in Figure 4.12.

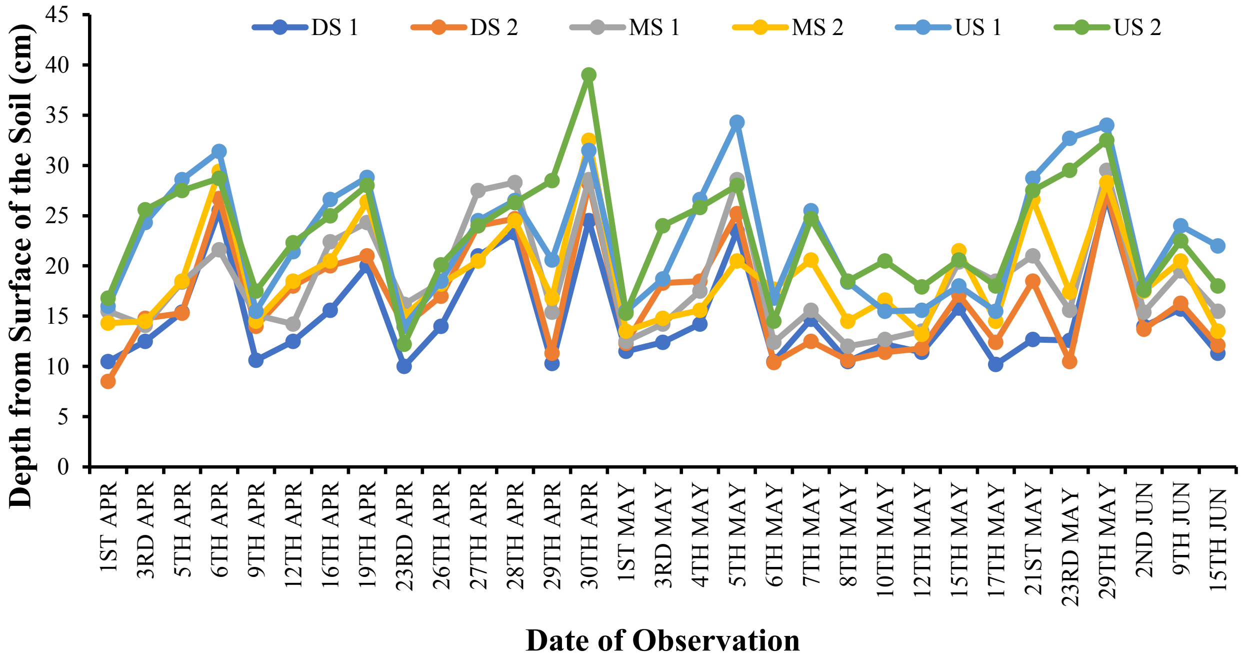

Figure 4.11: Watertable Fluctuations with Time

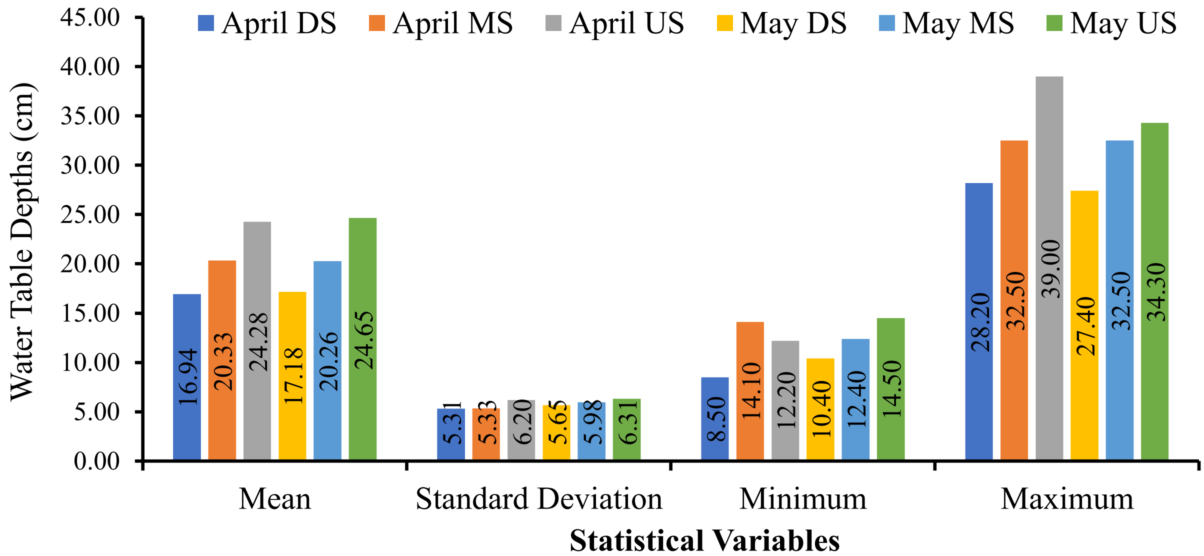

Figure 4.12: Statistical Summary of Water Table Depths (cm) in Lowland of the Bontanga Irrigable Area

4.4 Drainage Coefficients of the Lowlands of the Bontanga Irrigable Area

4.4.1 Input Parameters of the Water Balance Method

The water balance method used in the computation of drainage coefficients has its major input parameters as soil characteristics, peak evapotranspiration of the crop, amount of irrigation water applied, rainfall, readily available moisture, shortest irrigation interval, seepage and percolation (FAO, 2002).

4.4.1.1 Irrigable Area Soil Characteristics

Soil characteristics results are presented in Table 4.4.

Table 4.4: Soil Characteristics for Paddy Fields at Bontanga Irrigation Scheme

Location	Bulk Density (g/cm^3)	Saturation (%)	FC (%)	PWP (%)	RZD (mm)
Upstream	1.47	44.1	15.7	6.9	300
Midstream	1.40	44.1	15.9	7.2	300
Downstream	1.32	44.3	16.6	7.5	300

FC = Field Capacity; PWP = Permanent Wilting Point; RZD = Root zone depth

Bulk densities for upstream, midstream and downstream were 1.47, 1.40 and 1.32 g/cm^3 respectively. Yimer *et al.* (2008) stated that, higher bulk density decreases the pore volume as a result of soil compaction and trampling by humans coupled with a decline of the soil organic carbon content at the upper horizon. The water content at saturation for both the upstream and midstream were 44.1 %, while that of the downstream was 44.3 %. The field capacity was 15.7 % for the upstream, 15.9 % for the midstream and 16.6 % for the downstream. The permanent wilting point for the upstream, midstream and downstream were 6.9, 7.2 and 7.5 % respectively. The root zone depth was considered as 300 mm for rice based on FAO (1998) and 20 % management allowable depletion was also considered as adopted by Allen *et al.* (1998). The results of the water content at saturation were similar to the findings of Abdul-Ganiyu *et al.* (2015) who in their findings recorded water saturation of 33.6 - 45.4 %. Since the estimation of the drainage coefficient for the scheme for the months of April and May was based on farmers practice, water content at saturation was taken to be the upper limit in the simulation of the readily available moisture (RAM) with a 20 % depletion factor. Rice in lowland is extremely sensitive to the shortage of water and because of this, farmers would want to see water in their fields at all times to avoid the effects that will occur when soil water content drops below saturation.

4.4.1.2 Peak Evapotranspiration for Rice

The peak evapotranspiration for rice for the month of June was computed as 3.64 mm day^{-1}. Peak potential crop evapotranspiration of rice for the months of March, April and May have been computed by Sadick *et al.* (2014) and June ET_c estimated to be 3.64 mm day^{-1}. FAO (2005) referred to potential evapotranspiration (ETc) as the amount of water that is lost through the evaporation process from disease-free and well-fertilized crop field. The values of ETc from different crops differ as the ground cover, canopy properties and aerodynamic resistance of crops are different from one another.

4.4.1.3 Amount of Irrigation Water Applied

The amount of water applied during the months of April, May and the entire season by individual farmers was recorded and presented in Tables 4.5a, 4.5b and 4.5c respectively.

Table 4.5a: Irrigation Water Applied per Farmer for the Month of April

Amount of Water per Irrigation (m^3)	Number of Irrigation Events	Amount of Water per Farmer (m^3)	Area of Land (ha)	Total Amount of Water per Farmer ($m^3\ ha^{-1}$)
1344.00	5	6720.00	0.61	11070.08
1296.00	5	6480.00	0.57	11437.20
1536.00	6	9216.00	0.59	15705.34
1488.00	5	7440.00	0.61	12256.16
1094.40	6	6566.40	0.81	8112.79
1036.80	6	6220.80	0.61	10247.73
Mean				**11471.55**

Table 4.5b: Irrigation Water Applied per Farmer for the Month of May

Amount of Water per Irrigation (m^3)	Number of Irrigation Events	Amount of Water per Farmer (m^3)	Area of Land (ha)	Total Amount of Water per Farmer ($m^3\ ha^{-1}$)
1344.00	6	8064.00	0.61	13284.10
1296.00	5	6480.00	0.57	11437.20
1536.00	6	9216.00	0.59	15705.34
1488.00	5	7440.00	0.61	12256.16
1094.40	6	6566.40	0.81	8112.79
1036.80	6	6220.80	0.61	10247.73
Mean				**11840.55**

Table 4.5c: Irrigation Water Applied per Farmer for the Entire Season

Amount of Water per Irrigation (m^3)	Number of Irrigation Events	Amount of Water per Farmer (m^3)	Area of Land (ha)	Total Amount of Water per Farmer (m^3 ha^{-1})
1344.00	16	21504.00	0.61	35424.26
1296.00	14	18144.00	0.57	32024.16
1536.00	15	23040.00	0.59	39263.34
1488.00	15	22320.00	0.61	36768.48
1094.40	18	19699.20	0.81	24338.36
1036.80	16	16588.80	0.61	27327.28
Mean				**32524.1**

From Table 4.5 a, b and c, the mean volume of water applied by the six (6) selected farmers was 11471.55 m^3 ha^{-1} (1147.155 mm) for the month of April and 11840.55 m^3 ha^{-1} (1184.055mm) for the month of May. However, the mean amount of irrigation water applied for the season was 32524.1 m^3 ha^{-1} (3252.41 mm).

The results of the findings are in conformity to an on-farm experiment conducted by Abdul-Ganiyu *et al.* (2015) on the evaluation of economic water productivity and water balance of dry season irrigated rice under different irrigation regimes who recorded 32409.7 m^3 ha^{-1} for total water applied under continuous flooding.

4.4.1.4 Readily Available Moisture, Monthly Peak Evapotranspiration and Shortest Irrigation Interval

Readily available moisture, peak evapotranspiration and shortest irrigation interval for the months of April and May are presented in Table 4.6.

Table 4.6: Readily Available Moisture, Monthly Peak Evapotranspiration and Shortest Irrigation Interval

Location	RAM (mm)	April ET_c ($mm.month^{-1}$)	May ET_c ($mm.month^{-1}$)	SII_April (days)	SII_May (days)
Downstream	869.62	166.8	156.9	5.2	5.5
Midstream	929.88	166.8	156.9	5.6	5.9
Upstream	984.31	166.8	156.9	5.9	6.3

4.4.1.5 Rainfall, Crop Water Requirement, Seepage and Percolation

Total amount of water from irrigation was 1147.55 and 1184.05 mm for the months of April and May respectively. Rainfall for April was 42.1 mm and 43.6 mm for May. Seepage and percolation were the same for April and May (993 mm $month^{-1}$). Crop water requirement for April was 166.8 mm $month^{-1}$ for April and 156.9 mm. $month^{-1}$ for May. Total water into the drains was 29.85 mm for April and 77.75 mm for May.

4.4.2 Estimated Drainage Coefficients

Drainage coefficients for the months of April and May were estimated as in Table 4.7.

Table 4.7: Estimated Drainage Coefficients for the Months of April and May

Location	Drainage Coefficient (mm day^{-1})	
	April	May
Upstream	5.1	12.4
Midstream	5.4	13.1
Downstream	5.7	14.0

The drainage coefficient for April was 5.1 mm day^{-1} for upstream, 5.4 mm day^{-1} for midstream and 5.7 mm day^{-1} for the downstream. During the month of May, drainage coefficient for the upstream was 12.4 mm day^{-1}, 13.1 mm day^{-1} for the midstream and 14.0 mm day^{-1} for the downstream. The differences in drainage coefficients could be attributed to the uncontrolled manner in which individual farmers apply water to their farmlands, the difference in rainfall intensity within the months (as inflows) and the difference in the peak evapotranspiration of rice (as outflow) for the two months.

Murty and Jha (2009) defines drainage coefficient as the volume of excess water that should be eliminated from an area of production in 24 hours so that surplus water will not cause the crops to be stressed. Therefore, the determination of drainage coefficients is important as it determines the capacity of the drainage system entirely and ensure accurate application of field water balance. Crops can grow well and produce yields when they are properly aerated or are in well-drained root zone environment. When crops are allowed to grow in a waterlogged/ponded soil, suffocation of roots will occur and they will be unable to take in nutrient in the form of solutions from the soil. Murty and Jha (2009) stated that, the drainage coefficients for any place differs due to geographical locations, landuse, sizes of area, irrigation/rainfall intensity, frequency and duration and other climatic factors.

Paswan *et al.* (2018) stated that, in India, the design drainage rate for surface drainage is usually taken as an approximate value of 9.3 mm day^{-1} of agricultural watersheds of various command areas.

4.5 Farmers Perception on the Need and Benefits of Drainage in the Bontanga Irrigation Scheme

4.5.1 Socio-demographic Characteristics of Farmers in the Bontanga Irrigation Scheme

The socio-demographic characteristics of the farmers in the Bontanga irrigation scheme are presented in Figure 4.13. This includes distribution of gender, age, educational level, marital status, farming experience and farm size of the respondents. The results revealed that, 87.7 % of the farmers in the scheme were men while 12.3 % were women. The mean age of the farmers was 51 years with a standard deviation of 11. 0. Studies have revealed that women are more productive than men especially, when they all have equal access to resources (Njuki *et al.,* 2006). Similarly, FAO State of Food and Agriculture Report in 2010–2011 emphasized that if women are given equal opportunities to productive resources as men, would have a 20 – 30 % improvement of yields on their farms thereby increasing the total agricultural output in developing countries by 2.5 – 4 %.

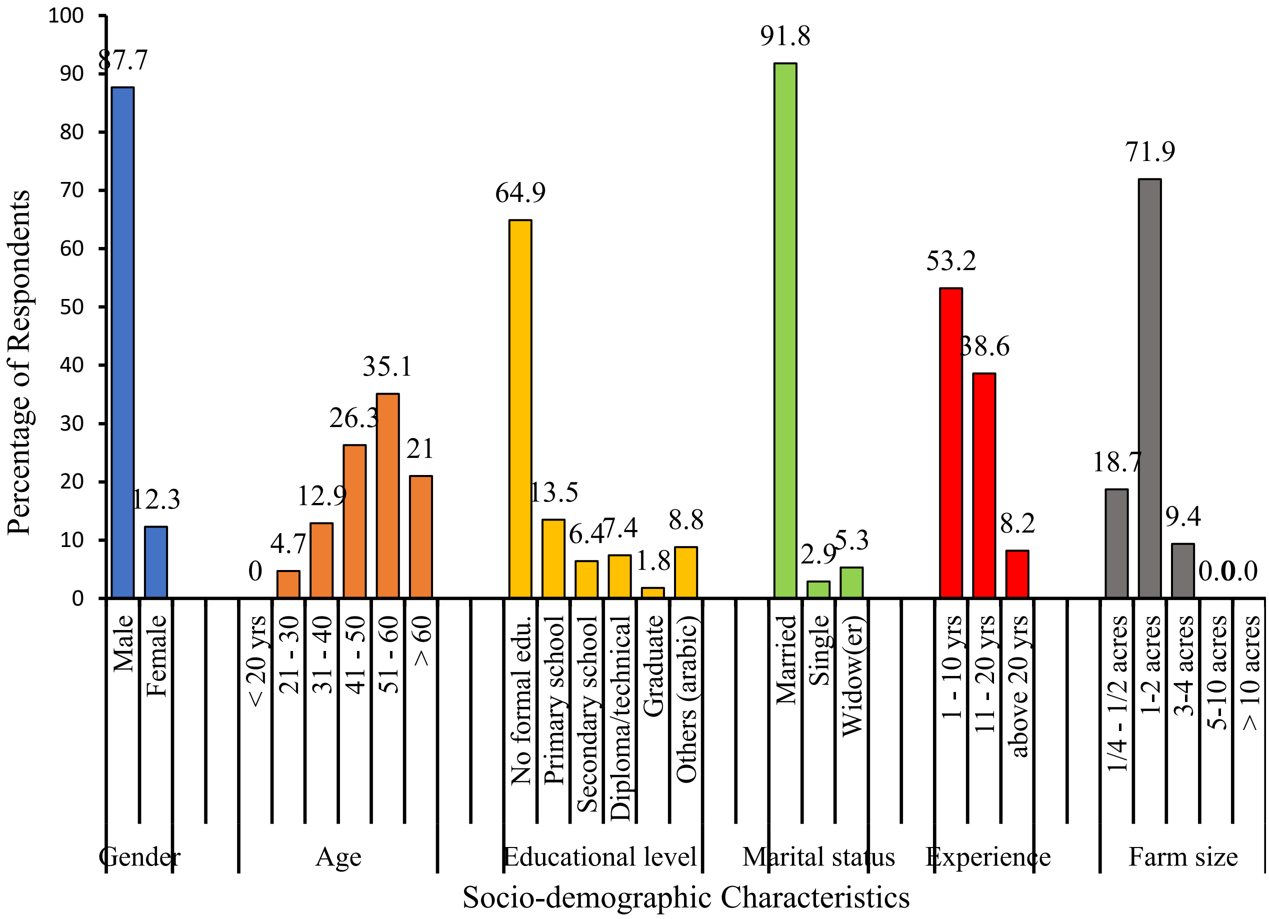

Figure 4.13: Socio-demographic Characteristics of Farmers in the Bontanga Irrigation Scheme

Access and control of land and water resources by women is very important in every society. El Kady *et al.* (2004) stated that, women role in water management and irrigation in most African and Asian countries is seemingly low because, women experience with water has been perceived as being limited to household usage.

From Figure 4.13, majority (79 %) of the working population are within the economically active working age category of 21 – 60 years, while 21 % are over 60 years. Adongo *et al.* (2015) revealed a similar trend though, there was a decrease in the number of farmers within this age range. FAO (1998) noted the active age of farmers to be between 40 to 50 years, suggesting that respondents are relatively young and active farmers. Oguoma (2003) also found out that, 75 % of the farmers were in the age bracket of 45 – 50years.

About 64.9 % of the farmers had no formal education, 13.5 % had primary education, 6.4 % had secondary education, 7.4 % had diploma or technical certificate, 1.8 % had first degree and 8.8 % had Arabic education. Several studies have been conducted relating education to agricultural productivity and results have shown that there is a strong relationship between the two (Weir, 1999; Asadullah and Rahman, 2009). Gasperini (2000) noted in a survey conducted by the World Bank in 1992 that farmers who had basic education were 8.7 % more productive than farmers with no education.

91.8 % of the farmers were married with 2.9 % being single and 5.3 % being widow or widower. The mean farm experience of respondents was 11 years with a standard deviation of 6.4. The average farm size of farmers at the scheme was 0.99 acres with 71.9 % having farm sizes ranging from 1 – 2 acres.

4.5.2 Farmers' Attitude, Need and Benefits of Drainage in the Bontanga Irrigation Scheme

The perception of farmers towards drainage in the Bontanga irrigation scheme is as presented in Table 4.8a.

Table 4.8a: Perception of Farmers Towards Drainage in the Bontanga Irrigation Scheme

Variable	Response	Frequency	Percentage
Any idea on drainage	- Yes	100	58.5
	- No	71	41.5
Cultivating in the drains	- Yes	149	81.9
	- No	22	18.1
Importance of drainage	- Yes	128	74.9
	- No	43	25.1
Reasons for cultivating in the drains	- For effective weed control	56	40
	- Adding to farm size	84	60
Role of WUA in drainage management	- WUA gives supervision during the process	23	13.5
	- WUA provides labour during the process	0	0.0
	- WUA provides incentives to farmers	0	0.0
	- Others (cleaning of lateral drains)	108	63.2
	- Don't know	40	23.4
Effectiveness of WUA in drainage management	- Not effective	92	53.8
	- Effective	77	45.0
	- Very effective	2	1.2
Existence of laws on drainage management	- Yes	92	55.6
	- No	77	0.0
	- Don't know	2	44.4

From Table 4.8a, 58.5 % of the farmers had an idea of drainage while 41.5 % said they had no idea on drainage. 81.9 % of the farmers cultivated in the drains while 18.1 % were not involved in such practices. Of those who cultivated in the drains, 60 % did so in order to add to their farm size, while 40 % did so to be effective in cleaning the drains. The farmers indicated that, cleaning the drains while there is no crop cultivated in it is time wasting and would not be productive to them. 74.9 % of the farmers perceived drainage to be important in their farming system, while 25.1 % viewed drainage as not being important in crop production. Shahroudi and Chizari (2006) noted that farmers' attitude due to lack of knowledge and skills on the application of sound agricultural water management practices can be blamed for inadequate irrigation and drainage management. Careful management and efficient use of water is crucial component of any irrigation and drainage project and therefore appropriate actions have to be put in place for appropriate management of resources in agriculture which includes soil and water.

The role that is mostly played by Water Users Associations (WUAs) in the scheme is cleaning of lateral drains with a percentage of 63.2 % followed by supervision of farmers in cleaning of their field drains with 13.5 %. However, 23.4 % of the farmers stated that, they did not even know the role of WUAs in the management of drainage system. 53.8 % of the farmers said the WUAs were ineffective in performing their roles in relation to drainage system management, 45 % said they were effective while 1.2 % noted they were very effective.

Rogers and Hall (2003) stated that, in order to achieve and sustain effective water governance in agricultural sector, certain key principles such as the involvement of key stakeholders in the governance of the system at relevant levels should be done; and achieving this requires the institutional and policy environments to facilitate the necessary levels of participation.

It is worth noting that, the WUA within the scheme was formed just a year ago, which means, WUAs are still in their early stages and therefore, their impact or benefits may not be so visible. Most of the farmers (55.6 %) in the scheme were aware of the existence of laws pertaining to the management of the drainage system, while 44.4 % indicated that, they were not aware of the existence of any law within the scheme regarding drainage system.

The results in Table 4.8b indicated that, 69.6 % of farmers who cleaned their field drains only did that before cultivation, 29.8 % cleaned their drains 1 – 3 times during the cropping season, while 0.6 % cleaned 4 – 6 times during the cropping season. 56.1 % of the farmers used family labour during the cleaning exercise, 40.4 % used hired labour, 2.3 % asked their colleague farmers to help, while 1.2 % invited friends to help with the cleaning. However, 53.8 % spent no money during the process of cleaning the drains, while those who paid for hired labour spent < 100 Ghana Cedis (GHS). This adds up to the cost of production and could be viewed as a reason why farmers were not maintaining their drains as expected.

Table 4.8b: Perception of Farmers Towards Drainage in the Bontanga Irrigation Scheme

Variable	Response	Frequency	Percentage (%)
Cleaning of drains	Only before cultivation	119	69.6
	1 - 3 times during the season	51	29.8
	4 - 6 times during season	1	0.6
	Don't clean	0	0.0
Labour for cleaning drains	Family	96	56.1
	Friends	2	1.2
	Hired	69	40.4
	Colleague farmers	4	2.3
	Others	0	0.0
Expenditure for cleaning of drains	< 100 GHS	79	46.2
	101 - 200 GHS	0	0.0
	> 200 GHS	0	0.0
	0 GHS	92	53.8

73.1 % of the farmers perceived drainage to be beneficial in improving workability, 72.5 % believed that, with good drainage system and practices, losses during harvest will be minimized and hence will lead to increase in crop yields. However, 47.4 % believed proper drainage helps remove toxic substances (salts) from the soil, 46.8 % perceived drainage to be important in improving soil structure and infiltration while 5.8 % indicated that it increases microbial decomposition.

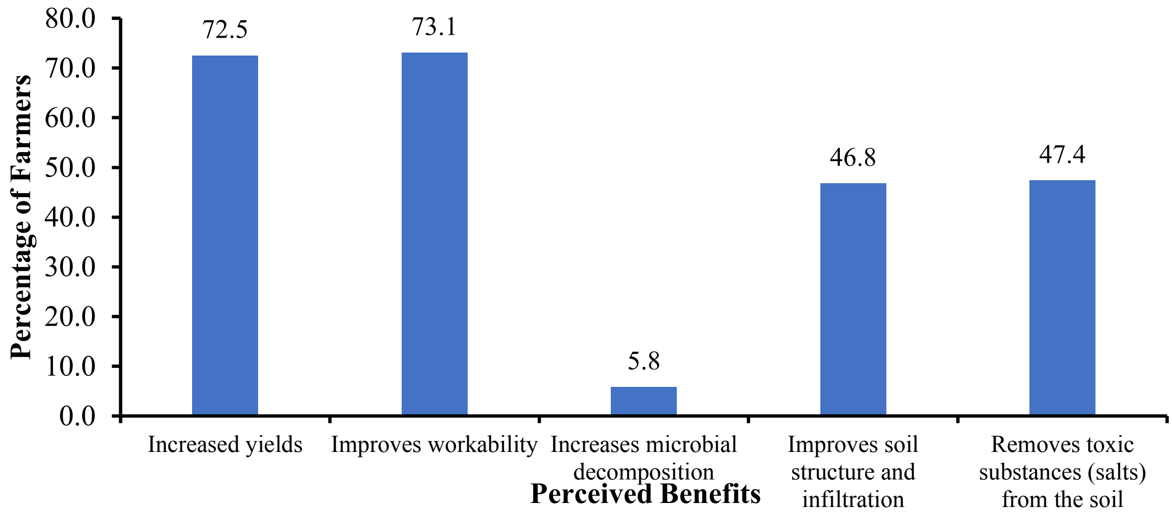

Figure 4.14: Percentage of Perceived Benefits of Drainage by Farmers

4.5.3 Farmers' Perception on the Consequences of Drainage on Rice Production

Depending on farmers' perception (Table 4.9) relating to the consequences of drainage in the study area, waterlogging/ponding recorded the highest Problem Confrontation Index (PCI) (468) indicating high perception and therefore was ranked as 1^{st}. Reduced yields was ranked 2^{nd} with a PCI value of 364, inadequate drainage makes work difficult was 3^{rd} with a PCI value of 300. Drainage problems increased cost of production was 4^{th} and saline sodic soils resulting from inadequate drainage was ranked 5^{th}.

Table 4.9: Farmers' Perception on the Consequences of Drainage on Rice Production

Constraints	Very Serious Problem	Serious Problem	Problem	No Problem	PCI	Rank
Reduce yields	91	35	21	24	364	2
Saline/Sodic soils	6	21	115	29	175	5
Drainage problems make work difficult	8	114	48	1	300	3
Drainage problems contribute to increase cost of production	8	86	67	10	263	4
Ponding/ Waterlogging	137	26	5	3	468	1

The results of the study are in line with Kassa *et al*. (2013), who stated that, farmers perceptions on drainage problems are serious in finding solutions to problems of soil and water management. Measures that will safeguard the farmers' production within a particular location could best be achieved when a clear understanding of their perception on the consequences of poor drainage system have been looked at. Any intervention that takes into consideration environmental conservation should use the perception of farmers as a good point of entry and should endeavour to either change their perception through field demonstration or by investing on what they already know (Wickham *et al.,* 2006).

Table 4.10: Farmers' Perception on Factors Contributing to Salinity, Sodicity and Waterlogging/ Ponding

Constraints	Very Serious Problem	Serious Problem	Problem	No Problem	PCI	Rank
Poor drainage system	127	37	0	7	455	1
Poor land preparation	0	12	97	62	121	3
Poor quality of irrigation water	0	2	42	127	46	4
Wrong use of fertilizers	9	129	27	6	312	2

Farmers' perception on factors contributing to salinity, sodicity and waterlogging/ponding as presented in Table 4.10 revealed very high PCI value for poor drainage system, making it 1st among the factors contributing to salinity, sodicity and waterlogging/ponding. Wrong use of fertilizers with a PCI value of 312 was ranked 2nd; poor land preparation with PCI value of 121 was 3rd, while poor quality of irrigation water was ranked 4th with a PCI value of 46. Farmers were satisfied with the quality of irrigation water being provided to them by the irrigation system.

According to Zaman *et al.* (2018), most significant guideline on water quality for crop production is the salinity of water which is being measured using electrical conductivity (EC_w); and a value of ≤ 0.75 dS/m is considered suitable for crop production. Kashenge-Killenga (2010) stated that, most irrigation schemes in arid and semiarid regions are already facing increasing levels of soil salinity, sodicity and waterlogging mainly due to improper management of the soils, poor drainage system, poor quality irrigation water, excessive use of irrigation water, poorly designed and managed irrigation infrastructures, and climate change. Dolo *et al.* (2017) suggested that, farmers' perception on factors contributing to salinity, sodicity and waterlogging/ponding are based on the knowledge they have on these factors and the effect on their crops.

4.5.4 Sources of Information by Farmers on Drainage Problems in the Bontanga Irrigation Scheme

The results on farmers' sources of information on drainage issues in the Bontanga irrigation scheme are presented in Figure 4.15.

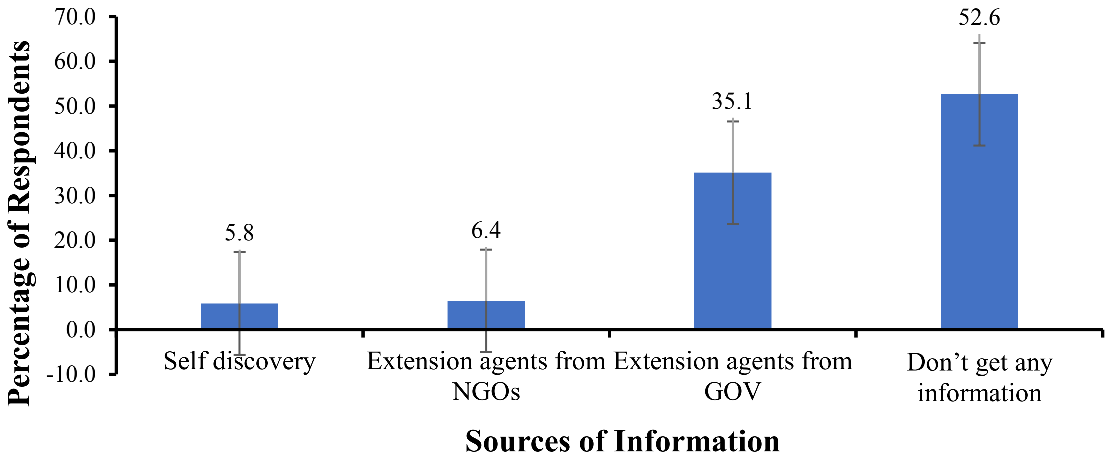

Figure 4.15: Farmers’ Sources of Information on Drainage Problems in the Bontanga Irrigation Scheme

It is worth noting that, most farmers do not have access to information on drainage problems within the scheme. From Figure 4.15, 52.6 % of farmers were not accessing information, 35.1 % obtain information through extension agents from government agencies, 6.4 % obtained information through extension agents from Non-Governmental Organizations while 5.8 % have no source of information.

Information is very vital towards improving productivity by farmers and lack of it on modern and efficient agricultural practices which includes drainage system management would bring about low farm productivity. Munyua (2000) stated that, rural farmers need information on environmental sound production techniques which includes drainage, agricultural inputs, market prices, new agricultural technologies, food processing and preservation, decision making as well as early warning systems to achieve maximum yield in agricultural production.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The study assessed the drainage system in the lowland of Bontanga irrigation scheme in Ghana. Specifically, it characterized the physico-chemical and hydraulic properties of the soils, assessed the drainage system using performance indicators, determined the drainage coefficients for the upstream, midstream and downstream and examine famers perception on the need, benefits and problems of drainage within the scheme.

From the study, it was found out that, the soils showed variations in their physical and chemical properties before sowing and after harvesting. Hydraulic conductivity and infiltration values were within the recommended values for sandy loam soils. Soil bulk density, electrical conductivity, exchangeable sodium percentage, total nitrogen and cation exchange capacity were observed to have a slight increase after harvesting. The soil pH, organic carbon and organic matter however were realised to decrease after harvesting. Farmers' practice of not embarking on adequate drainage might have influenced the changes in the physico-chemical and hydraulic properties of the soils.

It was also revealed that the drainage system design of the scheme has the various components as prescribed from standard literature. However, it was observed that, the farmers pay less attention to the drainage system management, as most of them did cultivate in the drains or did not embark on cleaning them. The salinity and sodicity of the soil were within the threshold for crop production although there has been an increase with time. If proper management decisions are not taken on the use of water, and proper drainage practices are not enforced, there is tendency of salinisation of the soils within the scheme in the near future. From the results of the SEW_{30} index, the waterlogging condition of the study area during the study period was classified as moderately drained. Water table was observed to fluctuate with respect to irrigation periods and most times is within the 30 cm layer of the soil.

Drainage coefficients (DC) for the upstream, midstream and downstream of the scheme were estimated. From the results, it was observed that the drainage coefficients vary based on the amount of water used by the farmer, the rainfall event and crop evapotranspiration for a particular month. For the month of April, DC was 5.1 mm day^{-1} for upstream, 5.4 mm day^{-1} for the midstream and 5.7 mm day^{-1} for the downstream. For the month of May, DC was 12.4 mm day^{-1} for the upstream, 13.1 mm day^{-1} for the midstream and 14.0 mm day^{-1} for the downstream.

Most of the farmers in the scheme were in the category of economically active working age (21 – 60 years) with majority of them (64.9 %) having no formal education. Farmers defined their perception on factors contributing to salinity, sodicity and waterlogging/ponding depending on the knowledge they have on those factors and the effect on crop productivity. From the study, farmers perceived poor drainage to be the major factor contributing to salinity, sodicity and waterlogging/ponding. From the farmers' perception on the consequences of drainage in the area of study, waterlogging/ponding got the highest PCI value of 468. It was revealed from the study that, most of the farmers did not have access to information on drainage.

5.2 Recommendations for Policy

From the findings of this study, the following recommendations are made:

1. Proper management actions should be put in place in order to avert the incidences of salinisation within the scheme.
2. Provision of flow meters by government of Ghana through GIDA to farmers to enable them control the amount of water being used for irrigation.
3. The use of farmer field schools and/or innovation platforms should be utilized in the sensitization of farmers on drainage best practices
4. GIDA should collaborate with the WUAs to enforce bye laws prohibiting the cultivation in the drains and ensuring that every farmer maintains the drains by carrying out proper cleaning.
5. WUAs should be encouraged to undertake regular monitoring and supervision of farmers to ensure compliance with drainage system management.
6. Government of Ghana through GIDA should ensure equal or parallel investment of resources in drainage projects jointly with irrigation.
7. GIDA as a management body for the irrigation scheme should ensure the involvement of drainage system management issues in their outreach programmes
8. Training programmes should ensure the involvement of women farmers as beneficiaries to equip them with knowledge on water management strategies.
9. GIDA should continuously embark on site-specific investigations of drainage problems in order to inform actions, interventions and strategies within the irrigation schemes of Ghana.

5.3 Recommendations for Future Research

1. Assessment of the intensity of waterlogging, salinity and sodicity in the Bontanga irrigation scheme under rainfed cultivation.
2. Investigating the design criteria using appropriate drainage models and cost-benefit analysis of sub-surface drainage system in Ghana.
3. Use of remote sensing to map out saline, sodic and waterlogged soils in the scheme and compare with observed data.
4. Assessment of the performance of drainage system in other irrigation schemes in Ghana using drainage performance indicators.

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APPENDIX

Research Questionnaire on "Assessing Farmers' Perception on the Need, Benefits and Problems of Drainage in the Bontanga Irrigation Scheme"

Section A: Socio-demographic Information of Respondents

1. Name of Respondent: -- Date:-------------

2. Sex: M [ ] F [ ]

3. Age: < 20 Years [ ] 21-30 [ ] 31-40 [ ] 41-50 [ ] 51-60 [ ] > 60 [ ]

4. Educational level: No formal education [ ] Primary school [ ] Secondary school [ ] Diploma/Technical certificate [ ] Graduate [ ] Others: (Please specify)-----------

5. Marital status: Married [ ] Single [ ] Widow/Widower [ ]

6. Years of Experience: 1 – 10 years [ ] 11 – 20 years [ ] Above 20 years

7. How many acres of land do you hold within the irrigation scheme? < ¼ acre [ ]

¼ acre [ ] 1 acre [ ] 2 acres [ ] 3 acres [ ] 4 acres [ ] 5 - 1 0 acres [ ] >10 acres [ ]

8. What crops do you grow? Rice [ ] Okra [ ] Pepper [ ] Other (s): -------------------

Section B: Farmers' attitude, Need and Benefit of Drainage

9. Do you have an idea of drainage system? Yes [ ] No [ ]

10. Do you practice drainage in your farm? Yes [ ] No [ ]

11. What time during crop cultivation do you drain your farm?

[ ] Before fertilizer/chemical application [ ] After excessive irrigation/rainfall event

[ ] Before land preparation [ ] Before harvest [ ] Don't drain

12a. Do you cultivate in the drains? Yes [ ] No [ ]

12b. If yes, why do you engage in such practice

13a. In your own opinion, do you think drainage is important for crop production? Yes [ ] No [ ]

13b. If yes, what are some of the benefits of drainage? (Tick all that applies)

[ ] Increased yields

[ ] Improves workability

[ ] Increases microbial decomposition

[ ] Improves soil structure and infiltration

[ ] Removes toxic substances (salts) from the soil

[ ] Others (Please specify): --

13c. If no, why do you think drainage is not important

[ ] Increases cost of production

[ ] Time wasting

[ ] Accelerates loss of soil organic matter

[ ] Less groundwater recharge

[ ] Others (Please specify)--

Section C: Management of the Drainage System

14. Is there a WUA in the scheme? Yes [ ]   No [ ]

15. How effective is the WUA in water management issues and the control of drainage?

Not effective [ ] Effective [ ]   Very effective [ ]

16. Are there existing laws on drainage within the scheme

Yes [ ]   No [ ]   Don’t know [ ]

If yes, what are the specific laws

----

17. What is the role of WUA in the maintenance of drains?

[ ] WUA gives supervision during the process

[ ] WUA provides labour during the process

[ ] WUA provides incentives to farmers

[ ] Others (Please specify) ---

18. How often do you clean and maintain the drains?

[ ] Only before cultivation   [ ] 1 – 3 times during the season

[ ] 4 – 6 times during season   [ ]Don't clean

19. How do you get labour for the cleaning of your drains?

[ ] Family labour

[ ] Friends

[ ] Hired labour

[ ] Colleague farmers

[ ] Others (Please specify) ---

20. Approximately, how much do you spend in the cleaning and maintenance of your drains?

[ ] < 100 GHS

[ ] 100 – 200 GHS

[ ] > 200 GHS

Section D: Farmers' perceptions on the consequences of drainage (Salinity, sodicity and waterlogging/ ponding) affecting rice farming.

21. In the table below, please tick in the box the most appropriate that describes the situation

Constraints	Ranking				
	Very serious problem	Serious Problem	Problem	No Problem	Don't Know
Poor yields					
Saline/ sodic soils					
Drainage problems make work difficult					
Drainage problems contribute to increase cost of production					
Ponding / waterlogging					

Farmers' Perceptions on factors contributing to salinity, sodicity and waterlogging/ponding

22. In the table below, please tick in the box the most appropriate that describes the situation

Constraints	Ranking				
	Very serious problem	Serious Problem	Problem	No Problem	Don't Know
Poor drainage system					
Poor land preparation					
Poor quality of irrigation water					
Wrong use of fertilizers					

Farmers' sources of information on drainage problems (salinity, sodicity and waterlogging/ponding)

23. How do you get information pertaining to the control of drainage problems in your farm?

[ ] Self-discovery

[ ] Extension agents from NGO

[ ] Extension agent from government

[ ] Don't get any information

[ ] Others (specify) ---

THANK YOU