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Presented by

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Conceptual Analysis and Prototypical Design of a Smart Solar Water Pumping System for Irrigation:

Case Study of a Farm in the Gambia

Defended on *20th November, 2021* ***before the following committee:***

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DECLARATION

I, Modou Alpha Jallow, hereby declare that this research thesis represents my personal work, realized to the best of my knowledge. I also declare that all information, material and results from other works presented here have been fully cited and referenced in accordance with the academic rules and ethics.

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DEDICATION

This work is dedicated to my best friend and father Mamadou Juldeh Jallow who passed away on 20th August, 2021 three months into the process of writing this thesis. His relentless assistance and determination to see me succeed in life despite the challenges is the reason I am where I am today. He never gave up on me and was constantly available throughout my journey in life and academia. This work is also dedicated to my beautiful and loving mother, who is my rock and source of inspiration.

THESIS APPROVAL

THESIS TOPIC: Conceptual Analysis and Prototypical Design of a Smart Solar Water Pumping System for Irrigation: Case Study of a Farm in the Gambia

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Finally, to my friends and family member for the love and support through this journey and difficult times. I thank you all deeply from my heart.

Abbreviations and Acronyms

AICCA	Adapting irrigation to climate change
APV	Agro-Photovoltaic
COE	Cost of Energy
CRR	Central River Region
DHT	Digital Temperature and Humidity
DSA	Deep Stone Aquifer
FAO	Food and Agricultural Organization
GDP	Gross Domestic Product
GEG	Global Energy Group
GNAIP	Gambia National Agricultural Investment Plan
GW	Gigawatts
HOMER	Hybrid Optimization of Multiple Electric Renewables
IEA	International Energy Agency
IOT	Internet of Things
IRENA	International Renewable Energy Agency
JMP	Joint Monitoring Programme
LCOE	Levelised Cost of Energy
NASA	National Aeronautics and Space Administration
MPPT	Maximum Power Point Tracker
NAWEC	National Water and Electricity Company
NDP	National Development Plan
NGO	Non-Governmental Organization
NPC	Net Present Cost
NREL	National Renewable Energy Laboratory
PCB	Printed Circuit Board
SDG	Sustainable Development Goals
SPVWPS	Solar Photovoltaic Water Pumping System
SSA	Shallow Sand Aquifer
TDH	Total Dynamic Head
TJ	Terajoule
UN	United Nations
WB	World Bank

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Abstract

Food, water and energy are essential components in our daily lives. Often conflicts arise due to the availability of space for the production and management of all three on the same piece of land. Agro photovoltaic(APV), a concept that propose the multiple use of land for energy and food production can be an ideal solution to this conflict. The solar panels can be used to provide shade to the crops to protect them from the extreme heat conditions and provide energy that can power the systems of the farm including pumping water for irrigation. This thesis was written to study the existing water supply and monitoring system in the Gambia and to make a prototypical design of a smart solar water pumping system for irrigation and community water supply. The study included assessing the irrigation water needs of the Maruo Farm (Case study farm) and to size a solar water pumping system. The Pvsyst software was used to size and design the system. Homer Software was used to evaluate the economic feasibility of the system. A comparative analysis was done further to ascertain the suitability of a stand-alone solar powered system as compared to a solar powered system with backup. A smart water monitoring and regulation system was also simulated by extension using the Protues 8 professional software. The system consists of a power source, soil moisture sensor, water level sensor, Arduino Uno with cellular communication protocol. A simulation was done to monitor and regulate the irrigation system.

Keywords: **Agro photovoltaic**, **PVsyst, Proteus Design Suit, Irrigation system, Solar System.**

Chapter 1: INTRODUCTION

1.1 Background of the study

Currently, access to freshwater for drinking, bathing and irrigation is a major challenge to many people globally. It is estimated that 1.1 billion people worldwide lack access to water and a total of 2.7 billion find water to be scarce for at least a month annually(Water Scarcity | Threats | WWF n.d.). This challenge in turn hinders the development of agriculture for food production in these places leading to high level of food insecurity. At current estimates, about 690 million people are hungry(FAO 2020a). This is about 8.9% of the world population.

In Africa, agricultural production, specifically food production has been hit with a lot of challenges. To meet the growing demand for food and eradicate malnutrition, these challenges needs to be dealt with. These challenges are mainly due to technological constraints, dependence on rain-fed agriculture, meagre investment into the sector, crude agricultural systems, climate change, poor water management and irrigation systems, gender gap in access to resources. Research has shown that the pervasiveness of malnutrition in African has slowed down but there exist about 256 million (20% of the population) hungry people. Sub Saharan Africa showed 239 million of people out of the 256 million people in Africa and North African showed 17 million people(FAO 2016).

The energy sector is not doing better and is still lagging behind. Compared to the other parts of the world, African countries have struggled with affordable, reliable and modern access to sustainable energy despite to vast availability of energy resources. It is estimated that about 600 million are deprived of access to electricity with 900 million of the population lack access to clean cooking according to IEA’s 2019 report on Africa Energy Outlook. Projections shows that only 70million of the 500 million will have access to electricity and access to clean cooking persisting to be a major challenge with one billion people deprived as of 2030(Africa Energy Outlook 2019 – Analysis - IEA n.d.).

This thesis is written under the frame of the Agro photovoltaic project in Mali and the Gambia (APV MaGa) with focus on the project sites in the Gambia. This study will be aligned with the objectives and deliverables of the Agro photovoltaic project in Mali and the Gambia (APV-MAGA) in the Gambia. The project is a Research and Development project that aims at proofing the technical and economic viability of an integrated triple land use system in order to contribute to a more ecological and socio-economic sustainable development of the partner countries and in general, the West Africa's economy. The APV provides a path for both food and electricity production on the same unit of land. The project by extension will focus on water provision and other socio-economic issues. In the Gambia, the project aims to install four (4) APV pilot demonstrations with a capacity of 62.5Kwp. the four demonstrations include an irrigated rice farm, integrated rainwater harvesting APV plot plant, a transformation platform and a cold storage facility for Agricultural products.

This project utilizes the simultaneous harmonious production of energy from solar photovoltaics and crop production on the same piece of land. The panels will provide shade to the crops from the hot and sunny weathers in Mali and the Gambia in order to facilitate high yield production by protecting the crops from the adverse weather. At the same time the solar panels will provide the energy to supply the energy needs of the farm including the water supply to the farm. This work will be geared towards the conceptual analysis and prototype development of a smart system for the regulation and monitoring of water supply to the agricultural field and the nearby by communities.

1.2 Problem Statement

The water-food-energy nexus is key to sustainable development as the demand for the three is rising due to the rising population, rapid urbanization, changing diet and economic growth(Water, Food and Energy | UN-Water n.d.). The global population was estimated to be 7 billion in 2011 and is expected to rise by 2 billion persons in the next 30 years, from 7.7 billion currently to 9.7 billion in 2050 and could peak at nearly 11 billion around 2100(Population | United Nations n.d.). In order to meet these demands, expeditious actions must be taken.

In the Gambia, climate change has manifested itself in the form of torrential rainfall, flooding, drought, heat waves and rising sea level and unseasonal rains(World Bank Climate Change Knowledge Portal | for global climate data and information! n.d.). These impacts directly affect crop production in the country. The country's economy depends largely on agriculture accounting for 22.5% of GDP in 2015 according to the African Development Bank. This shows that the country's economy is vulnerable to the variations in weather conditions and climate change. In addition, most families live on subsistence agriculture. Thus the climate vulnerabilities have exposed them to poor yield, poverty due to low income and food insecurities.

Access to water for domestic application is also a very burdensome task. Estimates showed that just about 69% of the population have access to safe drinking water. Reliable and affordable access to water is a right hence the lack of access to water to the remaining 31% is a right that is abused. For the 69% of people with access to water, this comes with instabilities and a weak service with some neighbours not receiving water for days, weeks and even months(The Gambia: World Bank to Strengthen Access to Energy and Water n.d.).

The integration of water pumping systems offers a vital opportunity in improving water access to agricultural lands for irrigation and water supply to the neighbouring communities. However, the challenge to this comes from the access to sustainable and reliable energy source to power the system. According to IRENA's Renewable Readiness of the Gambia currently, electricity utilization per capita is 136 kilowatts-hour. This is by far below the average for an African which is over 575 kilowatts-hours and a global average of over 2770 kilowatts-hours. This power is mostly generated by the utility company which uses petroleum for its power production. Petroleum and Petroleum products accounts for 37% of the country's energy consumption and the importation of this fuel cost the country most of its foreign exchange generated(Renewable and Agency 2013). Another problem arises from the lack of grid extension to areas accessible to farmlands which are mostly located in the rural areas.

The use of diesel fuel to power water pumping systems to some extent is discourage due to rising fuel prices and emissions associated with it. These emissions pollute the environment and are major contributors to climate change. Research has shown that the cost of solar Photovoltaic panels is decreasing. Solar systems seem to be an ideal power source due to the availability of solar energy in the country. Solar energy is found to be clean with no emission, free and available throughout the country. Direct solar irrigation is found to be the simplest, most efficient and lowest cost solution(Bricca and Bocci 2019).

The possibility of energy and water wastage due to poor efficiency standards and management of equipment poses a considerable complication. With poor monitoring of equipment and material handling, these resources can be wasted. This escalates losses in the form of indirect cost to the farmer. This problem can be solved by assimilating the solar water pumping system with an Internet of Things (IoT) smart monitoring system that monitors different parameters of the system.

The smart system has sensors, controllers and actuators that regulate the performance of the different components of the system.

1.3 Research Objectives

The main objective of this study is to Design a smart solar powered water pumping technology for irrigation and community water supply in the Gambia.

1.3.1 Specific Objectives

I. To analyse the existing water supply and monitoring systems used in agricultural farms and in the APV MaGa site in the Gambia.
II. To make a review of the current state of food, water and Energy Supply in the Gambia.
III. To assess the water and energy requirements for the distribution of water to the farm in one of the APV MaGa sites in the Gambia.
IV. To design a prototype for the automatic distribution and monitoring of water distribution to the farm.

1.4 Research Questions

I. What are the existing mechanisms farmers use in accessing water?
II. What is the current state of food, water and energy supply in the Gambia?
III. How much water and Energy is needed to supply water to the farm?
IV. What are IoT components that can be used to a prototype that can automatically manage the distribution and monitoring of water in the farm?

1.5 Situating the Study in the Field

The synthesis of a smart irrigation system not only audits and balance the supply of water to slash the amount of water wastage, over flooding which may result to low productivity can be avoided. The systems have been extensively seen to increase productivity and profitability in agriculture. This work will focus on pumping water for an irrigation system. The research will also delve into the problems and challenges farmers and Gambian communities go through in getting access to water.

The study will focus on the applied concept of the Internet of things, electronics and Web or App development in the irrigation water supply applications. The work will also include the application of solar photovoltaics technology in water pumping systems. An economic comparison will be made on the designed solar PV system and the A PV system with a backup generator.

1.6 Significance of the study

The relevance of the outcome of this is both unequivocal and unmatched due to the following reasons:

1. The outcome of the study will help in modernizing the Gambia's Agricultural sector
2. It will help in boosting the sector which successively improves quantity and quality of produce, income of farmers and food security in the Gambia.
3. The outcome will help in increasing accessibility of water among farms in the Gambia
4. The system can be used in water management system in order to reduce wastage.
5. The study will help in achieving Africa's agenda 2063 in various ways as well as the SDGs 1, 2, 6, 7, 8, 9, 11, 13.

1.7 Possible Obstacles

1. Covid-19 has been a menace to normalcy and in this case of this study, its problem will be felt mostly in terms of mobility. The restrictions made in place will hinder movements for data collection, visiting the field and acquiring the necessary components for the prototype.

2. The acquisition of the components is going to be the principal challenge since the components are to be ordered online from overseas which is subjected to faulty equipment, delay and increased cost.

3. Availability of data will be an issue since data in the Gambia is most unavailable or inadequate.

4. Time frame is short form designing the prototype, testing it and writing the report and submitting it within the designated time.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter begins with the definition of water resources, outlining the amount of fresh water available for human consumption. A diagram illustrates the distribution of water resources on the globe. Next, the chapter highlights the water resource situation in the Gambia. Herein, it is revealed that the total renewable water resource (TRWR) is estimated to be $8.0km^3$ with Guinea and Senegal accounting for about 62.5% of this month. Also, the annual water usage is valued at 30.6 million cubic meters, accounting for 0,38% of the annual TRWR. The corresponding per capita consumption is $23.5m^3$. in the Gambia, 67% of the water usage is for agricultural purposes. Next, the discussion takes on the definition of IoT, highlighting the essential technologies enabling the successful implementation IoT systems. Finally, the chapter climaxes with the review of other academic papers focused on IoT based water monitoring and regulation.

2.2 Water Resources. What are they?

When water sources are useful or have the potential for use by people, experts call it water resources. All unanimously agree that water resources are essential to humans because without it, life could not have evolved. Five of the uses of water resources include domestic, recreational, economic, agricultural, and environmental activities. Without water, practitioners of these activities would fail in their duties. Studies have shown that 97% of the water on the Earth is salty, leaving a meniscal 3% of fresh water for an ever-growing human population. Similarly, a study about the distribution of earth's water resources shows that glaciers hold 69% of the water and that 30% are groundwater. The figure following show the water distribution summary on the globe.

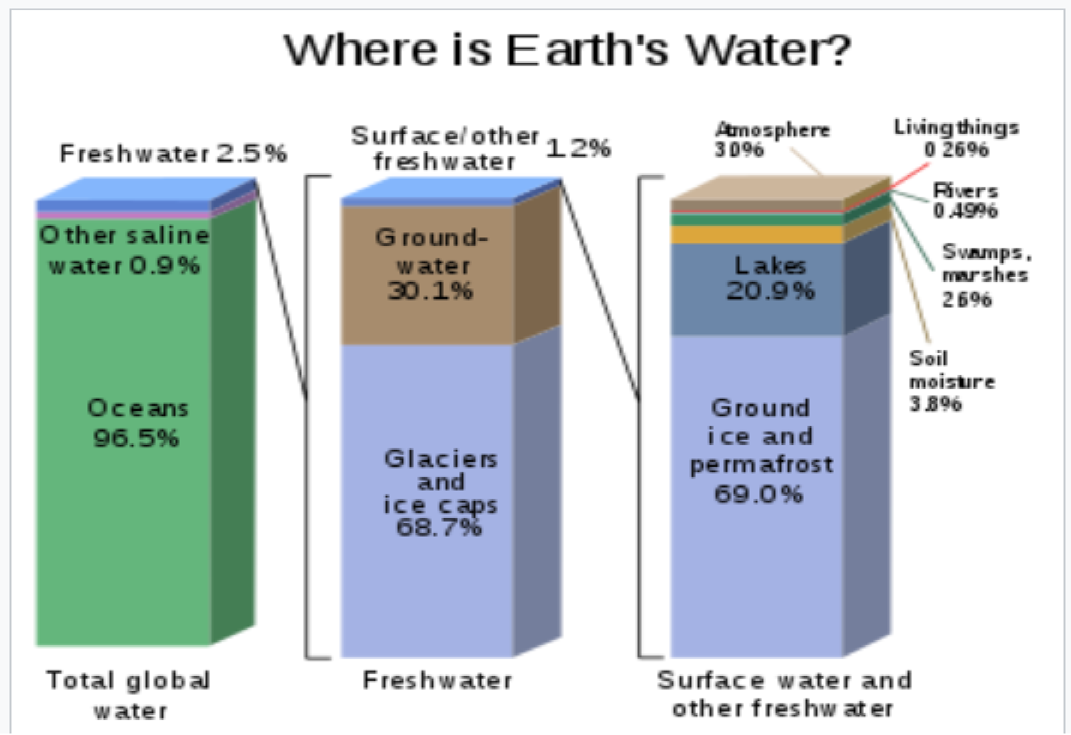


Figure 1*: *Global Water Resources

The diagram also reveals that of the 2.5% fresh water on earth, only 1.2% that amount is surface water. This minuteness of easily accessible water is the reason 785 million humans lack access to clean water.

2.3 Water demand and supply

The dynamics of the water cycle has directly been altered by humans for their water storage for dams and usage for their economic and domestic purposes in the form of industrial, agricultural and household uses(Haddeland et al. 2014). The emergence of climate change woes has further affected the supply patterns against the rising demand. There have been 20% decrease in water availability per capita from the last two decades(FAO 2020b). As of 2017, at least 70% of the people in the sub Saharan Africa region lacked safely managed water for drinking, sanitation and hygiene facilities(Strategy 2021). The rising population and human intervention along with climate change being a significant cause. Currently, 1.2 billion people reside in areas where water availability is a challenge with 520 million of them from rural areas.

The global water withdrawn for people’s livelihood, industrial growth and environmental sustainability is projected to rise to almost 5000 cubic kilometres against the 3906 cubic kilometres of 1995. Water withdrawal is defined as the water taken from the water sources and transported to their place of use(Senthil Kumar and Yaashikaa 2019). This increase in withdrawal is attributed to the evolving population and economic activities in the world. This is depicted in the figure below with sub Saharan Africa consuming the least of all the regions in the world.

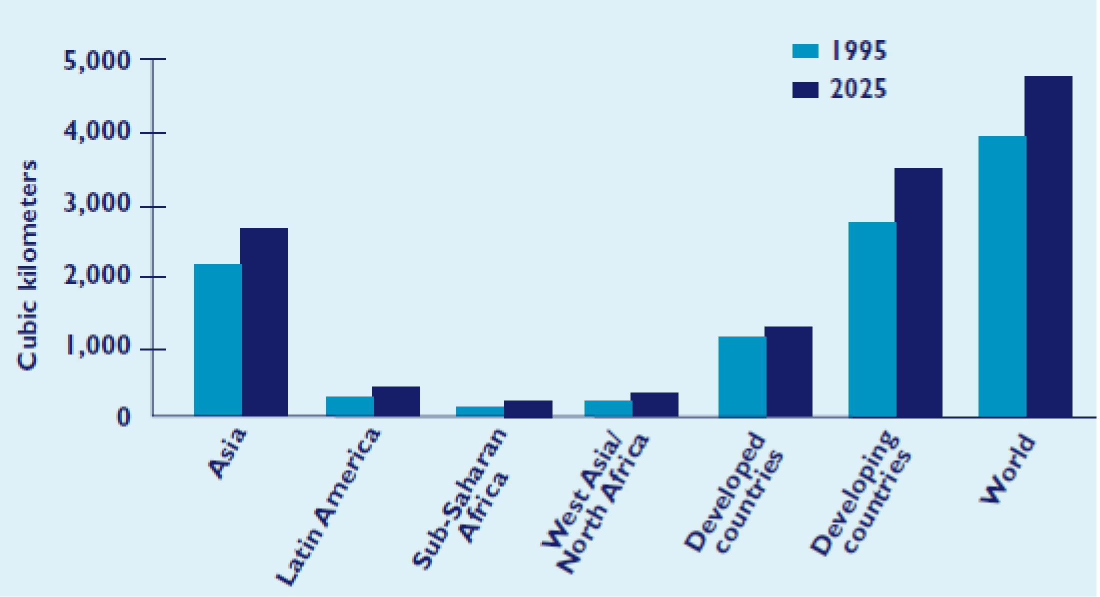


***Figure 2*:Total water withdrawn by region, 1995 and 2025.(Rosegrant, Cai, and Cline 2007)**

Agriculture accounts for almost 70% of the global water withdrawn(Ritchie and Roser 2017). The rise in population increases the demand for food security thus putting pressure on the demand for water supply for agriculture. Hence, the growing dependencies on food supply by the rising population although less obvious but still serve as an indicator to the increasing demand for water supply(Hoekstra and Chapagain 2007). Estimates suggest that about 250million hectares of land are irrigated globally which is five times more than the irrigated land in the early 20th century(Rosegrant, Cai, and Cline 2007). Irrigation have contributed immensely to the increased crop yield and helped stabilized food production and prices and has taken the major percentage of water withdrawn for agricultural purposes.

Second to the agricultural sector to withdraw the largest amount of water is the industrial sector with 19% of the total water withdrawn globally. Water in this sector is use for steam production, dilution, cleaning and cooling of manufacturing equipment(Water Use and Stress - Our World in Data n.d.). Industrial water use comes with its major constraints of physical and chemical contamination of waters, thermal solutions and dissolved solids residual in cooling towers with new compounds from industrial processes being non-biodegradable(Gloyna and Ford 1982).

Water for domestic purposes is used for drinking, cleaning, cooking, bathing, water for space heating etc. The amount of water withdrawn against the total water withdrawn globally is 11%.

The other aspect of water withdrawn from water bodies which is mostly talked about the least is the evapotranspiration which is water loss from through evaporation and transpiration from plants. Accurate forecasting of evapotranspiration plays a significant role in water resource management, irrigation planning for agricultural and forest lands(Granata and Di Nunno 2021).

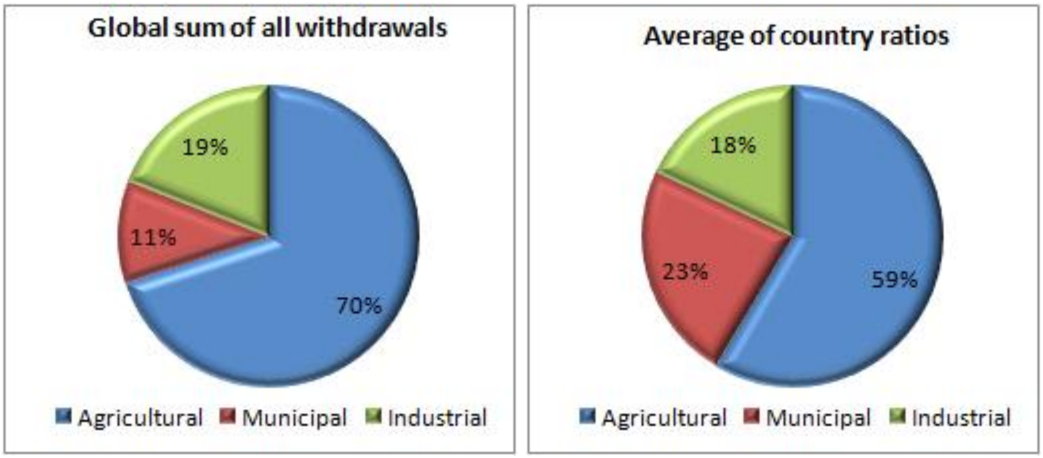


Figure 3*: *Global water withdrawals and average country ratios.(AQUASTAT database Database Query Results n.d.)

Globally, large volume of water is withdrawn to support processes in the sectors mentioned above. This resource is most of the time used haphazardly without proper management. Water conservation measures should be implemented to improve availability. The use and reuse method of utilizing these resources should be taken into great consideration by recycling. This will reduce pressure on water resources and enhance availability(Moya-Fernández et al. 2021).

2.3.1 Water Resources in the Gambia

Water Resources in the Gambia are of three types; Rainfall, surface water and groundwater. The River Gambia and its tributaries, and the Atlantic Ocean constitute the surface water. The river Gambia flows westwards from the republic of Guinea to the Atlantic Ocean with a length of flow of 1120km(Gambia River | river, West Africa | Britannica n.d.). The river is divided into two zones, estuarine and freshwater zones. These zones define the vegetation pattern around them. The freshwater zone is characterized by a forest gallery while the estuarine zone has mangrove vegetation around it. The Gambia declares 20530 sq. km of the economic zone of the Atlantic Ocean.

The total Renewable Water Resource is estimated to be 8 billion m^3/year with 5 billion m^3/year (62.5%) of this flowing from Senegal and Guinea with 3 billion m^3/year produced internally, Renewable groundwater produced internally is estimated at 0.5 billion m^3/year(Aquastat 2008).

Figure 4*: *The Gambia River Basin. (Gambia River - Wikipedia n.d.)

The Gambia has two main aquifers; the Shallow Sand Aquifer(SSA) known as the Quaternary unconsolidated sands compromise and the Deep Stone Aquifer(DSA)(Hydrogeology of Gambia - Earthwise n.d.).

The depth of the SSA ranges from 4 to 30 meters below the ground level. This is the major source of drinking water in the Gambia(Atherton 2013). The size of the sand in this aquifer comprises of fine to course sand and is subdivided into two; the phreatic aquifer composing of Holocene sediments and the semi-confined sediment of Pliocene sediment composition(Atherton 2013). The separation between the two aquifer is of 15-30m clay-silt layer. The aquifer recharges fully during the wet season as absorption is far less than recharge. This aquifer is not characterized by water quality issues and recharge ranges from 250-300mm when the annual mean precipitation is above 900mm.

The DSA is 250-450 meters below ground level. The composition of this aquifer is of loosely consolidated sandstone and consolidated sand. The potable water out of the 650,000Mm^3 is 80,000Mm^3(Atherton 2013). The water quality issues in this zone is the mineralised groundwater in the west with dissolved solids of the range 1000-2000mg/l. To ensure total groundwater availability, the DSA should be exploited.

Rainfall is also another water resource in the Gambia. It is a widely used resource among farmers for crop production. This is because crop production in the Gambia hugely depends on rainfall(Thorpe 1998). Rainfall in the Gambia is seen in the rainy season which spans from July to September. Annual rainfall in the Gambia ranges between 900mm and 1100mm with the areas in the coast receiving the highest amount. Rainfall peaks in the months of August and September. Due to poor irrigation facilities, farmers mostly capitalize on the rainfall for their crop production.

2.3.2 Current state of water supply in the Gambia

Water is an essential commodity for all living things. Available and safely managed water for drinking and sanitation is significant for good health and wellbeing. It is widely regarded as a human right(MICS 2018). The state of water supply and sanitation in the Gambia has been progressively improving since the Sahelian drought in the 1970s and 1980s(McGarry 1991). This improvement has been influence by the response strategies being implemented to overcome the increasing demand and the challenges associated with maintaining the sector related infrastructures. It is estimated that 85% of the population have access to improved water sources for drinking as of 2018(Hotel 2015). Progress have been seen in the sanitation and hygiene subsector with reports in the NDP 69.4% of the population having access to better sanitation(Hotel 2015). The overall water supply coverage has increased by 17% from 58% in 1990 to 75% in 2009. The increase in sanitation is much less than the water supply with an only increase of 9% in the same period(McGarry 1991). The figure below gives a comparative highlight of the state of water supply for drinking, sanitation and hygiene in the Gambia from 2015 to 2020 reported in the JMP report(JMP n.d.).

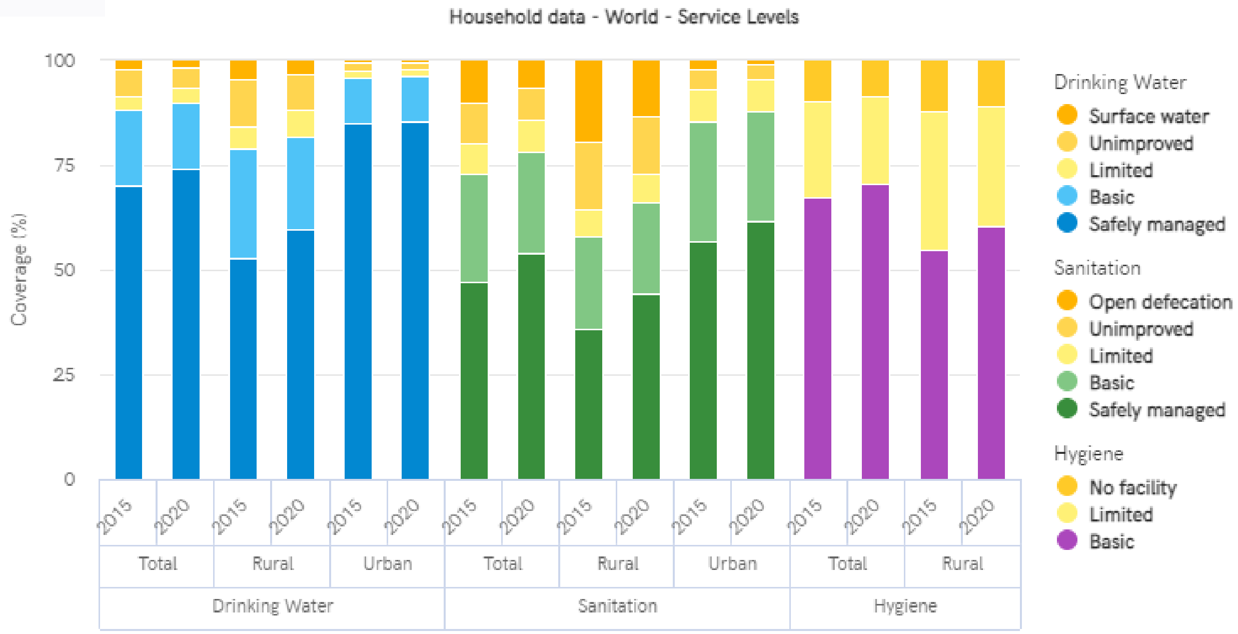


Figure 5*: *Rural and Urban water service levels for drinking, sanitation and hygiene. (JMP n.d.)

Water coverage rate in the rural areas is showing positive increment but the government's target of 90% coverage is still yet to be achieved as of 2015 with a percentage missed points of 14%(McGarry 1991). The water used in the rural Gambia is predominantly for domestic and agricultural purposes. Agriculture is widespread in the rural areas due to the dependence on it for food production. Most families depend on subsistent agriculture for their living(Gambia at a glance | FAO in Gambia | Food and Agriculture Organization of the United Nations n.d.). The urban coverage shows only 6% increase from 1990 to 2009 with the 100% coverage target of the government by 2015 not met as current percentage coverage shows 80%(McGarry 1991).

2.4 Crop Production in the Gambia

Agriculture in the Gambia is one of the main contributor to the country's GDP amounting to around 20-30%(The Gambia National Development Plan 2021). This sector employs 44% of the countries workforce and provides an estimate 66.67% of household income(Gambia, The | World Bank Climate Change Knowledge Portal n.d.). The sector contributes 50% of the national food requirement and covers majorly in the domestic exports of the country with 73%(Renewable and Agency 2013). The sector when enhance has the capacity to reduce food insecurity, reduce poverty and improve income levels(Gambia Agriculture n.d.).

Agriculture is primarily for food production and it is characterized by subsistence farming and, is rain-fed. The main food crops grown in the country are mostly cereals like rice, millet, maize and sorghum. Cash crops are in the form of groundnut with cashew and horticulture showing positive prospects. Most farmers, about 80% in the country are producing groundnut as 60-80% of their income comes from groundnut sales(WB 2019). The figure below shows the centre stage groundnut takes in terms of the harvested area and the production value in the country depicting the interest it has from farmers in the Gambia.

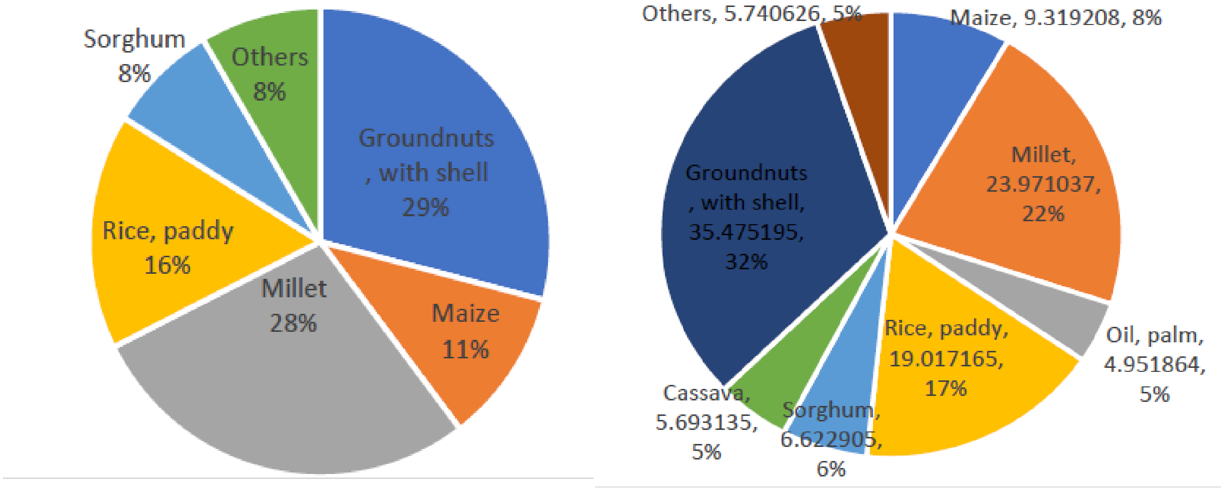


***Figure 6**: Harvested Area and Gross Production Value of Harvested Crop.(WB 2019)*

The Gambia has about 54% of her land area considered to be good quality arable land with 39% of this currently used by 41,000 subsistence farmers(Gambia Agriculture n.d.). The farming practices are crude and labour intensive hence it is subjected to low yield productions. Rice is regarded as the main staple food in the country having a national requirement of about 180,000 to 200,000 tonnes with the country only producing 12,000 tonnes.

The performance of the agricultural sector has been declining from 8.5% per year during 1995-2003 to -1.1% per year during 2003-2008 making it one of the countries in West Africa with the poorest growth rate. Currently, the agricultural value added growth rate stands at -9.96%(WA Map | ReSAKSS n.d.). The weak performance of the sector is due to the fact that most rural dwellers depend on their produce for their livelihood(WB 2019). Since agriculture is predominantly for subsistence agriculture and not commercialized the growth rate of the sector is greatly hindered. The dependence on rainfall which is highly vulnerable to climate change for crop production leads to low output for farmers. The climate change portal of the world bank shows that drought and flood which are highly link to rainfall and water availability as one of the major naturally occurring hazards each having a percentage of 29.03%(World Bank Climate Change Knowledge Portal | for global climate data and information! n.d.). River Flooding, water scarcity and coastal flood and extreme heat are all considered high by Thinkhazard, which are all factors that can contribute to the low production output of farmers(Think Hazard - The Gambia n.d.). Climate variability has also led to shorter crop growing seasons and reduced annual rainfall with projections showing high erratic rainfall causing frequent droughts and floods(Warning and Forecasting 2019).

The sector needs increased attention taken into consideration the vital position it has on the livelihood of people and economy of the country. Efforts have to be taken to revitalize the sector since it has a lot of potential in the country and as a response to the declining growth rate. The government of the Gambia is looking into strategies in the form of enabling policy environment for private sector participation and pro-poor public investment initiatives to help optimize the performance of the sector(The Gambia National Development Plan 2021). Simulations have also shown that huge agricultural and economic growth can be achieve with improved productivity and competitiveness of the main agricultural value chains(WB 2019).

The production value of rice which is the main staple food of the Gambia has a huge potential which when invested in can be key to improved food security in the country. Current irrigation systems that are crude and labour intensive should be enhanced to improve water availability for rice farming. The Gambia National Agricultural Investment Plan (GNAIP) targets to increase rice production on a 24,000ha of land under the various low land ecologies to achieve annual production of about 70,000 tonnes(Thorpe 1998).

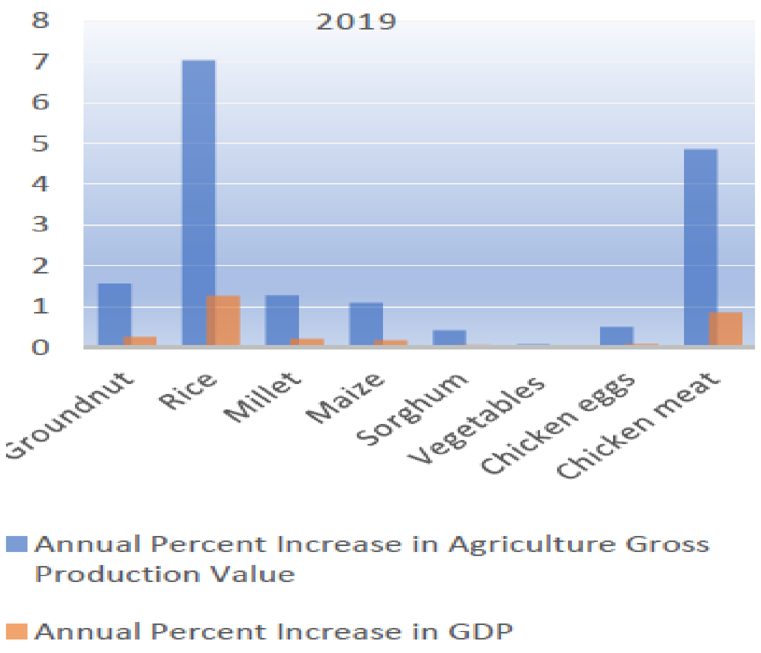


***Figure 7*: Simulations of potential sources of growth from the agriculture sector.(WB 2019)**

2.4.1 Irrigation Systems

Estimates show that of the 558,000ha of total arable land area, only 3000ha is most of time under irrigation(Thorpe 1998). The current irrigation systems constitute the use of watering can, dependence on the river tides for irrigation, sprinkler and localized irrigation, inland valley bottoms and pump irrigation (low lift pumps) etc. (Irrigation technologies | (AICCA) | Food and Agriculture Organization of the United Nations n.d.). The irrigation system mostly used in the country are the groundwater systems where water is drawn from wells and the tidal schemes with lowland rice cultivation showing successful outcomes(Irrigation technologies | Adapting irrigation to climate change (AICCA) | Food and Agriculture Organization of the United Nations n.d.). The adoption of these systems is more feasible as they have low investment cost, are affordable and easy to operate. The use of pumps for irrigation is avoided the flow of water to the field is natural.

Drip irrigation systems are implemented but on smaller scales and used mostly in gardens. Solar water pumps are also used but in community gardens. The Government of the Gambia is working on schemes to enhance these systems and provide cheaper systems to facilitate increased in production(Irrigation technologies | Adapting irrigation to climate change (AICCA) | Food and Agriculture Organization of the United Nations n.d.).

2.5 The Gambia’s Energy Overview

The Gambia’s energy sector imports more than it exports energy in the primary energy trade. The sector has imported about 8207 (TJ)of energy against the 175 (TJ) that is exported in 2017(Profile 2017). The net energy trade stands at -8032 (TJ) against the -6968 (TJ) of 2012(Profile 2017). The imported energy predominantly comprises of Petroleum and Petroleum products for its electricity production and fuel oil for the transport sector.

In 2017, 51% of the total primary energy consumption comes from Non-Renewables in the form of oil, gas, coal etc. Bioenergy showed the most consumed form of Renewable Energy(Profile 2017). The Gambia also has abundant solar potential across the whole country with a moderate wind potential along the coastal areas(Agenda 2014). Tapping into these naturally available resources will increase access and reduce the dependence of the expensive imported energy products. Off-grid power supply can be promoted to meet the demand in rural and remote areas and the use of the available renewable energy sources can serve as a substitute for the existing diesel driven systems(Agenda 2014).

Almost all household in the Gambia depend on Biomass to realized their energy needs(Renewable and Agency 2013). Some households with stronger financial standing have switched to Liquefied Petroleum Gas(LPG) for it is seen to be a more convenient option(Of and Gambia 2020). Hence the subtle increase in the demand for LPG in the country. Wood fuel has some associated health risk and excessive time and money spent on collecting it decreasing its convenience to some households(Design et al. n.d.).

Sector wise, household consumes largely the highest energy followed by industries then transport as of 2017(Profile 2017). The energy sector should be capacitated to increase production and improve the socioeconomic capital of the population and attain the development targets of the country(Of and Gambia 2020).

2.5.1 Installed Capacity

The Gambia, as of 2019 has a total electricity capacity of 105MW with 97% of the capacity coming from Non-Renewable. The Renewable portion comprises of Solar of 2MW and 1MW coming from wind. In terms of generation, 392GWh of non-renewable was generated with only 4GWh of renewable generated in 2018(Profile 2017).Solar energy is the dominant form of energy generated from the renewable as shown in the diagram below.

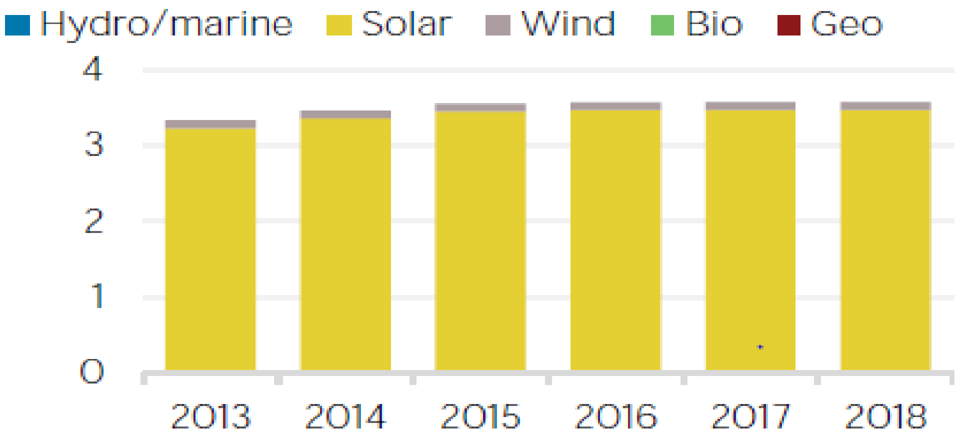
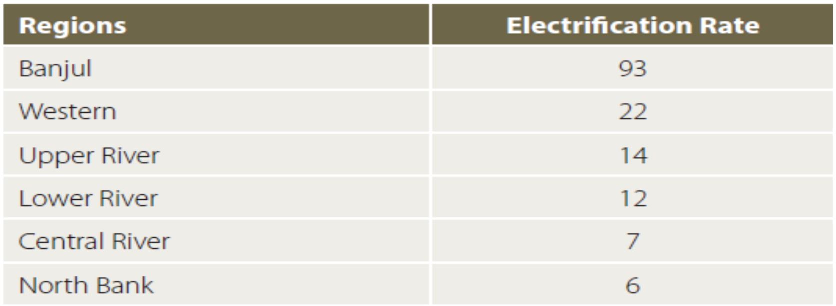


Figure 8*: *Renewable Generation(GWh). (Profile 2017)

Bioenergy is mostly used for domestic energy uses in the form of wood fuel for cooking. Overall, the Gambia has an electrification rate of approximately 35% as of 2011. There is however an imbalance in rural and urban electrification rates with the urban centres more electrified due to the highly concentrated population in these areas and peak energy demands. The government still struggles to provide sufficient electrification and lacks the resources to improve the situation given the large demand(Design et al. n.d.). The National Water and Electricity Company(NAWEC) supplies 130,000 customers of the needed 350,000 customers(Households)(Of and Gambia 2020).

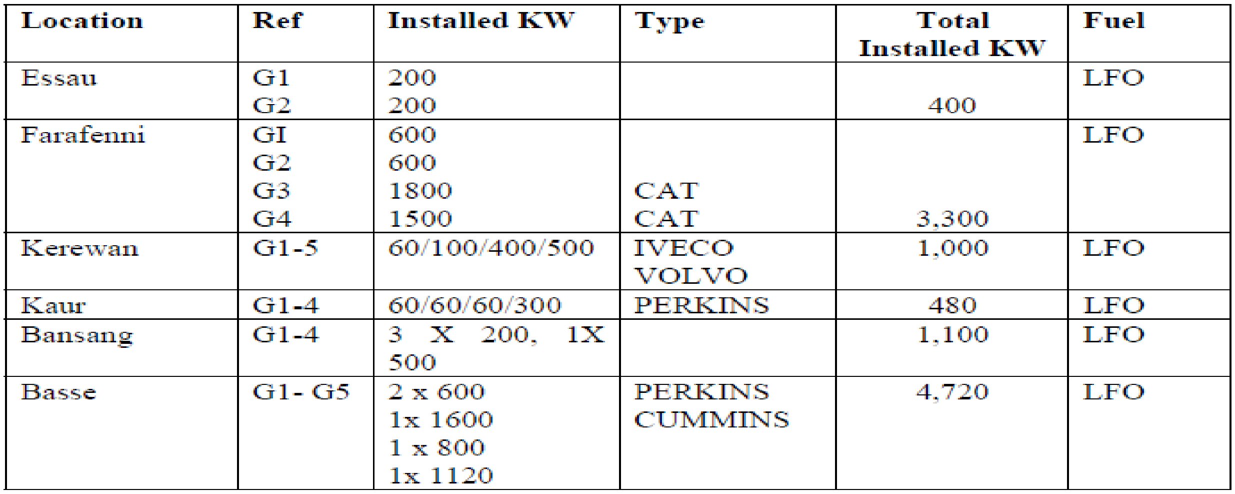
Banjul records the highest electrification rate of 93% with the North bank receiving the least with just 6% in 2011(Renewable and Agency 2013).



Regions	Electrification Rate
Banjul	93
Western	22
Upper River	14
Lower River	12
Central River	7
North Bank	6

Table 1*: *Electrification Rate per Region.(Renewable and Agency 2013)

The improvement in electricity access for both rural and urban populations is still a priority in the country. The year 2006 is a crucial year and shows significant improvement in the electricity access. GEG an Independent Power Producer inaugurated the 26MW plant in Brikama, West Coast Region. Six isolated generators (stand-alone) with a combined capacity of 4MW were installed in six communities in 2006 which was part of the initial phase of the Rural Electrification Project(Gambia n.d.). The installed capacities of the six isolated power stations are shown in the table below.



Location	Ref	Installed KW	Type	Total Installed KW	Fuel
Essau	G1 G2	200 200		400	LFO
Farafenni	GI G2 G3 G4	600 600 1800 1500	CAT CAT	3,300	LFO
Kerewan	G1-5	60/100/400/500	IVECO VOLVO	1,000	LFO
Kaur	G1-4	60/60/60/300	PERKINS	480	LFO
Bansang	G1-4	3 X 200, 1X 500		1,100	LFO
Basse	G1- G5	2 x 600 1x 1600 1 x 800 1x 1120	PERKINS CUMMINS	4,720	LFO

Table 2: Installed capacities of isolated power stations in the Gambia. (Of and Gambia 2020)

The installed capacities in Kotu and the stations in Brikama (1&2) as reported in the Gambia Energy Policy are 30.7, 37.6 and 8.9MW respectively having a 54% reliability against the peak power demand of 46 to 50MW(Of and Gambia 2020).

2.6 Solar Powered Water Pumping System

The continuous growth in population has led to an increased demand and exploitation of water supplies thus increasing the need for a reliable and efficient supply of energy to meet this demand(Water and Sanitation Initiative and Sustainable Energy and Climate Change Initiative 2011). Electricity prices are rising with challenges in grid access in the distant rural areas. The conventional system has been seen to in cooperate the pumping system with power sources from diesel, solar, wind etc. to places where the grid cannot reach. Diesel powered pumps have been associated with challenges ranging from availability, reliability, capital cost, maintenance cost, and short life expectancy(Aliyu et al. 2018). With the recent rise in climate change crises and an increased consciousness of the health risk associated with environmental pollution coming from the burnt diesel, the prominence of the use of these systems is gradually been replaced. The economic feasibility of the solar water powered systems is seen to be more attractive than that of the Diesel powered system.

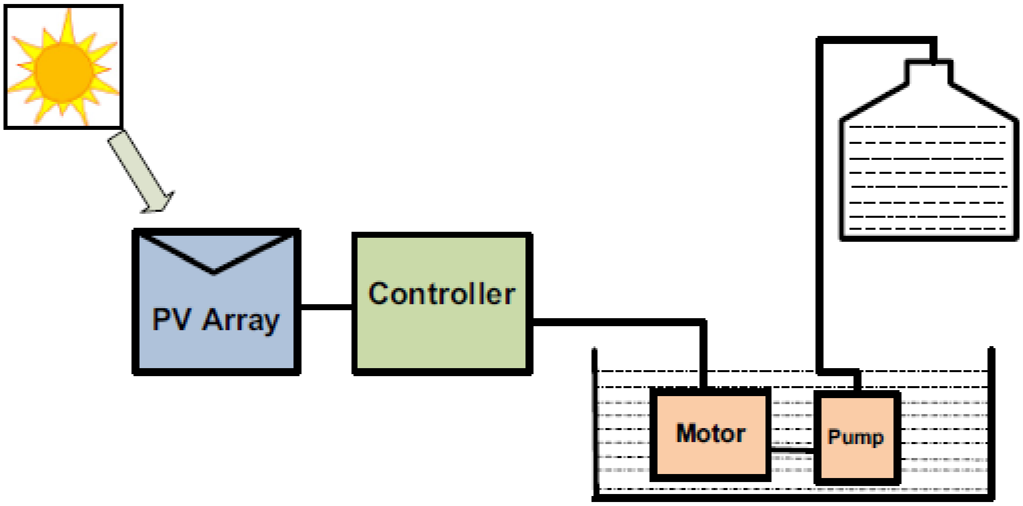


Figure 9: *Schematic Diagram of a Solar Photovoltaic Water Pumping System. (Tiwari et al. 2020)*

2.6.1 Current state of the Technology

There have been significant advances in the technology ranging from the design, operation and performance of the system. The earlier generations of the technology used centrifugal pumps which is driven by a DC motor and a variable frequency AC motors. The system has long term reliability and hydraulic efficiencies of 25% and 35%(Chandel, Nagaraju Naik, and Chandel 2015). The second generation of the technology are characterized with high hydraulic efficiencies of even 70%. They used positive displacement pumps, progressing cavity pumps or diaphragm pumps generally known to have low photovoltaic input requirements and low capital cost. The current state of the technology is embedded with electronic technologies thus increasing the output power, performance and overall efficiencies of the system. The controller enables monitoring of the water level of the storage tank, controlling of the speed of the pump and uses the maximum power point tracking(MPPT) technology to optimize the water.

2.6.2 Solar Powered Water Pumping System Designs

There are various designs of the solar water pumping system but solar photovoltaic system is the most widely used system. The solar water pumping system is made up of two basic components; the PV panel and the pump(Adenugba et al. 2019) . The PV panel is made up of semiconductor materials that can covert solar radiation to direct current (DC) that is used to power the pump. The pump system pumps the water from the source to the place where it is needed. The other components of the system include the inverter, charge controller, motor, storage tank, piping system and a tracking system if necessary.

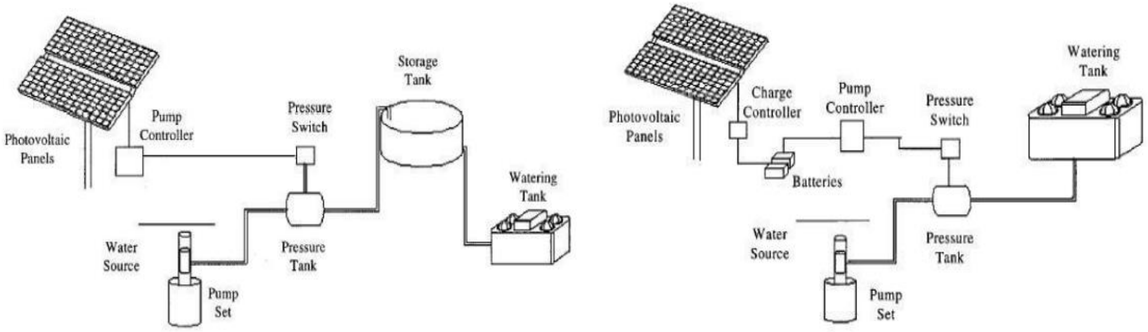


Figure 10. Direct and battery coupled water pumping systems. (Abu-Aligah 2011)

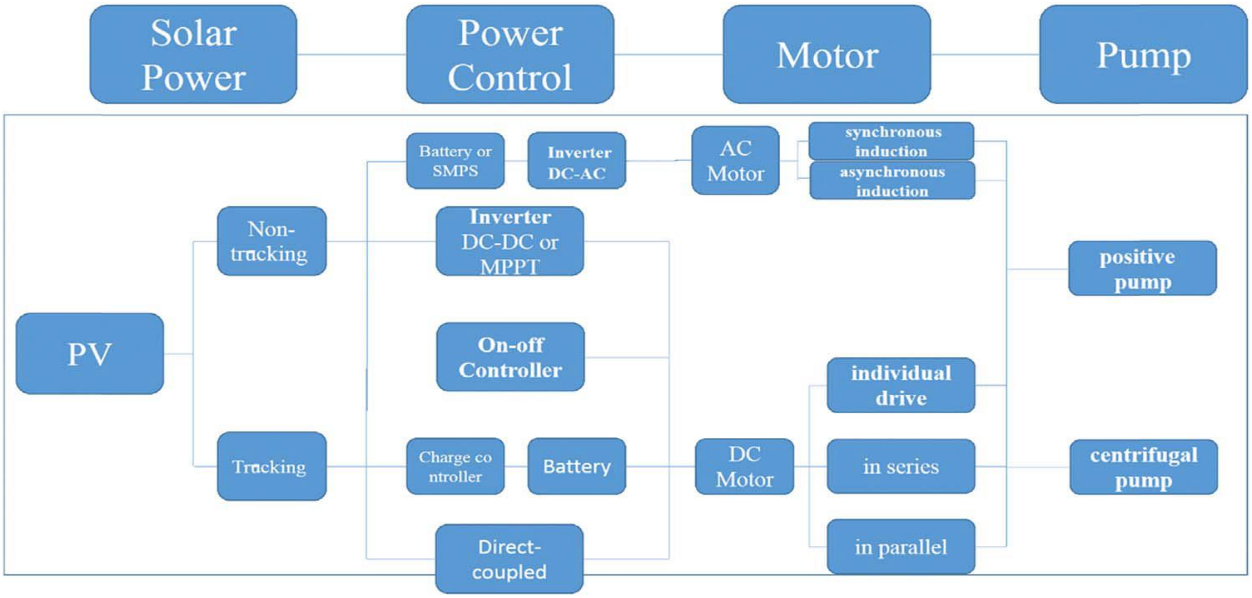


Figure 11. Structural Outline of Solar Photovoltaic Pumping System. (Li et al. 2017)

2.6.3 Economics of Solar Water Pumping Systems

The solar water pumping systems are known to have a high investment cost and is associated with decreasing efficiency when operated under high temperatures. The improvement in technological developments in the solar industry has resulted in reduced PV panel prices. This reduction in prices has increased the economic feasibility of solar powered water pumping system in contrast to the diesel operated systems(Aliyu et al. 2018). It has been seen that there is a dramatic price reduction in PV modules by 80% while the prices of gasoline and diesel have a 250% growth(Foster and

Cota 2014). The use of propane or diesel base fuel is expensive. The upfront cost, operation and maintenance cost and replacement of diesel based pumps are two to four times higher than the PV pumps(Chandel, Nagaraju Naik, and Chandel 2015).

Ranjan Parajuli et al(Parajuli, Pokharel, and Østergaard 2014) conducted a study on the comparison of diesel, bio-diesel and solar PV based water pumping system in the context of rural Nepal. The analysis was done on three technical scenarios of using Petro-diesel, jatropha-based biodiesel and solar PV pumps. The system comprises of the sizing of the prime movers i.e. engines, solar panels and pumps and the determination of the reservoir capacity. The financial analysis of these energy sources where done on the following economic parameters; net present value, equivalent annualised cost and levelised cost of water pumping. These analyses were done considering the water head, discharge and incentives on the investment which reflects on the cost of the pumped water. Different yield rate of the jatropha plants were used in estimating the cost of producing the biodiesel. The result showed that the levelised cost of pumping 1L of water is higher in the Jatropha-based biodiesel than the solar powered pump and even more with the use of petro diesel for a biodiesel yield rate of 2kg. However, with a production rate of 2.5kg, the biodiesel was seen to be more attractive than the diesel base system but still more unattractive than the solar powered system.

Another study conducted by Gitika et al(Dadhich and Shrivastava 2018) delves around the economic comparison of Diesel and solar PV water pumping system. A solar PV is used to run a 5hp pump that supplies the water to an irrigated field. Likewise, the diesel engine is used to run the same pump. The parameters considered for the process are; net present value, benefit cost ratio and internal rate of return. The result showed that the solar water pumping system is more feasible than the diesel operated pump.

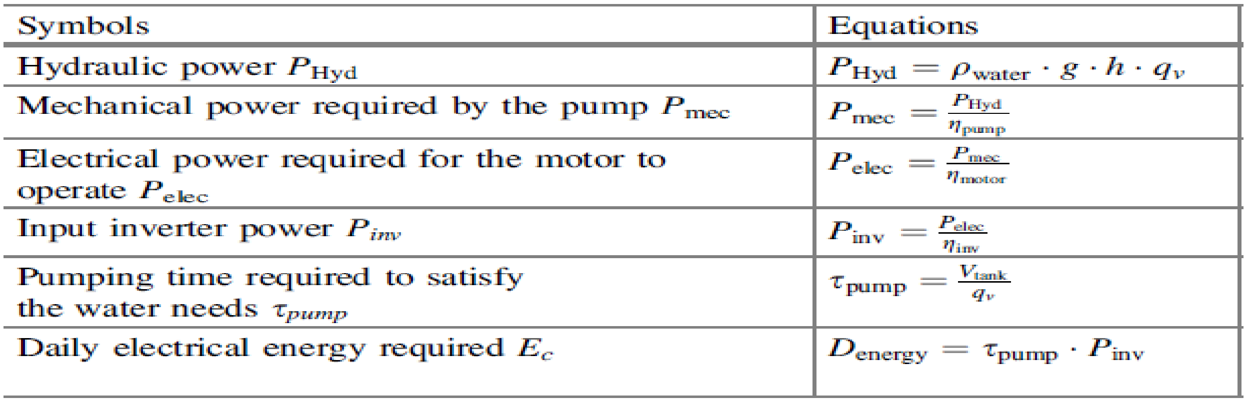
2.6.4 Energy Consumption of the SPVWPS

Designing the solar water pumping system requires assessment of the source of water, the water needs of the area, the solar irradiation potential and the location of the photovoltaic system, the flow rate in the pipe and the total dynamic head of the pumping system. The flow rate and the head are essential components in selecting the pump type along with the verification if the water source is surface or a deep well(SIDSDOCK and WBG 2019).

When all conditions are met and satisfied, the following specifications must be considered(Shah 2015):

- The volume of water to be pumped per day.
- The height of the water tank.
- The nominal flow rate of the water.

The higher the height of the tank the more the power requirement. Considering the effect of the efficiencies of the different components of the system, the daily energy requirement of the system can be determined as shown in the table below;



Symbols	Equations
Hydraulic power P_{Hyd}	$P_{\mathrm{Hyd}} = \rho_{\mathrm{water}} \cdot g \cdot h \cdot q_v$
Mechanical power required by the pump P_{mec}	$P_{\mathrm{mec}} = \frac{P_{\mathrm{Hyd}}}{\eta_{\mathrm{pump}}}$
Electrical power required for the motor to operate P_{elec}	$P_{\mathrm{elec}} = \frac{P_{\mathrm{mec}}}{\eta_{\mathrm{motor}}}$
Input inverter power P_{inv}	$P_{\mathrm{inv}} = \frac{P_{\mathrm{elec}}}{\eta_{\mathrm{inv}}}$
Pumping time required to satisfy the water needs τ_{pump}	$\tau_{\mathrm{pump}} = \frac{V_{\mathrm{tank}}}{q_v}$
Daily electrical energy required E_c	$D_{\mathrm{energy}} = \tau_{\mathrm{pump}} \cdot P_{\mathrm{inv}}$

Table 3*: *Energy Consumption of the SPVWPS. (Shah 2015)

2.6.5 Configuration of SPVWPS

The performance of the solar photovoltaic water pumping system strongly depends on the configuration of the solar PV array(Aliyu et al. 2018). Configuration here refers to series, parallel or series-parallel connections of the PV array. The output current and voltage from the system depends on the configuration of the system.

A study conducted by Boutelhig et al.(Boutelhig, Hadjarab, and Bakelli 2011) which is to conduct a comparative analysis on the performance of a solar PV pumping system for a different configuration showed a 12.5% efficiency for the 2x2 modules configuration with a 300W pump and a 12% efficiency for the 2x1 modules configuration with a 130W pump.

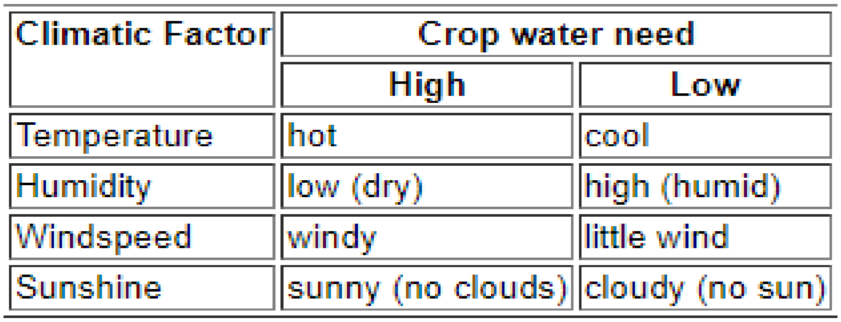
Benghanem et al.(Benghanem et al. 2013) studied the optimum PV configuration that can supply a DC helical pump with an optimum energy amount. Configuration of (6S _ 3P, 6S _ 4P, 8S _ 3P and 12S _ 2P) were analysed. The test which was conducted for a head of 80m under sunny daylight hours showed that the configurations of (6S _ 4P) and (8S _ 3P) were able to provide the optimum energy needed. The helical pump was able to pump a maximum daily average volume of water of 22m^3/day using the selected configurations.

2.7 Crop Water Needs

This is also known as the Evapotranspiration of crops. It is defined as the depth of water needed to replenish the water loss during transpiration and is influenced by the climatic conditions, type of crop and the growth stage of the crop(CHAPTER 3: CROP WATER NEEDS n.d.). This makes determining the plant water needs is a complex process and involving the assessment of the climatic condition of the region, the type of plant and its state of growth, properties of the soil and the irrigation method(Difallah et al. 2017).

The effects of climatic conditions on the crop water needs is presented in the table below. The crop water needs are high when the crop is grown in hot temperatures, low humidity, high wind speed and sunny conditions with the crop demanding less water when the conditions are otherwise.

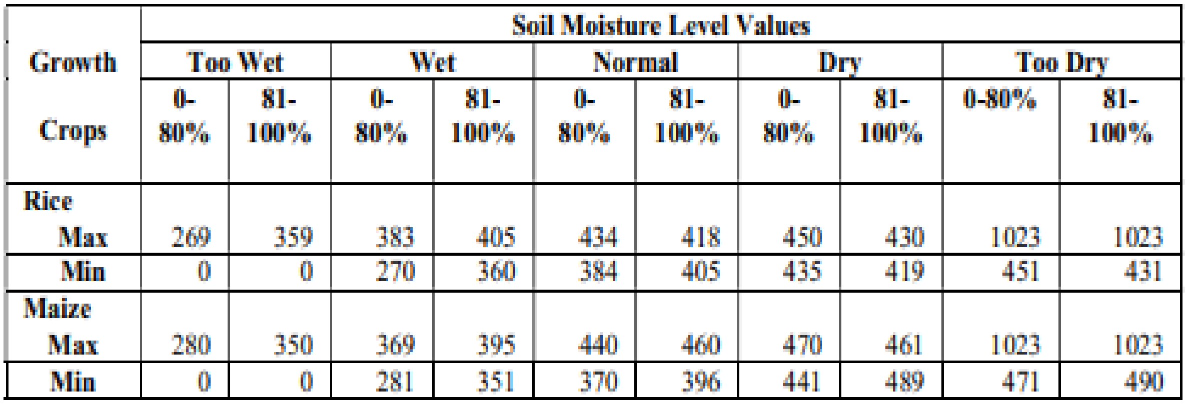
Different crops need different amount of water for their growth. The rice crop which is considered as an aquatic crop needs a lot of water to grow. The paddy rice for example is considered to require more water than any other crop hence, the reason why it is grown in areas with at least 115cm of rainfall(Cultivation of Rice: Suitable Conditions Required for the Cultivation of Rice (6 Conditions) n.d.).



Climatic Factor	Crop water need	
	High	Low
Temperature	hot	cool
Humidity	low (dry)	high (humid)
Windspeed	windy	little wind
Sunshine	sunny (no clouds)	cloudy (no sun)

Table 4*: *Effects of Climatic Conditions on Crop Water Needs (FAO)

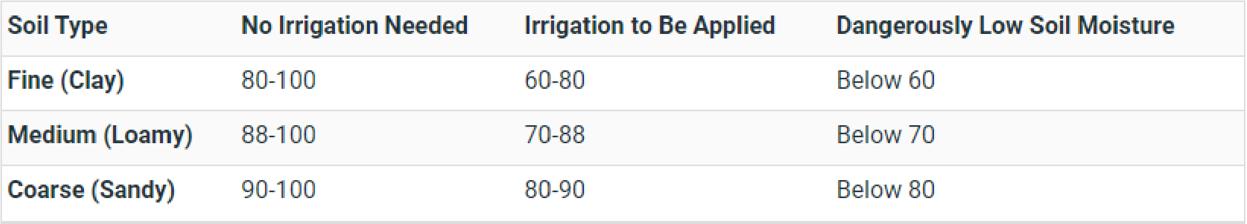
The rice crop has been seen to grow in many soil types but the clayey loam soil has shown the most effective soil type due its high water retention potential(Cultivation of Rice: Suitable Conditions Required for the Cultivation of Rice (6 Conditions) n.d.). The soil moisture level is an important factor to consider in rice cultivation. It is a determinant of when and how much irrigation is required in the field. Too little water supply normally leads to the crop to be water stress. It is observed that soil moisture level is high in rice and maize crops when the crop has grown up to 81% to the harvesting period reducing the need to supply water to the field(Gines, Bea, and Palaoag 2018).



Growth Crops	Soil Moisture Level Values									
	Too Wet		Wet		Normal		Dry		Too Dry	
	0-80%	81-100%	0-80%	81-100%	0-80%	81-100%	0-80%	81-100%	0-80%	81-100%
Rice Max	269	359	383	405	434	418	450	430	1023	1023
Min	0	0	270	360	384	405	435	419	451	431
Maize Max	280	350	369	395	440	460	470	461	1023	1023
Min	0	0	281	351	370	396	441	489	471	490

***Table 5**: Characteristics of Soil Moisture level for Rice and Maize with Fuzzy Logic:(Gines, Bea, and Palaoag 2018)*

The table below shows the ideal moisture level for the three major types of soil indicating the level of irrigation water requirement.



Soil Type	No Irrigation Needed	Irrigation to Be Applied	Dangerously Low Soil Moisture
Fine (Clay)	80-100	60-80	Below 60
Medium (Loamy)	88-100	70-88	Below 70
Coarse (Sandy)	90-100	80-90	Below 80

***Table 6**: Ideal Moisture level for Clayey, Loamy and Sandy Soil*

2.8 What is IoT?

According to the *Oracle*, IoT is the combination of physical objects that are embedded with sensors, processing power, software, and other technologies, enabling these objects to connect and exchange data with like devices and systems over the internet or other communications networks. They are a system of interrelated objects that can collect and send data through wireless connection with limited human interference(What is IoT? Defining the Internet of Things (IoT) | Aeris n.d.). This technology is regarded as one of the important future technologies hence the vast attention from a wide variety of industries(Lee and Lee 2015). Its application ranges from monitoring and management of household equipment, smart agriculture, transportation etc.

2.8.1 IoT based water monitoring and regulation

The solar water pumping system along with the farm conditions if not monitored properly may result to reduced efficiency and wastage of water. The increase interest in irrigation systems is attributed to the growing demand for food cause by the increasing population and global warming(Abba et al. 2019). Irrigation is an agricultural activity that demand a lot of water and it has risen over time as a proportion to the rising demand for food. The IoT technology enables data collection and processing of data from the field for the farmer to be able to monitor and regulate the farm operations automatically. The smart irrigation technology employs sensors and actuators designed to ensure adequate supply of water to the crops in the most efficient way to avoid wastage(Abba et al. 2019).

A lot of research has been conducted in the application of IoT in agriculture especially in the water monitoring and control sector. (Pratilastiarso, Tridianto, and Diana 2019) wrote a paper on a smart solar water pumping system that is connect to a mobile phone for the operator to monitor the system. The farmer can monitor the irrigation system automatically. The system is embedded with a humidity sensor device, a controller, an alarm system which when triggered send signals to the controller when necessary actuations are activated. The system features the transfer of data directly to the farmer via text messages via SMS gateway.

On a different design, (Waleed et al. 2019) developed a design a system of water pumping for irrigation using solar PV with an irrigation control feature. The system has a humidity sensor and a Global System for Mobile wireless irrigation monitoring to reduce manpower needs. This enables farmers to run their farms automatically and remotely. They can use their phones to turn on and off their system.

A similar paper written by (Kunal et al. 2019) aimed at applying the functionality integrated architecture in the field of agriculture to provide an ideal fresh water usage and better crop production. The components included an Arduino Uno board, a DHT sensor, soil moisture sensor, an ultrasonic sensor and a relay. The system accomplished the objective of reducing manpower and controlling motor to fill the tank. The system however could not perform the objective of forecasting weather and monitoring the system through an app in a mobile phone.

The emergence of IoT has offered the opportunity in monitoring systems thereby helping operators to monitor energy or water needs to where it is needed or switching pump of when the required amount of water is made available. A study conducted by (Ismail et al. 2019)designed an IoT base system that both monitors and regulates the water consumption and, functioning of the overall system. Sensors such as water level sensor which detects the water level in soil, humidity and temperature sensor to sense the temperature variations in the soil and pressure sensors were used. The sensors were connected to a Wi-Fi network and data collected were uploaded for viewing in form of graphs to the cloud. These displayed graphs were seen through an App and a website(Ismail et al. 2019).

Lastly, (Natividad and Palaoag 2019) developed a n IoT based model for monitoring and controlling a water distribution system which consists of ultrasonic sensors, pressure sensors, motorized electric water valve, GSM module, Arduino micro-controller, Raspberry Pi, and a solid-state relay switch. Their design is in the figure below.

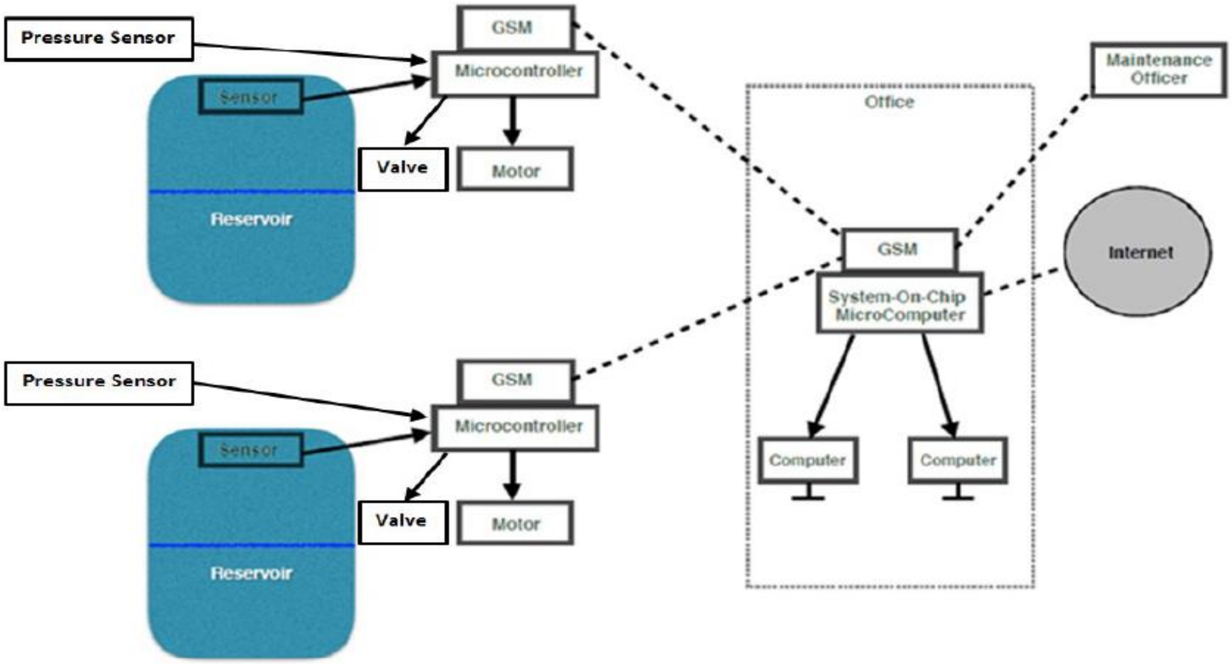


Figure 12: System Architecture(Natividad and Palaoag 2019)

Chapter 3: Methodology

3.1 Introduction

This research is conducted under the purview of the APV MaGa and is aimed at Designing and sizing a solar water pumping system, and to conduct a simulation for a prototype to be developed that can automatically monitor remotely and regulate the water distribution in one of the APV MaGa sites. The methods of site assessment identification and selection are highlighted in this chapter. This chapter also include climate data of the site and data relevant to the design selection and sizing of the system.

3.2 Case Study Location and Description

The republic of the Gambia was taken as the case study country for this research since it is one of the countries in focus for the APV MaGa project. The country is a small West African country bordered by Senegal all around her three sides and the Atlantic Ocean in the West. The small country has an area of 10, 689 square kilometres with a population of 1,857, 181 (Appendix A) as reported in the 2013 census by the Gambia Bureau of Statistics (GBoS). The capital city, Banjul (13.28N 16.36W) is located along the coastal areas and is one of the metropolitan areas. Banjul is also one of the eight (8) Local Government Areas (LGA) including; Kanifing, Brikama, Mansakonko, Kerewan, Kuntuar, Janjanburreh and Basse.

The Gambia has a tropical climate with a hot and rainy season that span from June to November and a dry, cold and dusty season from November to May.

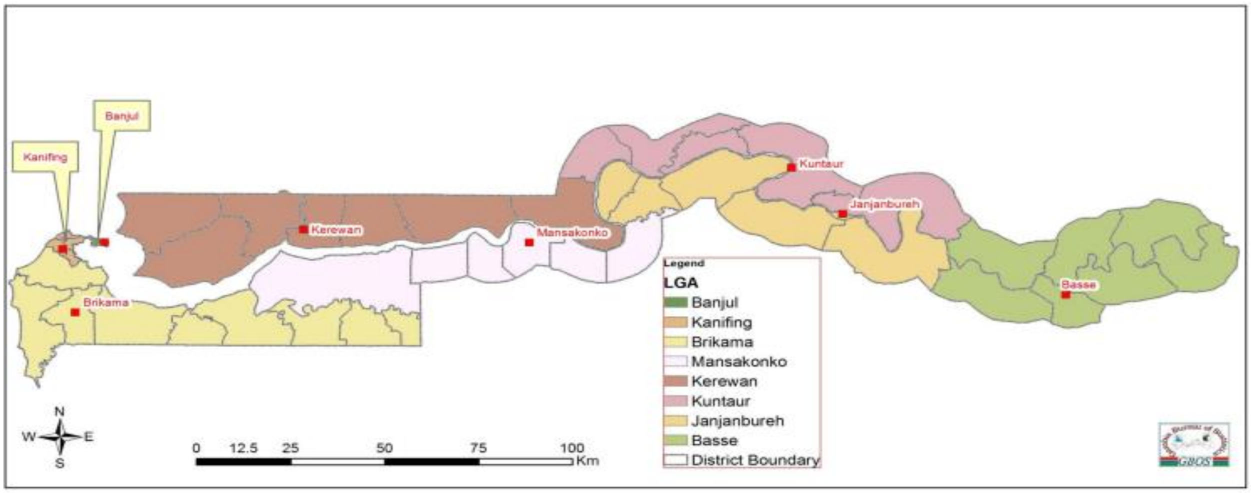


Figure 12: *Map of the Gambia showing all the Local Government Areas, (source: GBoS)*

Maruo Farms was chosen for the research area, located in Pacharr (latitude 13.529597, Longitude -14.862808) in Fulladu West, central river region(CRR) of the Gambia. It is within the Janjanburreh District. According to the 2013 census conducted by GBoS, Pacharr village has a population of 1329 inhabitants along the south bank road as shown in (Appendix B). Pacharr is a community with many people engage in agriculture working in communal rice fields.

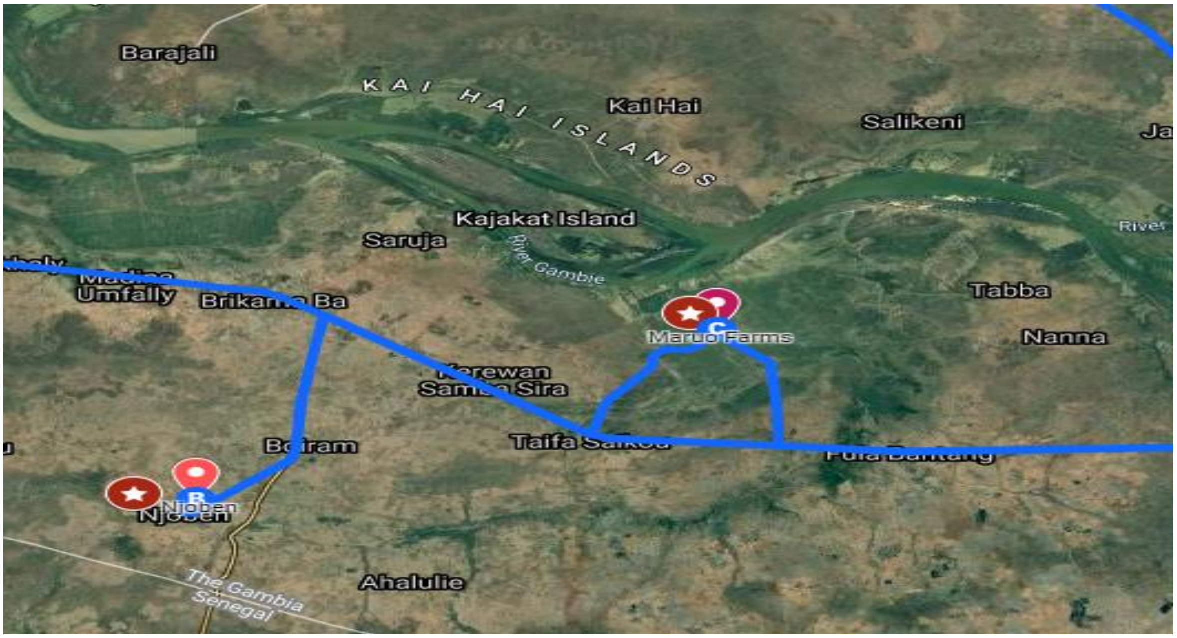


Figure 13*: *Satellite View of the Maruo Farms with the River Gambia and Surrounding Villages.

The farm is 4km from the village Pacharr, 8km from the nearest city in Brikama Baa and 260km from the capital city Banjul approximately. The river Gambia, which is the main source of water supply to the farm is just a few kilometres North of the farm.

This farm has a total land area of 30 hectares, divided into 5 zones and 2 blocks which are cultivated with different varieties of rice. The farm produced 800 metric tons of rice this year, and sold a 25 kg bag of rice for D650. They also have the out growers that cultivate groundnuts, beans, and corn but on a different site.

Maruo farms like many other rice farms in the Pacharr community struggle to have reliable water supply for production especially during the dry season. This is because they depend on high and low tides to access the water, and the water received is shared between them and the out growers.

They currently don’t have any form of irrigation system; channels are dug for the water passage from the canal.

3.3 Data Collection and Analysis

Data was collected from different institutions in the Gambia and in the research site in Pacharr at the Maruo Farms. A total of 10 different sites (Farms) across the country were investigated to analyse the different water supply systems in the farms. Climate data was collected from the data published on the website of the Gambia Bureau of Statistics. The Gambia Bureau of statistics is a government department under the Ministry of Finance and economic affairs. This department is responsible for the collection, analysis and dissemination of statistical data. The data collected from GBoS span from 2010 to 2017 covering Yundum, Jenoi, Kerewan, Janjanburreh and Basse.

Types of Data Collected:

1. Assessment of the Water Supply Systems
2. Temperature data of the Case Study Site
3. Relative Humidity
4. Rainfall Data

3.4 Analysis of the Collected Data

3.4.1 Assessment of the Water Supply Systems

Google maps was used to locate the farms and collect information from the contact person listed. A total of 10 farms were considered as per the criteria that are of interest to the project. Three sites were examined in West Coast region and the Central River Region, two in the Upper River Region and one in each of North Bank Region and Lower River Region.

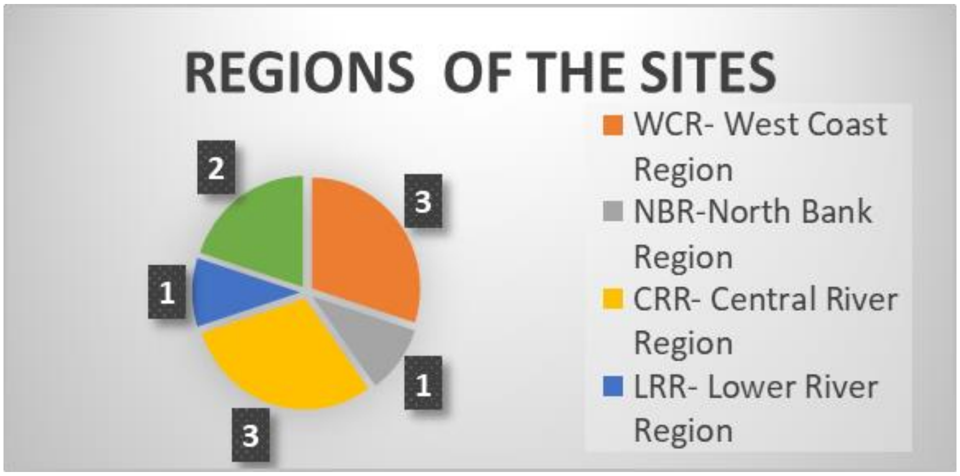


Figure 14: ***Site Selection by Region (Nadji Bi Report)***

EpiCollect5 tool was used for the data collection and entry of information collected from the site and interviews from the farm managers and supervisors. The tool is an android application that can be utilized offline hence it was ideal since internet connectivity is not stable across all the regions in the Gambia.

Data collection was done in collaboration with APV Maga project partners in the Gambia, the food and Agricultural Organization(FAO) and Nadji Bi Gambia.

Figure 15*: *Assessed sites and their location on the map of the Gambia

The shortlisted sites which were deemed suitable and are of the potential to partner with APV MaGa project are;

1. Sukuta Women's Garden,
2. Darsilami Youth Garden,
3. Njobo Bantang women Garden Berefet,
4. Conteh Kunda Njie Communal Garden,

5. Madina Lamin Kanteh Vegetable Garden,
6. Darsilameh Sandu Vegetable Garden,
7. Dampha Kunda vegetable Garden,
8. Njoben Vegetable Garden,
9. Sutukung Vegetable Garden
10. Maruo Farms

In this study, the farms were assessed based on their sources of water, irrigation method and whether or not there is a smart system method adopted for the monitoring and regulation of water supply and distribution in the farms.

3.4.2 Temperature Data of the Case Study Area

The case study area is located in the CRR region and in the Janjanburreh district. As it can be observed in the graph below, temperatures peak from March to June with the month of May showing the highest temperature of 43.4℃. Lowest temperatures are recorded from November to February during the dry and cold season.

In the hot season, the hottest day in Janjanburreh records a maximum temperature of 43.4℃ and the minimum temperature recorded averages 19.6℃ in around May 15th.

In the cold season likewise, the coldest day records a temperature averaging 10.6℃ and a high temperature of 38.3℃ in around January 15th as can be seen from the graph below. Appendixes C, D and E shows the Mean, maximum and Minimum temperature data from the Janjanburreh Station during the periods of 2010-2017.

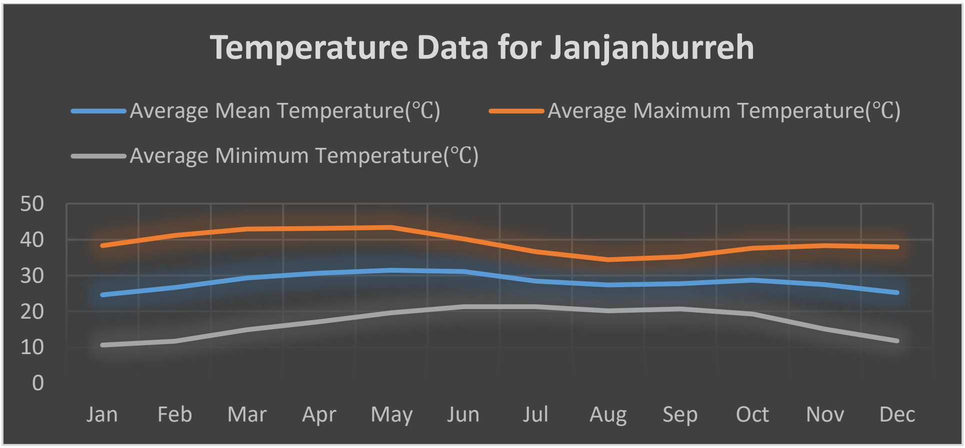


***Figure 16*: Average Temperature Data of Janjanburreh.**

3.4.3 Relative Humidity of the Case Study Area

August is the most humid month in the Gambia on average recording about 78% of humidity. This corresponds to the rainy season in the country. The peaked periods of rain are mostly recorded from June to October hence the high relative humidity readings during those months which are characterised by hot and wet conditions.

From the graph shown below, the month of February records the lowest humidity reading of 31%. This is during the cold and the dry periods of winter in the Gambia. The average annual percentage of humidity in the Gambia is 52.6%. Appendix F shows recorded Relative Humidity in the periods of 2010-2017.

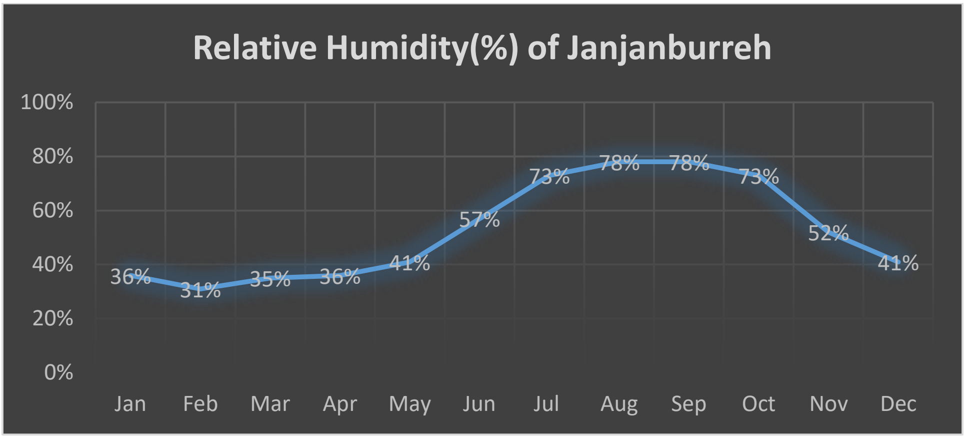


Figure 17**: *Average Relative Humidity reading in Janjanburreh***

3.4.5 Average Rainfall (mm) in the Janjanburreh Station

The rainy season in the Gambia spans from May to October with the month of August (the wettest) recording mostly the highest rains with 280.9mm. The driest month in the rainy season is May with 19.1mm Agricultural activities are mostly done during these period. Understanding the rainfall patter is important since most of crop production depend on rainfall.

Beginning November, the rain stops and the dry season begins lasting up to April with cold and dry conditions. The periods record 0mm of rainfall. This data is shown in the Appendix Shown in the Appendix section.

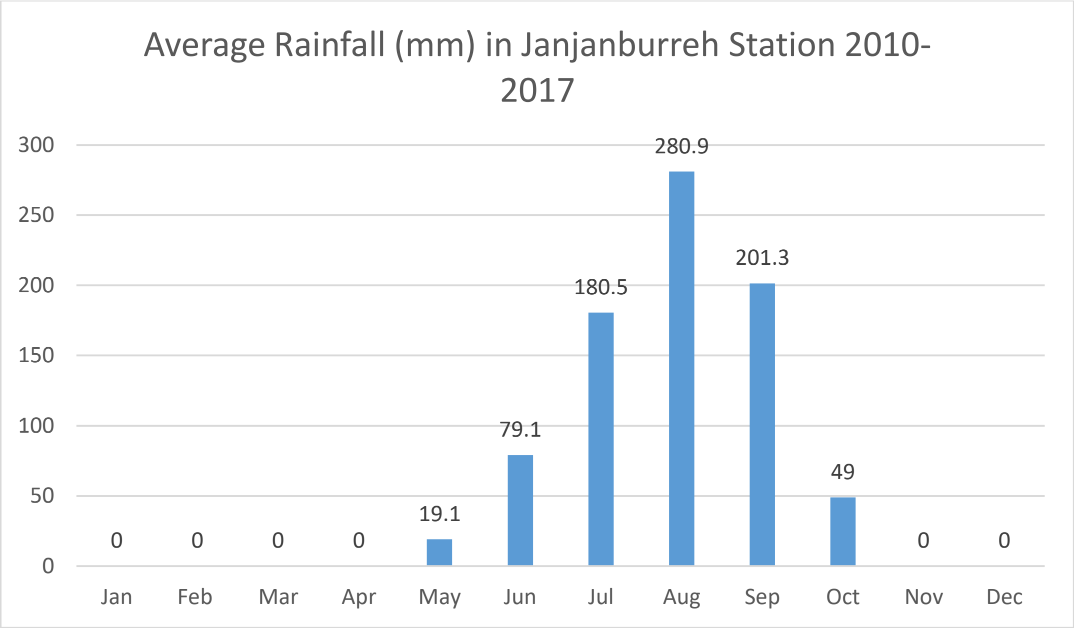


Figure 18**:** ***Average Rainfall data (mm) in Janjanburreh***

3.5 System Designing and Component Selection

The system design and Selection of the Components was done using HOMER software which enable to the optimization as well as the economic evaluation of the system.

3.5.1 HOMER Software

HOMER is a software that is used to simulate, optimized a design and perform sensitivity analysis of micro-grids and off-grid systems. The software is also use for the selection of low cost solutions for remote power systems, and islanded utilities. It stands for Hybrid Optimization of Multiple Energy Resources. The system was developed in the united states by the National Renewable Energy Laboratory(NREL).

3.5.2 Preliminary Site Assessment

Sizing the solar water pumping system requires the analysis of the site. Thorough assessment of the sources of water, water needs of the farm, solar irradiation of the site and the evaluation of the flow rate and Total Dynamic Head of the pumping system.

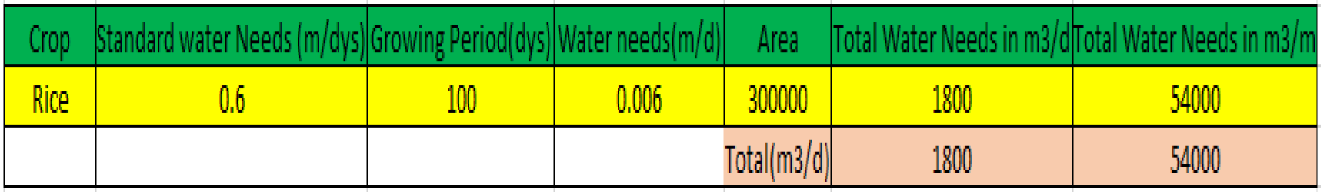
a. Source of water

As mentioned in the case study location and description, the area is not far from the River Gambia which is their main source of water. Tunnels are dug as a passage of water to the farm during high tides which is the form of irrigation adopted by the farm currently. In this study, we will assume that water from the river is channelled through the tunnel 0.5km of the Maruo farm. Water from this tunnel will be pumped to the farm, using a solar water pumping system.

b. Water needs of the Farm and the

The farm under study is a rice field which has a capacity of 30 hectares. Appendix H and I respectively show the crop water needs and total growing periods of various crops derived from a FAO Irrigation Water Management training manual(CHAPTER 3: CROP WATER NEEDS n.d.). The water supplied is mostly used for cooling purposes, only a little amount is taken up by the plant for growth(Schneekloth and Andales 2009).

According to the FAO manual, the crop water needs for rice over the total growing period is 450-700mm and the total growing period is between 90-150 days. In this study, we consider the crop water need for rice to be 600mm/total growing period and the total growing period of rice as 100 days.



Crop	Standard water Needs (m/dys)	Growing Period(dys)	Water needs(m/d)	Area	Total Water Needs in m3/d	Total Water Needs in m3/m
Rice	0.6	100	0.006	300000	1800	54000
				Total(m3/d)	1800	54000

Table 7*: *Irrigation Water Needs

From the table above, in a day, the farm requires 1800m^3 of water for the cultivation. This amounts to 54000m^3 of water in a month.

The farm cultivates crops in two seasons each of which spans for 3 months. The season commences in December and ends in May 6months later. The figure below outlines the monthly water supplied to the field over the two growing seasons.

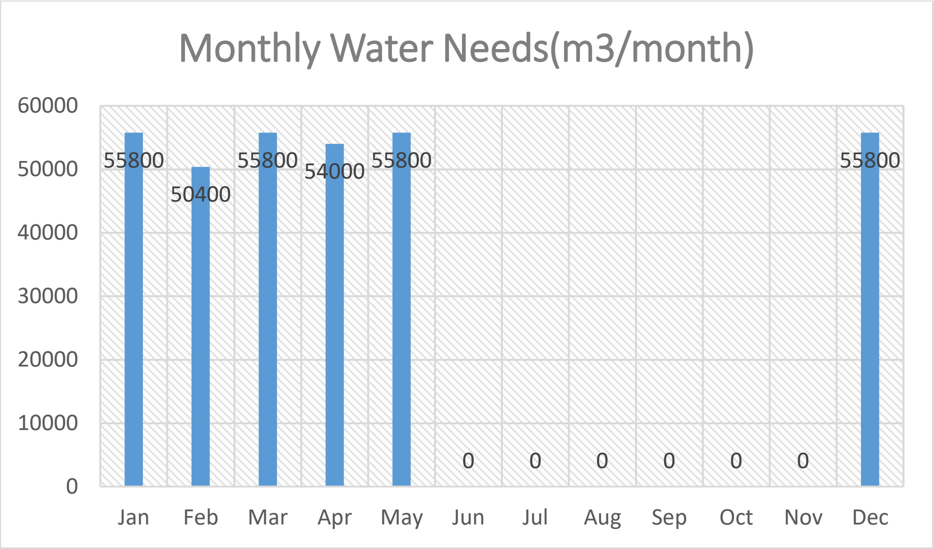


***Figure 19**: Monthly Irrigation Water Needs*

c. Solar Irradiation of the site

The Gambia is undoubtedly blessed with huge solar resources fit for a solar water pumping system. It has an average global solar radiation of 5.64kwh/m^2/day sufficient for solar applications. The solar radiation is evenly distributed throughout the country. The solar photovoltaic potential ranges from 4.4kwh/kwp to more than 4.6kwh/kwp. The site in concern has a solar photovoltaic potential of 4.5kwh/kwp as shown in figure 3.11 making the installation of a solar water pumping system feasible.

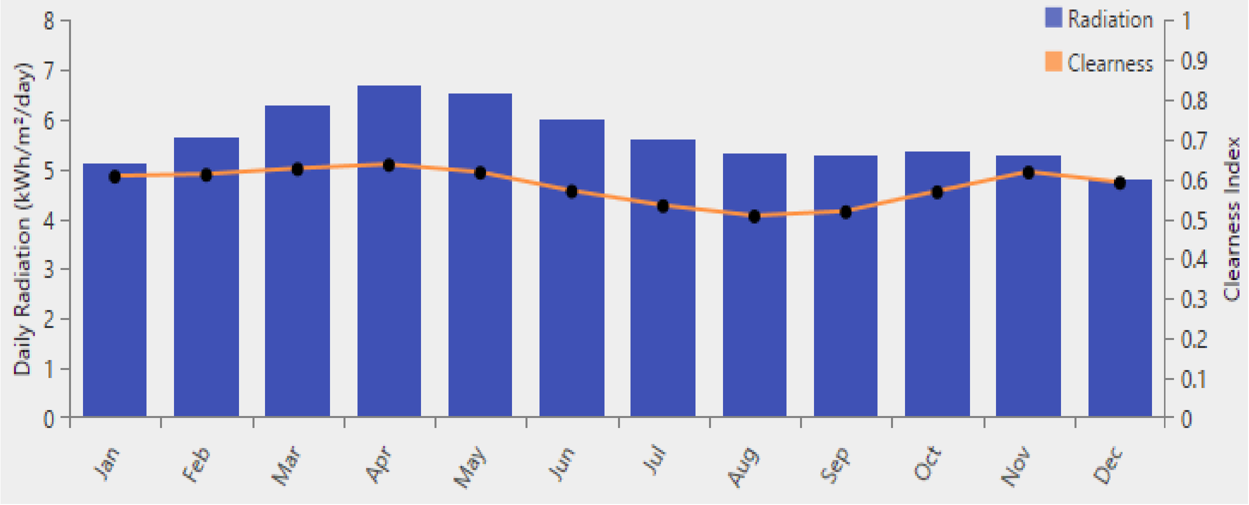


***Figure 20**: Monthly Average Global Horizontal Irradiation with Clearness Index in Janjanburreh (Homer)*

d. Flow Rate

The flow rate is also another entity that is very necessary for the determination of power to be supplied by the pump. In this research, the flow rate was calculated as shown below;

- The water needs of the farm in a day = 1800m^3
- Operation time of the pump is = 8 hours
- Flow rate = 1800m^3/8hrs = 225m^3/hours = 0.0625m^3/sec

e. Total Dynamic Head (TDH)

The total dynamic head is significant for the determination of the pump power required to supply the water to the community and the farm. It is important to note that the farm draws its water from the tunnel. In this case, a surface pump is recommended. The pump is placed at a height of 4m above the water level in the tunnel which is 5m deep. The diameter of the pipes in use is 160cm and is made up of plastic pipe (see the appendix).

NB: It was observed that there was no tank for storage in the farm and community, hence we consider using battery storage as it has a cheaper life cycle cost as compared to that of tank storage(Soenen et al. 2021).

- Total Dynamic Head (TDH) = Vertical Suction lift + Friction losses
- Vertical suction lift = 4m

Using the Hazen-William equation for pipe flow, the friction head was calculated as shown in the equation below.

$$H_f = 10.67\left(\frac{Qm3/s}{c}\right)^{1.852} \times LD^{-4.87} \qquad (3.3)$$

Q = Flow Rate in m^3/sec

D = Diameter of the pipe in m = 0.16m

f = Friction factor

C = Hazen-William coefficient = 150 for Poly pipes

L= Length of the Pipe in m = 500m

Using the equation above, the frictional head loss along the pipe wall as the water flows in it was calculated to be 21.68m.

Total Dynamic Head = 4m + 21.68m

Total Dynamic Head($h+\Delta H$) = 25.68m

3.5.3 Pump Sizing

After assessing the factors mentioned above, the system sizing followed. The sizing of the system began by sizing the pump. Since the water needs and head is known, sizing the pump requires the use the formula below(Al-Waeli et al. 2017):

$$P_{pump} = \frac{\rho g(h+\Delta H)Q}{\eta_{pump} \times \eta_{motor}} \qquad (3.6)$$

Where;

ρ = Density of water, 1000 kg/m^3

g = acceleration due to gravity, 9.81m/s^2

$h+\Delta H$ = Total Dynamic Head, TDH

Q = flow rate of the fluid

η_{pump} = pump efficiency = 85%

η_{motor} = motor efficiency = 85%

3.6 Economics of the System

The cost analysis was done using HOMER software. The HOMER software is inbuilt with the capability of determining the Levelised Cost of Energy(COE) as well as the Net Present Cost(NPC) of the optimized system. A sensitivity analysis was also conducted to ascertain the variation of the COE and NPC values with the fluidity of the average solar radiation.

3.6.1 Levelised Cost of Energy

This is the per unit cost of energy produced. It is the average NPC of electricity generated over the life span of the project. It is used as an indicator to compare the different methods of electricity generated.

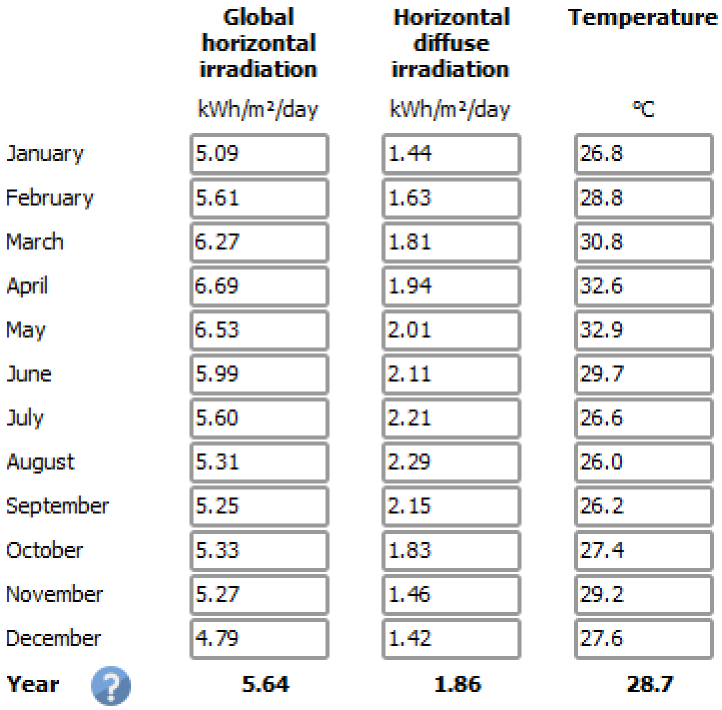
3.6.2 Net Present Cost

This is the difference between the present value of the cost of installing and operating the components of a system and the present value of all the revenues recovered from the system over its lifespan.

3.8 System Sizing with Pvsyst Software

The system was also sized using Pvsyst software to evaluate the performance of the system with a tank storage. The software helped us in the appropriate selection of the pump as well the selection of PV panels and appropriate inverters in designing the system. Certain input data were utilized such as total head for the pump, water demand, level of the pump and information about the characteristics of the site. It helped us in choosing the appropriate diameter and length of the pipe, and the features of the tank. The advantage of using the Pvsyst software is that it helped us size the storage tank capable of storing water when up to 2 days of autonomy are considered which is not possible with the use of Homer software.

The simulation process started with first identifying the site considered for the case study for the assessment of the meteorological data. The map on the software was used to locate the Maruo farm on the map. The meteorological data is the average data collected and compiled by NASA over a period of time. The Global horizontal irradiation, Horizontal diffuse irradiation and temperature values were recorded and was later used by the software during the simulation process. The table below shows the gathered meteorological data collected and compiled by NASA.



	Global horizontal irradiation	Horizontal diffuse irradiation	Temperature
	kWh/m^2/day	kWh/m^2/day	°C
January	5.09	1.44	26.8
February	5.61	1.63	28.8
March	6.27	1.81	30.8
April	6.69	1.94	32.6
May	6.53	2.01	32.9
June	5.99	2.11	29.7
July	5.60	2.21	26.6
August	5.31	2.29	26.0
September	5.25	2.15	26.2
October	5.33	1.83	27.4
November	5.27	1.46	29.2
December	4.79	1.42	27.6
Year ?	**5.64**	**1.86**	**28.7**

Table 8*: *Meteorological Data of Maruo Farms(Pvsyst).

The orientation of the solar photovoltaic systems was analysed with the tilt and azimuth angles taken as 17^{o} and 1^{o} respectively. The figure below shows the stage of the simulation process using Pvsyst software. The process involved the assessment of the water needs for the simulation which was determined in the subchapters above.

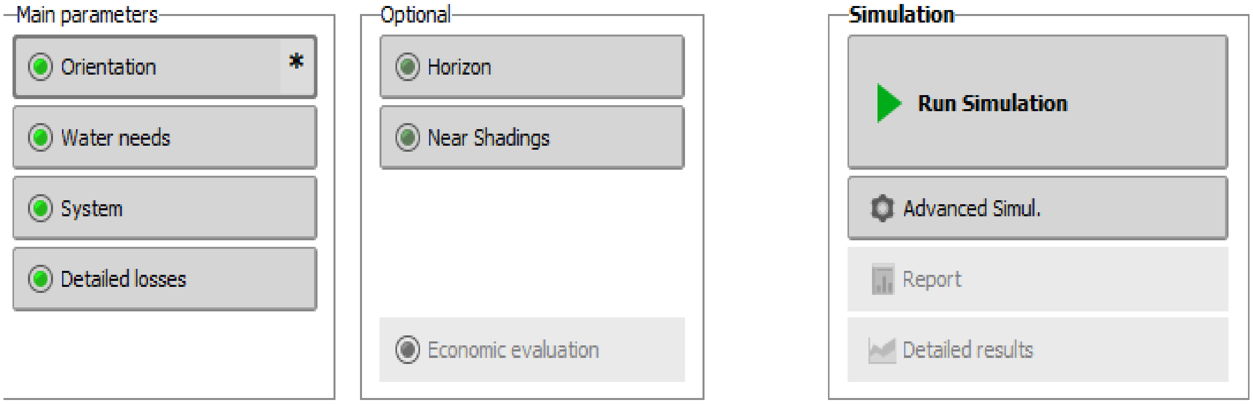
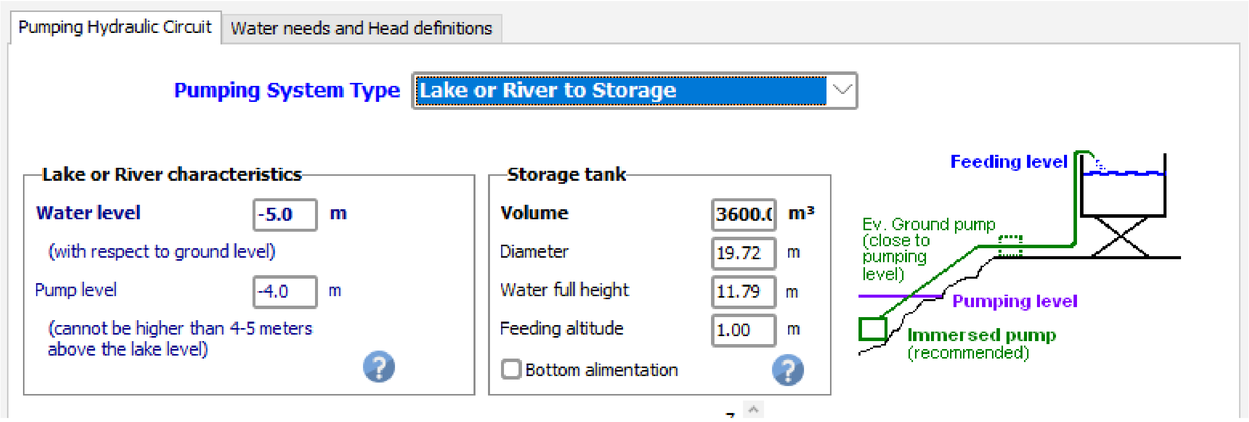


Figure 21*: *Simulation Processes (Pvsyst)



Pumping System Type Lake or River to Storage

Lake or River characteristics

Water level -5.0 **m**
(with respect to ground level)
Pump level -4.0 m
(cannot be higher than 4-5 meters above the lake level)

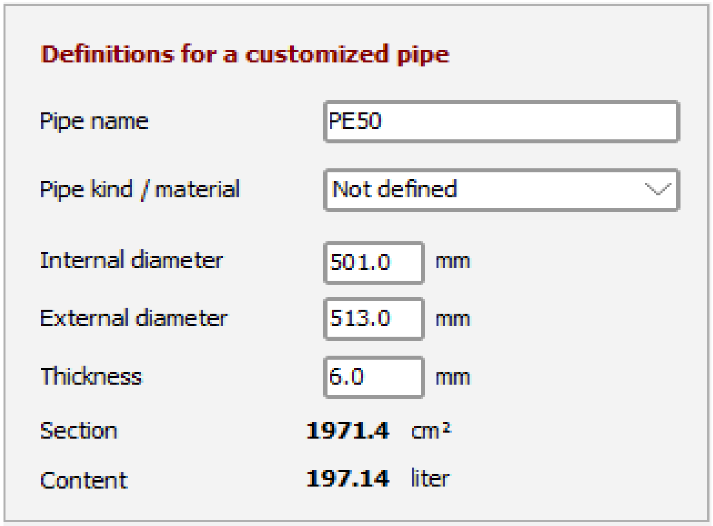
Storage tank

Volume 3600.(**m³**
Diameter 19.72 m
Water full height 11.79 m
Feeding altitude 1.00 m
☐ Bottom alimentation

Figure 22: Pumping Hydraulic Circuit

A lake or River storage was used since the source of the water is a surface water source flowing from the River Gambia. It is recommended to select an immersed pump by Pvsyst and a tank of volume 2000m^3 with specification of the tank shown in the figure above.

A pipe of length 500m was chosen since the water pathway is 0.5km away from the farm. The frictional losses were determined in the above subchapters. The size and the type of pipe chosen for this design is shown in the figure below.

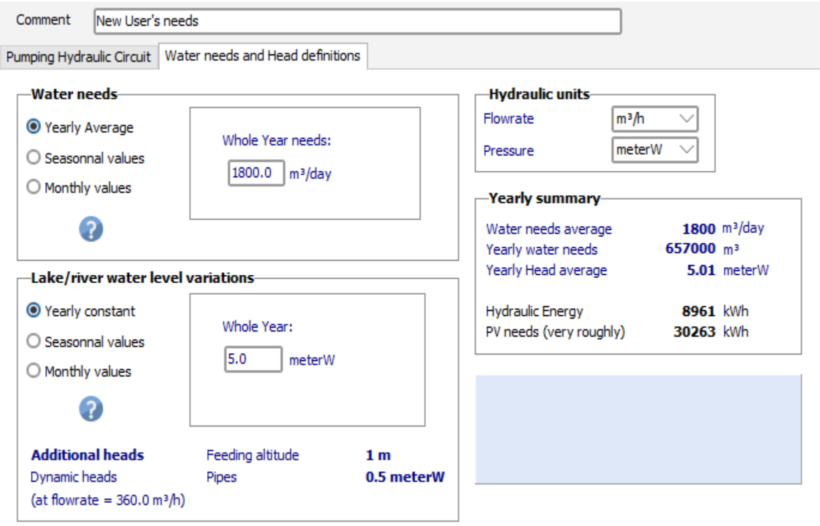


Definitions for a customized pipe

Pipe name	PE50	
Pipe kind / material	Not defined	
Internal diameter	501.0	mm
External diameter	513.0	mm
Thickness	6.0	mm
Section	**1971.4**	cm²
Content	**197.14**	liter

Figure 23: Pipe Size and Type.

The water needs were analysed as it has been done in the manual approach of assessing the water and energy required to supply water. The figure below shows the details of the daily and yearly water needs of the farm.


Comment: New User's needs

Water needs

- ● Yearly Average
- ○ Seasonnal values
- ○ Monthly values

Whole Year needs: 1800.0 m³/day

Hydraulic units

Flowrate: m³/h
Pressure: meterW

Yearly summary

Water needs average	1800	m³/day
Yearly water needs	657000	m³
Yearly Head average	5.01	meterW
Hydraulic Energy	8961	kWh
PV needs (very roughly)	30263	kWh

Lake/river water level variations

- ● Yearly constant
- ○ Seasonnal values
- ○ Monthly values

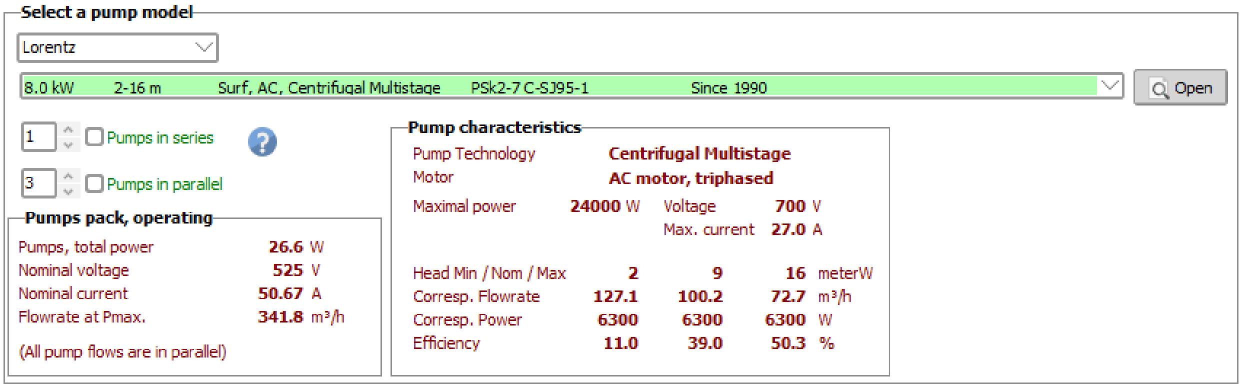
Whole Year: 5.0 meterW

Additional heads

Dynamic heads (at flowrate = 360.0 m³/h)	Feeding altitude	1 m
	Pipes	0.5 meterW

Figure 24: Water needs and Head Definitions

A Lorentz pumps of 8kw capacity was selected requiring 3 pumps in parallel to support the total pumping power required. It is a centrifugal multi stage surface pump, AC type of the model PSK2-7 C-5J95-1.


Select a pump model

Lorentz

8.0 kW 2-16 m Surf, AC, Centrifugal Multistage PSk2-7 C-SJ95-1 Since 1990

1 ☐ Pumps in series
3 ☐ Pumps in parallel

Pumps pack, operating

Pumps, total power	26.6	W
Nominal voltage	525	V
Nominal current	50.67	A
Flowrate at Pmax.	341.8	m³/h

(All pump flows are in parallel)

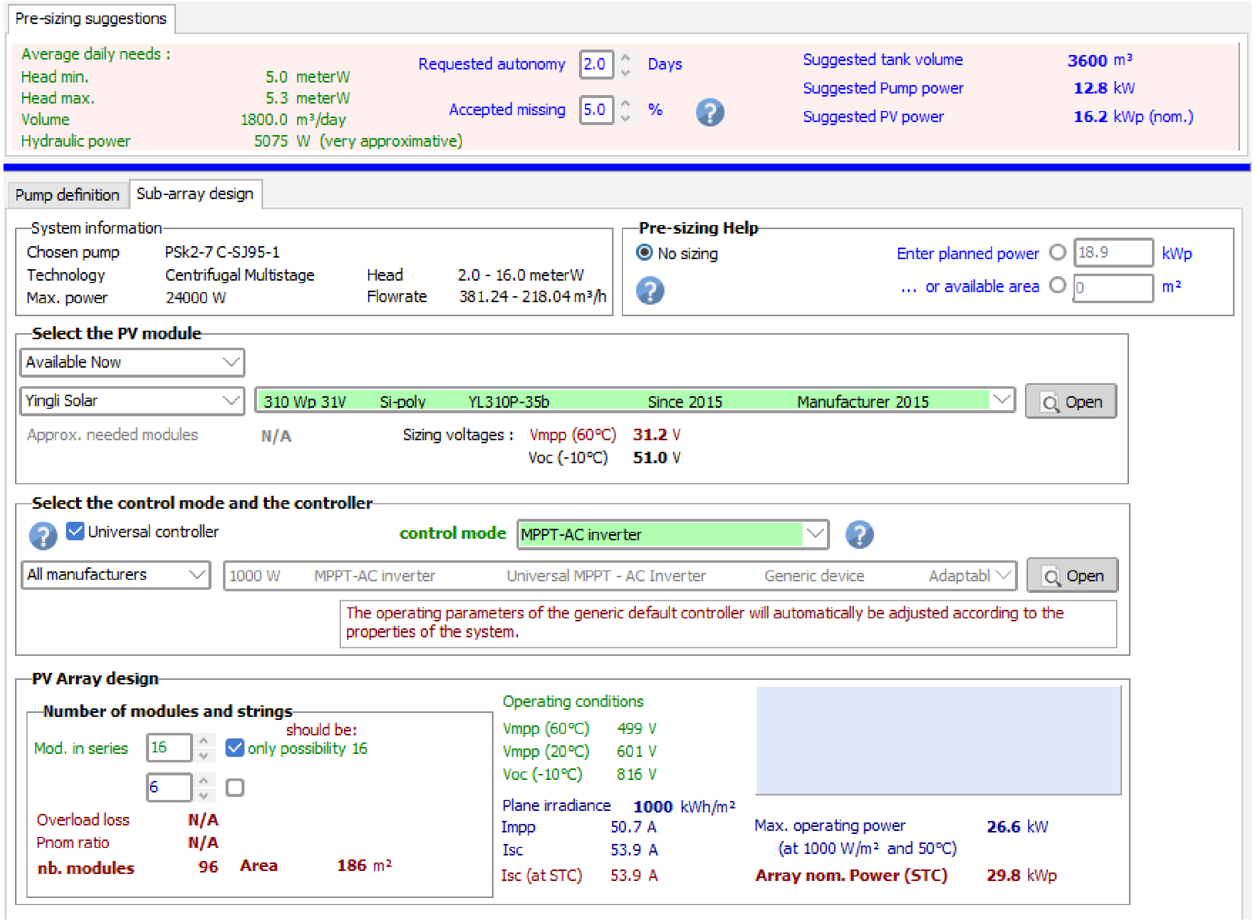
Pump characteristics

Pump Technology: Centrifugal Multistage
Motor: AC motor, triphased
Maximal power: 24000 W
Voltage: 700 V
Max. current: 27.0 A

	Min	Nom	Max	
Head Min / Nom / Max	2	9	16	meterW
Corresp. Flowrate	127.1	100.2	72.7	m³/h
Corresp. Power	6300	6300	6300	W
Efficiency	11.0	39.0	50.3	%

Figure 25: Pump model Selection

The solar panels used to power the system was Yingli Solar, model name YL310P-35b. A total of 96 panels of 310watts were used to size the system. A configuration of 16 series Panels by 6 Panels in parallel was suggested. An MPPT inverter was suggested to be able to support and run the system. The detailed sub-array design is shown in the diagram below.



Average daily needs :
Head min. 5.0 meterW
Head max. 5.3 meterW
Volume 1800.0 m³/day
Hydraulic power 5075 W (very approximative)

Requested autonomy 2.0 Days
Accepted missing 5.0 %

Suggested tank volume 3600 m³
Suggested Pump power 12.8 kW
Suggested PV power 16.2 kWp (nom.)

System information
Chosen pump PSk2-7 C-SJ95-1
Technology Centrifugal Multistage
Max. power 24000 W
Head 2.0 - 16.0 meterW
Flowrate 381.24 - 218.04 m³/h

Pre-sizing Help
● No sizing
Enter planned power ○ 18.9 kWp
... or available area ○ 0 m²

Select the PV module
Available Now
Yingli Solar
310 Wp 31V Si-poly YL310P-35b Since 2015 Manufacturer 2015
Approx. needed modules N/A
Sizing voltages : Vmpp (60°C) 31.2 V
Voc (-10°C) 51.0 V

Select the control mode and the controller
☑ Universal controller
control mode MPPT-AC inverter
All manufacturers
1000 W MPPT-AC inverter Universal MPPT - AC Inverter Generic device Adaptabl
The operating parameters of the generic default controller will automatically be adjusted according to the properties of the system.

PV Array design
Number of modules and strings
should be:
Mod. in series 16 ☑ only possibility 16
6 ☐
Overload loss N/A
Pnom ratio N/A
nb. modules 96 Area 186 m²

Operating conditions
Vmpp (60°C) 499 V
Vmpp (20°C) 601 V
Voc (-10°C) 816 V
Plane irradiance 1000 kWh/m²
Impp 50.7 A
Isc 53.9 A
Isc (at STC) 53.9 A

Max. operating power 26.6 kW
(at 1000 W/m² and 50°C)
Array nom. Power (STC) 29.8 kWp

Figure 26: PV Panels Design

If water is to be stored for to support farm operations in two days during cloudy days, a tank capable of storing 3600m^3 is suggested with the pump expected to consume 12.8kw of power.

3.8.1 Inverter and Solar Panel Sizing

The converter converts the DC current to AC that powers the pump and other electronic devices. The inverter and solar power required was calculated as;

- Inverter Power Required = $\frac{Pump\ Power}{\eta inverter}$
- Number of PV Panels = $\frac{Solar\ Power\ Required}{Panel\ Rating}$
- Number of Parallel strings = $\frac{Rated\ voltage\ of\ Inverter}{Rated\ voltage\ of\ PV\ Panel}$
- Number of series Panels = $\frac{Total\ Number\ of\ Panels}{Number\ of\ Parallel\ strings}$

3.7 Design of the Smart Water Monitoring System for Irrigation

The figure below illustrates the overview of the proposed design of the smart water monitoring and regulation system. The design consists of a solar photovoltaic system arrangement that produces the electrical power running all the other components. The electricity generated powers up a motor that is running the pump. The pump produces the pressure head needed to distribute the water to the farm and the community. The water is stored in a tank initially and is later distributed to the and the farm.

The sensors are embedded systems that interact with the microcontroller by sending measured field parameters to the microcontroller. Data collected by the microcontroller will be stored in a server where it can be analysed and then be accessed and manipulated by a user interface in the form of a mobile application or a web browser. This interaction can be called an Internet of Things Interaction.

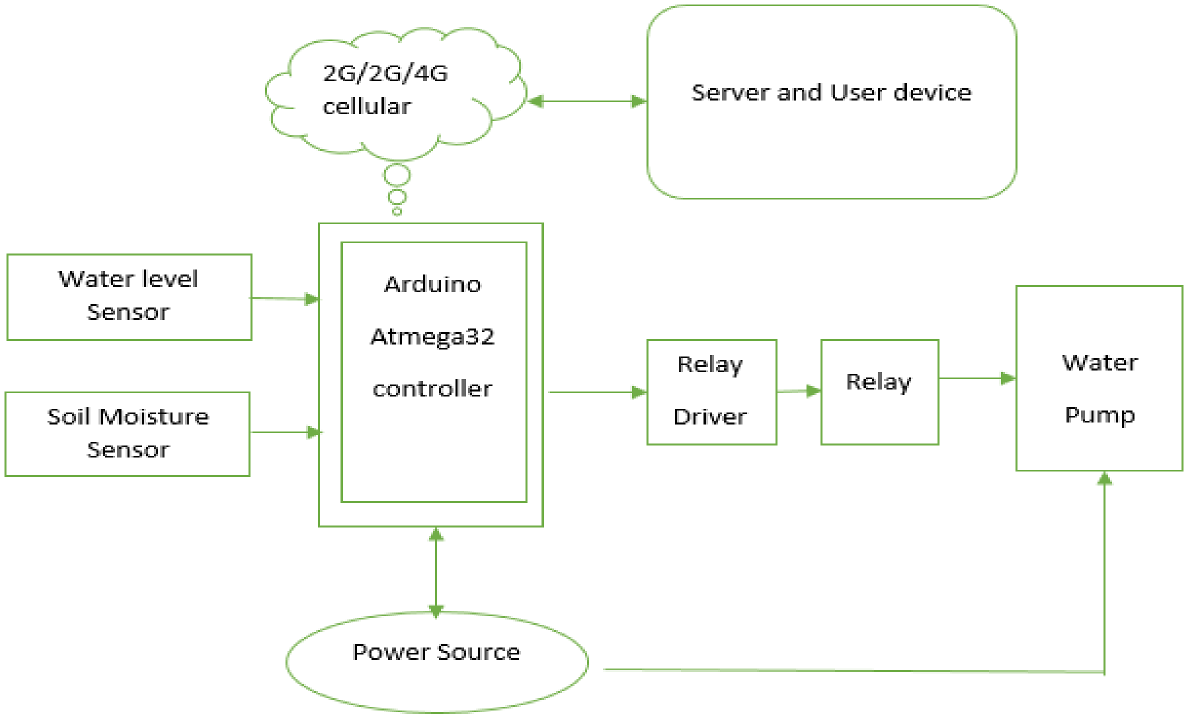


Figure 27: Overview of the smart Water Monitoring and Regulation System

3.7.1 Irrigation system Components and Description

The components of the system are a PV Power source, pump, storage tank, water level sensor, soil moisture sensor, cellular connection between the hardware and the internet or cloud system.

i. PV system

The PV system consist of the solar panels, controllers, inverters, and battery system. This is the power source power all other electricity consuming components in the overall system i.e. the pumps and the electronic components of the system. In our study we considered using Yingli Solar panels of 340W. The power is supplied to the Arduino board via an AC to DC power adapter to have a 9-12V DC from the power jerk or the VIN pin, or 5V from the USB connector(Abba et al. 2019)

ii. Motor Pump

A motor pump is included in this research the pump the water to the tank and the irrigation facility. The motor pump is controlled by the microcontroller when the relay switch connected to the pump is activated. The motor pump reacts to the field conditions sensed by the sensors and processed by the microcontroller.

iii. Storage Tank

The storage tank stores the water pump from the water source and supplies it to the irrigation field when required. It has an ultrasonic sensor that detects the water and works in tandem with the irrigation field sensors to make decision on the direction of flow of the water.

iv. Field Sensors

The sensors measure field parameters and send the signals to the microcontroller to be processed. The data is made available to the user through the user interface via a mobile application or a web browser. The microcontroller also sends signals back to the actuators e.g. the pump in response to the parameters detected by the sensor based on written programs or inputs from users via the interface.

The ultrasonic sensor measures distance by emitting an ultra sound of 40KHz that travels through the air and bounces back to the module when it hits an obstacle. The sensor HC-SR04 has 4 pins i.e. VCC which is connected to the power source of +5V, the trigger that sends the 8 cycle sonic burst that travels at the speed of sound in 10 micro seconds and is received by the echo pin and the GND pin which is connected to ground. It is used to measure the water level in the tank.

The soil moisture sensor measures the water level in the soil and helps to determine when the plant should be watered and how fast it is being drained. This sensor measures soil moisture by determining the dielectric permittivity of the soil using capacitance. It has a sensor probe which is dipped in the soil next to the plant and an electric circuit board that processes the signals from the probe and send this signal to the microcontroller through the Analog output pin. It has 4 pins i.e. the VCC, Analog output pin AO, Digital output pin DO and the ground pin GND.

Figure 28*: *HC-SR04 Ultrasonic Sensor

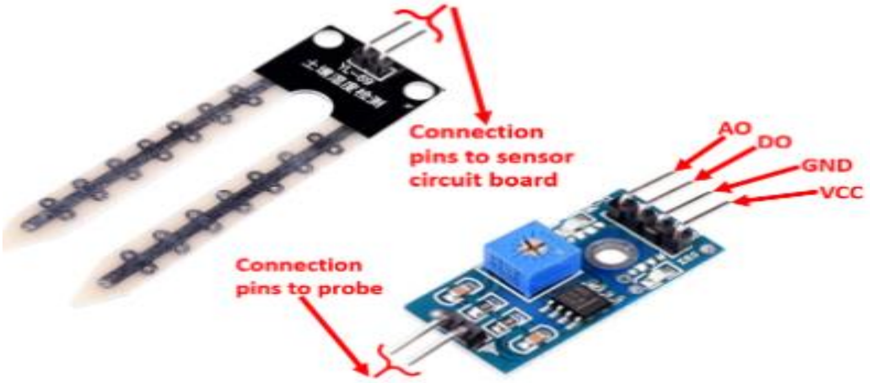


Figure 29*: *Soil Moisture Sensor

v. Microcontroller

This component receives data from the sensors, process the data and send it to the cloud system where it can be accessed by the end user. It initiates the actuation of pump by sending signals based on the processed data to the relay switch. The Arduino Uno board is considered in this study which is operating on an ATmega328 microcontroller.

For this simulation, only the Arduino Uno board is used and is programmed to work on a GSM communication protocol to send and receive data via a Sim card. This is due to the notion that most people in the Gambia especially farmers in the upcountry around the CRR region are more familiar with the basic sending and receiving text messages than the use of Wi-Fi for communication.

The microcontroller is at the pivotal point of the monitoring and regulation of the whole water management system. It is the part that monitors the field parameters with the sensors and regulates the water supply by controlling the watering pump and the tank pump using the relay switch. The board is programmed to monitor and control the mechanisms in the system.

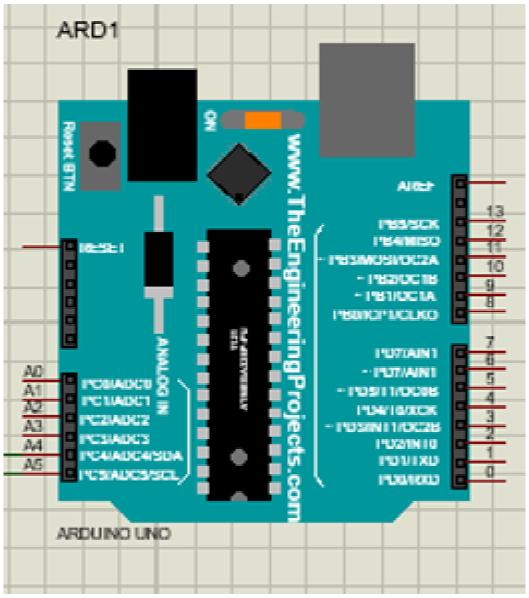


Figure 30*: *Arduino Connected to NodeMCU on Proteus

As it can be seen from the figure above, the Arduino board has 14 pins for input and output with 6 Analog pins.

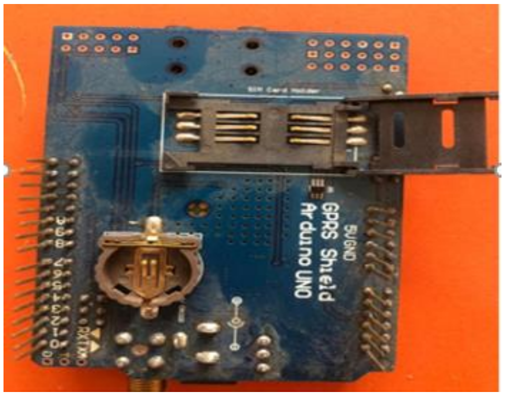


Figure 31*: *Arduino Uno with SIM Card Holder

vi. Relay Switch

The relay opens and closes the circuit when required to actuate the motor pump. It is an electric switch working on the principle of electromagnetism. The coil is magnetized as current flows through it. a lever will be attracted that closes the circuit. Signals to actuate the motor pump comes from the microcontroller as a response to the sensor data processed initially and based on the input uploaded programs and inputs from the user.

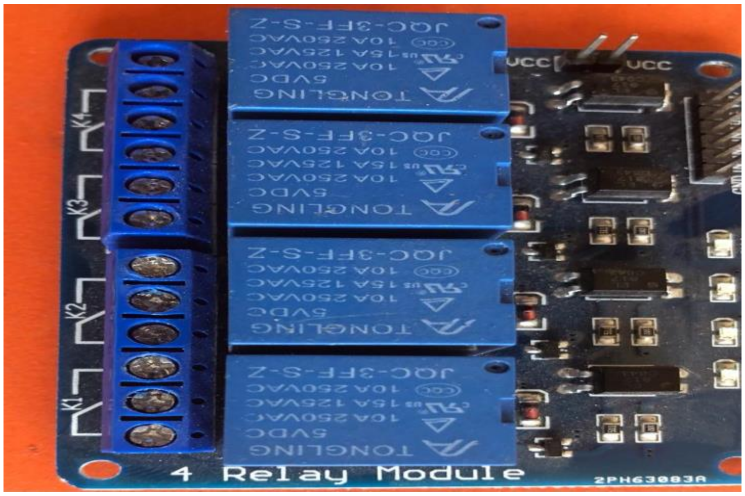


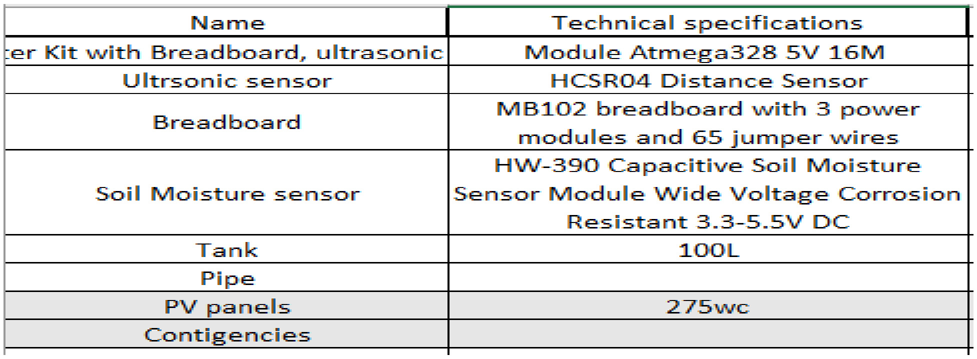
Figure 32*: *Relay Switch

vii. Communication Protocol

Smart devices can be either wired or wireless. The smart IoT devices integrate a communication protocols that eneable it to send and receive data. This data can be sensed data transmitted to the microcontroller to the a cell phone for the case of a cellular transmission or other protocols to an internet server or a database. Communication technologies such as Wi-Fi, bluetooth, zigbee, 2G/3G/4G cellular are well known and very common. Other technologies are also emerging however.

For this study, the cellular communication protocal is considered since it can send data over long distances. It has the ability to send high quantities of data over long distances. The downside of this protocol is that it consumes a lot of power and expensive. The familiarity to this protocol among local Gambians is the major determinant on chossing this protocol. It is comparably of the same cost with the Wi-Fi protocol.

Other communication protocols like WiFI, Zigbee, Bluetooth, LoRaWAN, Z-Wave etc may be considered during implementation depending on availability and cost in the place it is to be installed.



Name	Technical specifications
er Kit with Breadboard, ultrasonic	Module Atmega328 5V 16M
Ultrsonic sensor	HCSR04 Distance Sensor
Breadboard	MB102 breadboard with 3 power modules and 65 jumper wires
Soil Moisture sensor	HW-390 Capacitive Soil Moisture Sensor Module Wide Voltage Corrosion Resistant 3.3-5.5V DC
Tank	100L
Pipe	
PV panels	275wc
Contigencies	

Table 9: Component Specification

3.8 Designing the Prototype

The prototype was supposed to be developed but due to hindrances in getting the components in time, the option of doing a simulation was opted instead. The simulation is used to depict the operation of a real world system. The Proteus Design suite 8 professional was used to do the simulation. This is a PCB design and circuit simulator software. The software was designed by different energy industry professionals to help the energy industry in the transformation of the energy technologies and transition to a low carbon future.

A step by step approach was taken in assembling the components to examine the operation of the individual sensors and verifying the program codes from an open source platform. The programs are initially tested by compiling them in the Arduino software. The connections of the sensors with their respective program codes are shown in the figures below.

I. Ultrasonic Sensor:

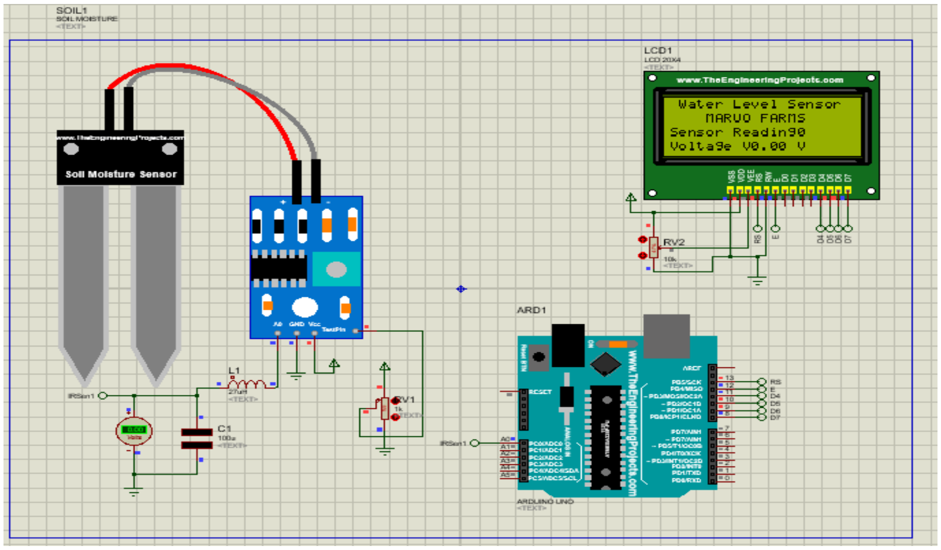


Figure 33: Ultrasonic Sensor Connected to Arduino Uno on Proteus Simulation

```
  const int echoPin = 2; // Echo Pin of Ultrasonic Sensor
  const int pingPin = 3; // Trigger Pin of Ultrasonic Sensor



  void setup()
  {
    Serial.begin(9600); // Starting Serial Communication
    pinMode(pingPin, OUTPUT); // initialising pin 3 as output
    pinMode(echoPin, INPUT); // initialising pin 2 as input
  }

  void loop()
  {
    long duration, inches, cm;

    digitalWrite(pingPin, LOW);
    delayMicroseconds(2);

    digitalWrite(pingPin, HIGH);
    delayMicroseconds(10);

    digitalWrite(pingPin, LOW);


    duration = pulseIn(echoPin, HIGH); // using pulsin function to determine total time
    inches = microsecondsToInches(duration); // calling method
    cm = microsecondsToCentimeters(duration); // calling method


  Serial.print(inches);
  Serial.print("in, ");
  Serial.print(cm);
  Serial.print("cm");
  Serial.println();

  delay(100);
}

long microsecondsToInches(long microseconds) // method to covert microsec to inches
{
 return microseconds / 74 / 2;
}

long microsecondsToCentimeters(long microseconds) // method to covert microsec to centimeters
{
   return microseconds / 29 / 2;
}
```

Figure 34: Program Codes for the Ultrasoni Sensor

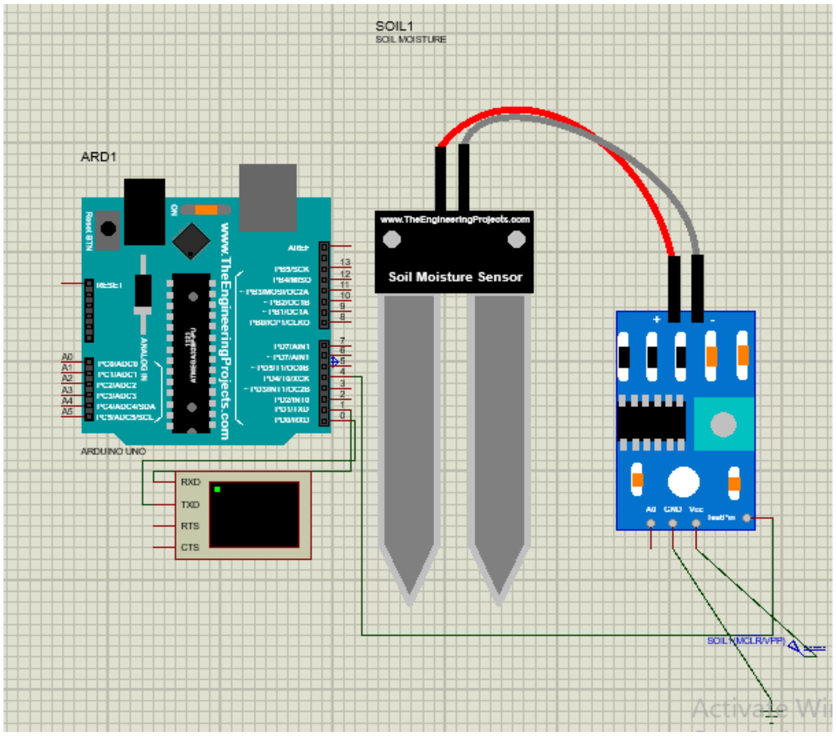
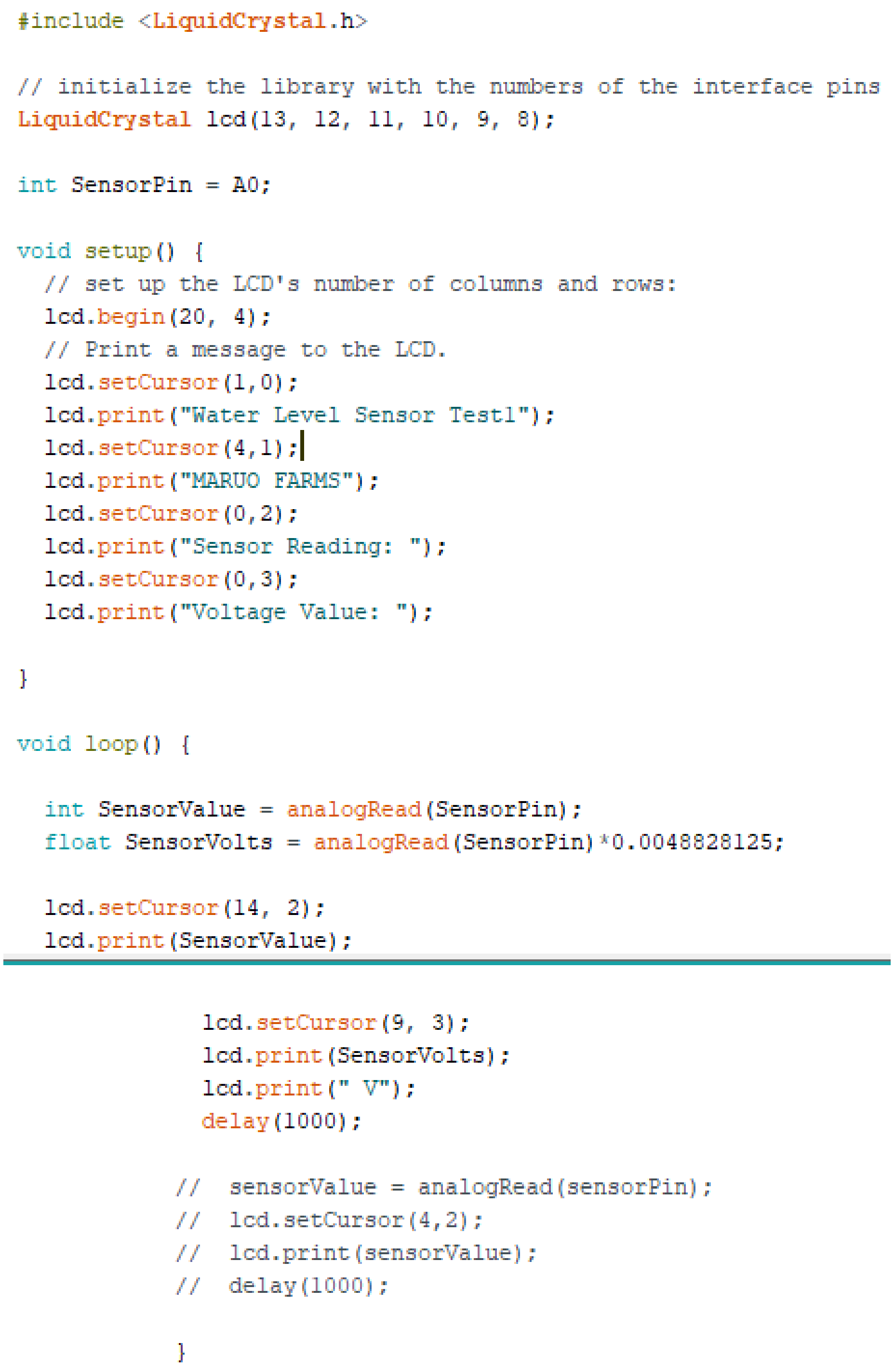


Figure 35: Soil Moisture Sensor Connected to Arduino Uno on Proteus Simulation



```
#include <LiquidCrystal.h>

// initialize the library with the numbers of the interface pins
LiquidCrystal lcd(13, 12, 11, 10, 9, 8);

int SensorPin = A0;

void setup() {
  // set up the LCD's number of columns and rows:
  lcd.begin(20, 4);
  // Print a message to the LCD.
  lcd.setCursor(1,0);
  lcd.print("Water Level Sensor Test1");
  lcd.setCursor(4,1);
  lcd.print("MARUO FARMS");
  lcd.setCursor(0,2);
  lcd.print("Sensor Reading: ");
  lcd.setCursor(0,3);
  lcd.print("Voltage Value: ");

}

void loop() {

  int SensorValue = analogRead(SensorPin);
  float SensorVolts = analogRead(SensorPin)*0.0048828125;

  lcd.setCursor(14, 2);
  lcd.print(SensorValue);
```

```
  lcd.setCursor(9, 3);
  lcd.print(SensorVolts);
  lcd.print(" V");
  delay(1000);

//  sensorValue = analogRead(sensorPin);
//  lcd.setCursor(4,2);
//  lcd.print(sensorValue);
//  delay(1000);

}
```

Figure 36*: *Program codes for the Soil Moisture Sensor

The schematic of the simulations showing the components and connections is shown below. The program codes are also shown below that enables the microcontroller to monitor the field parameters and regulate the water distribution in the system.

The system is program to control the two pumps, one supplies the agricultural field and the other supplies the tank. A water level limit of 65% beyond which the pump supplying the tank will switch off and below which it will be turned on. Likewise, for the moisture in the soil, when it is more than 80%, the pump supplying the irrigation field will be turned off. When the moisture level goes below 80%, the watering pump will be turned on.

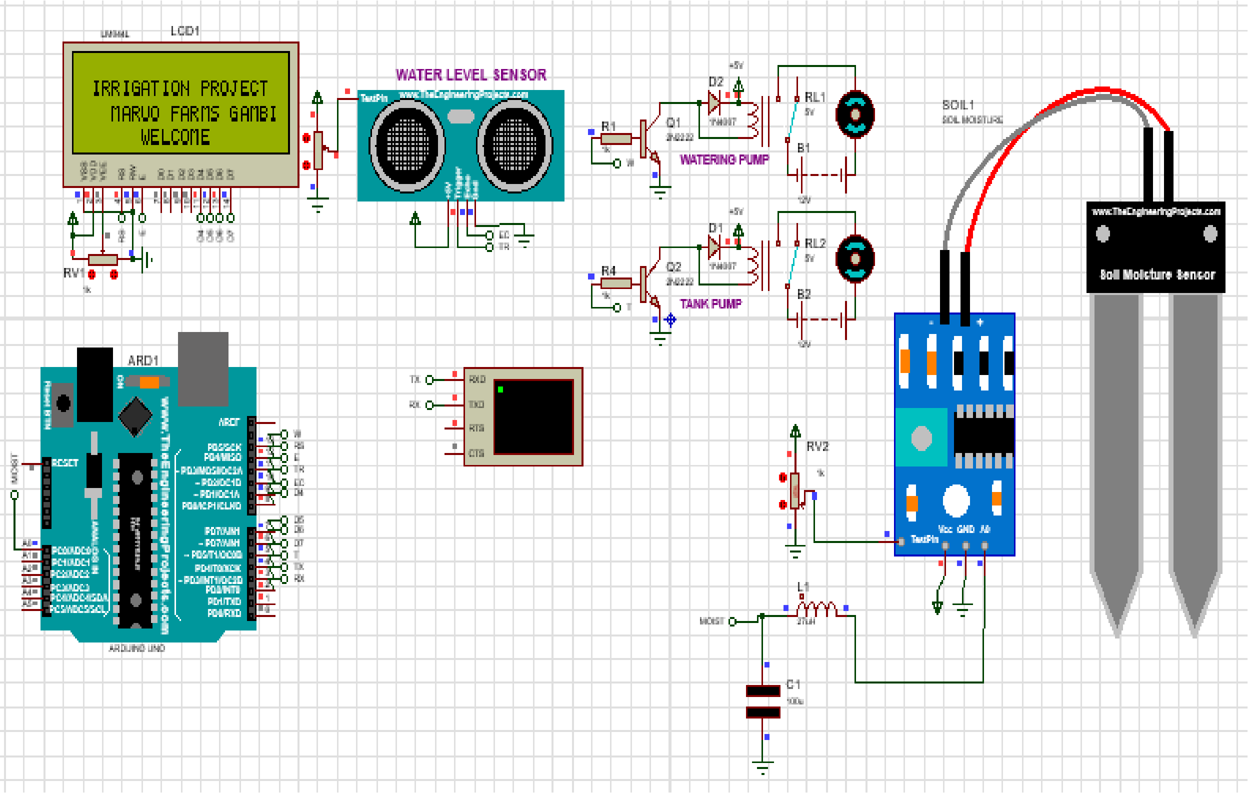


Figure 37: ***Schematic of the Prototype (Proteus 8)***

The Program Code

```
#include<LiquidCrystal.h>

#include <SoftwareSerial.h>

#define echo 9

#define trigger 10

#define tank_pump 4

#define watering_pump 13
```

```
#define moisture_sensor A0
long duration;
int distance;
int moisture_value;
int distance_percent;
int moist_percent;
SoftwareSerial SIM900(2, 3);
LiquidCrystal lcd(12,11,8,7,6,5);
void setup () {
lcd.begin(20,4);
SIM900.begin(9600);
Serial.begin(9600);
pinMode(echo,INPUT);
pinMode(moisture_sensor,INPUT);
pinMode(trigger,OUTPUT);
digitalWrite(trigger,LOW);
pinMode(watering_pump,OUTPUT);
pinMode(tank_pump,OUTPUT);
digitalWrite(watering_pump,LOW);
digitalWrite(tank_pump,LOW);
lcd.setCursor(0,1);
lcd.print(" IRRIGATION PROJECT"    );
lcd.setCursor(0,2);
```

```
lcd.print("   MARUO FARMS GAMBIA");
lcd.setCursor(0,3);
lcd.print("      WELCOME");
delay(500);
lcd.clear();
}
void loop(){
 // LEVEL SENSOR
 digitalWrite(trigger,LOW);
 delayMicroseconds(2);
 digitalWrite(trigger,HIGH);
 delayMicroseconds(10);
 digitalWrite(trigger,LOW);
 duration=pulseIn(echo,HIGH);
 distance=duration*0.017;
 distance_percent=map( distance,0,1023,0,100);
 moisture_value= analogRead(moisture_sensor);
moist_percent=map(moisture_value,0,1023,0,100);
 condition();
}
void sms(){
SIM900.print("AT+CMGF=1\r");
 SIM900.println("AT + CMGS = \"+2203335498\""); // recipient's mobile number
```

```
SIM900.println("WATERING PUMP IS OFF"); // message to send

SIM900.println((char)26); // End AT command with a ^Z, ASCII code 26

Serial.println((char)26);

SIM900.println();

}

void sms1(){

SIM900.print("AT+CMGF=1\r");

 SIM900.println("AT + CMGS = \"+2203335498\""); // recipient's mobile number

SIM900.println("TANK PUMP IS OFF"); // message to send

Serial.println("TANK PUMP IS OFF");

SIM900.println((char)26); // End AT command with a ^Z, ASCII code 26

Serial.println((char)26);

//delay(200);

SIM900.println();

}

void sms2(){

SIM900.print("AT+CMGF=1\r");

SIM900.println("AT + CMGS = \"+2203335498\""); // recipient's mobile number

SIM900.println("WATERING PUMP IS ON"); // message to send

Serial.println("WATERING PUMP IS ON");

//delay(200);

SIM900.println((char)26); // End AT command with a ^Z, ASCII code 26

Serial.println((char)26);
```

```
//delay(200);

SIM900.println();

}

void sms3(){

SIM900.print("AT+CMGF=1\r");

 delay(2000);

 SIM900.println("AT + CMGS = \"+2203335498\""); // recipient's mobile number

SIM900.println("TANK PUMP IS ON"); // message to send

Serial.println("TANK PUMP IS ON");

//delay(200);

SIM900.println((char)26); // End AT command with a ^Z, ASCII code 26

Serial.println((char)26);

//delay(200);

SIM900.println();

}

void condition(){

if (distance_percent>33 &&moist_percent<70){

LCD_3();

digitalWrite(tank_pump,LOW);

digitalWrite(watering_pump,HIGH);

 sms1();

 sms2();

delay(1000);
```

```
}

else if (distance_percent<33 &&moist_percent>70)

{

LCD_2();

digitalWrite(tank_pump,HIGH);

digitalWrite(watering_pump,LOW);

sms3();

sms();

delay(1000);

}

else if (distance_percent>33 &&moist_percent>70)

{

LCD_4();

digitalWrite(tank_pump,LOW);

digitalWrite(watering_pump,LOW);

sms1();

sms();

delay(1000);

}

else if (distance_percent<33 &&moist_percent<70)

{

LCD_1();

digitalWrite(tank_pump,HIGH);
```

```
digitalWrite(watering_pump,HIGH);
sms3();
sms2();
delay(1000);
}
}
 void LCD_1()
 {
 lcd.clear();
 lcd.setCursor(0,0);
 lcd.print("TANK LEVEL=  ");
 lcd.print(distance_percent);
 lcd.print("%");
 lcd.setCursor(0,1);
 lcd.print("MOIST CONTENT= ");
 lcd.print(moist_percent);
 lcd.print("%");
  lcd.setCursor(0,2);
 lcd.print("W-PUMP STATUS  ");
 lcd.print("  ON");
 lcd.setCursor(0,3);
 lcd.print("T-PUMP STATUS  ");
 lcd.print("  ON");
```

```
 }
void LCD_2(){
 lcd.clear();
 lcd.setCursor(0,0);
  lcd.print("TANK LEVEL=  ");
 lcd.print(distance_percent);
 lcd.print("%");
 lcd.setCursor(0,1);
 lcd.print("MOIST CONTENT= ");
 lcd.print(moist_percent);
 lcd.print("%");
  lcd.setCursor(0,2);
 lcd.print("W-PUMP STATUS ");
 lcd.print("  OFF");
 lcd.setCursor(0,3);
 lcd.print("T-PUMP STATUS ");
 lcd.print("   ON");
 }
 void LCD_3(){
 lcd.clear();
 lcd.setCursor(0,0);
  lcd.print("TANK LEVEL=  ");
 lcd.print(distance_percent);
```

```
lcd.print("%");
lcd.setCursor(0,1);
lcd.print("MOIST CONTENT= ");
lcd.print(moist_percent);
lcd.print("%");
 lcd.setCursor(0,2);
lcd.print("W-PUMP STATUS ");
lcd.print("  ON");
lcd.setCursor(0,3);
lcd.print("T-PUMP STATUS ");
lcd.print("  OFF");
}
void LCD_4(){
lcd.clear();
lcd.setCursor(0,0);
 lcd.print("TANK LEVEL=  ");
lcd.print(distance_percent);
lcd.print("%");
lcd.setCursor(0,1);
lcd.print("MOIST CONTENT= ");
lcd.print(moist_percent);
lcd.print("%");
 lcd.setCursor(0,2);
```

```
lcd.print("W-PUMP STATUS");

lcd.print("  OFF");

lcd.setCursor(0,3);

lcd.print("T-PUMP STATUS");

lcd.print("  OFF");

}
```

Chapter 4: Results and Discussion

4.1 Current state of Food, Water and Energy Supply in the Gambia

Different literatures and policy documents were reviewed to better understand the current state of water, food and energy supply in the Gambia. It was seen that the Gambia has only three water resources which are rainfall, surface water and groundwater. Rainfall, which usually span for just six months in a year is the most dependent resources by the agricultural sector. This is owed to the fact that there are financial and technical huddles associated with making it available in the fields from the other resources. The country has however ensured increased availability by up to 75% as of 2009 compared to the 58% in 1990. As of 2015, the coverage in the urban centres has reached 80% with the rural areas getting 765 coverage. This improvement is as a result of the Sahelian drought in the 1970s and 19802.

The agricultural sector in the country plays a very pivotal role and stands as one of the sectors contributing heavily in the country's GDP as it contributes to 50% of the national food requirement. The sector is characterized with archaic methods of production thus requiring a lot of power and investment with little yield. Farms in the Gambia are hardly private owned with only a small number of them that a private owned. The farms are mostly either owned by families that rely on subsistence agriculture for their living. These families do not grow crops in a large scale but only to the scale of their families. Seeing the pivotal position this sector has stood in the country over a very long period, Government interventions are needed to increase the capacities of these farmer to help the expand and grow crops in large scale. Increased technological and farm practise capacity building programs should be implemented. Most of the farms visited during the site assessment for the APV MaGa project complained about struggles in getting access to water. This has forced some of them to put production into halt. The reliance on rainfall for agricultural activities is unsustainable due to the spontaneity of the resource. Advanced irrigation technologies should be adopted to ensure reliable availability of water thus improving crop yield. The current irrigation systems constitute the use of watering can, dependence on the river tides for irrigation, sprinkler and localized irrigation, inland valley bottoms and pump irrigation (low lift pumps) etc. These systems are of small scale, primitive, labour intensive with little efficiency especially the case of the watering can.

Food, water and energy sectors are interconnected everywhere in the world with each sector relying on the other. This brings in the significance and need to discuss the current state of energy production and supply in the Gambia in relation to water supply and food production. Reliable availability of energy supply can help power agricultural activities that are highly energy reliant. The water pumping systems for example can be powered to ensure water availability in the farm for food production. Now, sufficient supply of energy to power these systems are a big issue in the Gambia due to the underperforming energy sector. The country relies heavily on imported fuel for the electricity generation which is unreliable and insufficient to supply the energy demanded. Energy resources in the country are not abundant but the available ones when tapped into can power systems autonomously without relying on power from the grid. The total primary energy supplied in 2017 was 48% Renewables and 51% Non-Renewable in the form of gas, oil, coal and others. The 48% renewable is all but Bioenergy which is mostly for household consumption. The pie charts below give a highlight of the total primary energy and renewable energy supplied as of 2017.

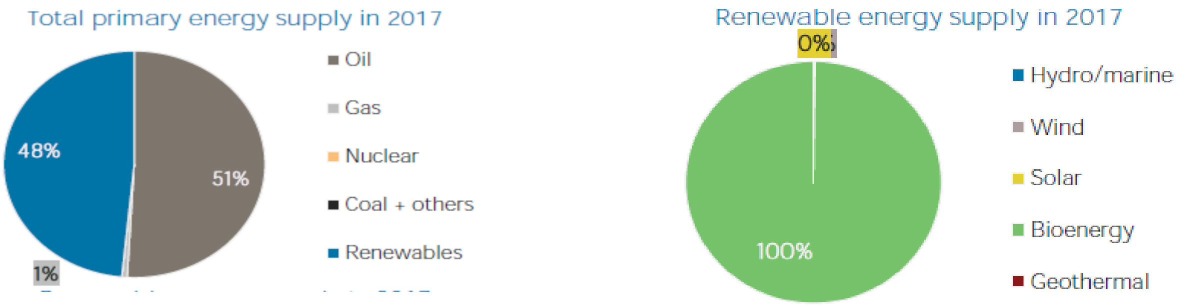


Figure 38*: *Total Energy and Renewable Energy Supplied in 2017: (Gambia Energy Profile 2017)

The total electricity capacity as of 2019 stands at 105MW of constituting mostly Non-Renewable. Only 3% comes from Renewables with 2MW came from solar and 1MW coming from wind energy. This is very small looking at the huge solar potential in the country. The country receives fairly a huge solar irradiation throughout the whole country hence, off-grid installations will reduce the demand for gird electricity. This will also allow activities to run uninterrupted due to frequent power cuts from the grid. Of the farms assessed, they are all located in areas with a very poor electrification rate below 25%. The capital city is the only place with electrification rate of about 93% and none of the farms assessed are from the capital city.

4.2 Existing Water Supply System Analysis

The sites were assessed on their compatibility to the objectives of the APV MaGa project. Their irrigation methods were also assessed. The availability of water monitoring system to help them manage water supply and examine field parameters was made as well. The figure 3.5 below depicts the data collected based on the source of water. It is shown that majority of the farms use borehole, electric pumps which are solar powered for their water needs. One farm which is the Sukuta Women's Garden uses borehole and electric pumps that are powered by both solar and grid to attain the water requirements of the farm. This Garden is located in the Garden centre and is not far from the capital city Banjul, thus the grid connectivity. One of the farms, Maruo farms in the Central river region rely on rainfall and water from the river Gambia for its water needs.

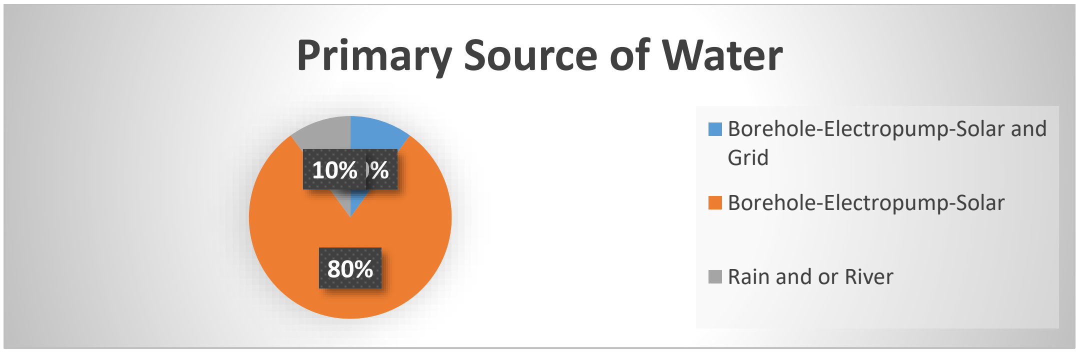


Figure 39: *Primary Source of Water*

Data on the method of irrigation was also collected with nine of the farms depending on manual irrigation methods to supply water to the farms with the use of buckets and or watering cans. Only one farm uses another method of irrigation, Maruo farms. This farms depends on rainfall and on tidal flow of water from the river Gambia to the farm through tunnels.

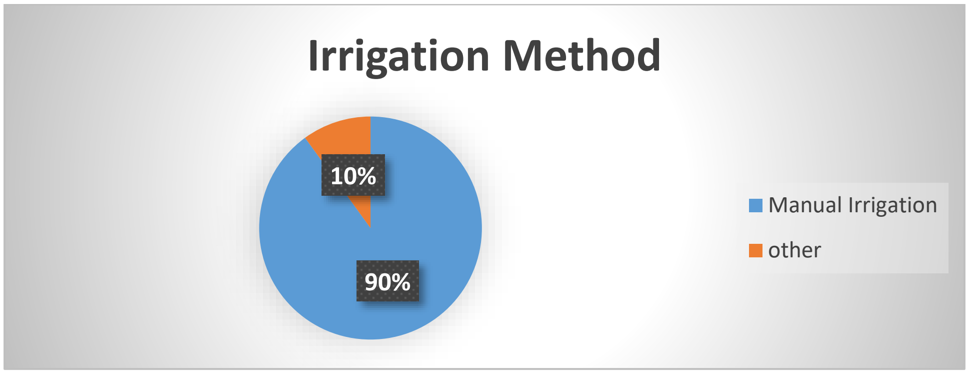


Figure 40: *Irrigation methods.*

The use of smart system for monitoring farm operations is something the assessed farms are not ready for since they are all not using practicing smart irrigation techniques or any other smart system application. The figure below shows the collected data on the use of smart systems for irrigation.

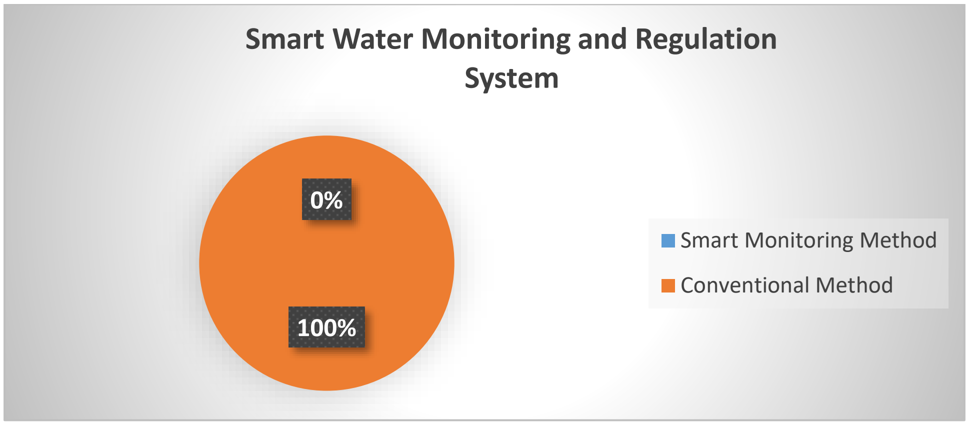


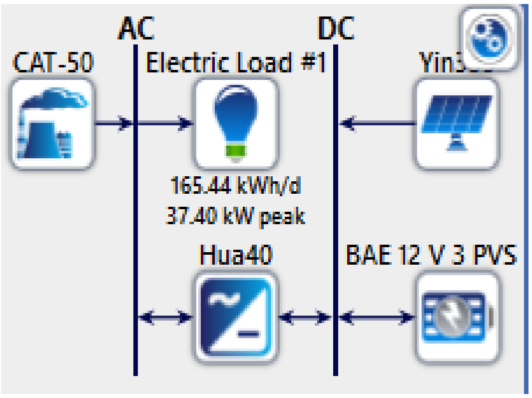
Figure 41*: *Smart water Monitoring and Regulation

The meteorological data of the place was also collected and analysed to see its suitability of the place for agricultural activities and solar PV installation. The annual average mean temperature of the area in study, Janjanburreh was calculated to be 28.2℃, average annual maximum temperature was 39.1℃ and the annual average minimum temperature was 17℃. The annual average for relative humidity was 52.6% and the annual average for rainfall that lasted for 6 months was 67.5 mm. The data showed that the Gambia receives on average 6-10hrs of sunlight yearly and solar irradiation values are good enough for PV installations throughout the country.

4.3 Homer Results

The software was used to design the off-grid system and cost analysis of the optimized system. Two systems were analysed and a comparative study was conducted based on the economics of the system and electricity production. A sensitivity analysis was conducted to study the variation of solar radiation against the economics of the system.

A comparative study was conducted to analyse the economic outcome of a hybrid system comprising of a Diesel generator as backup against a simple solar photovoltaic system.



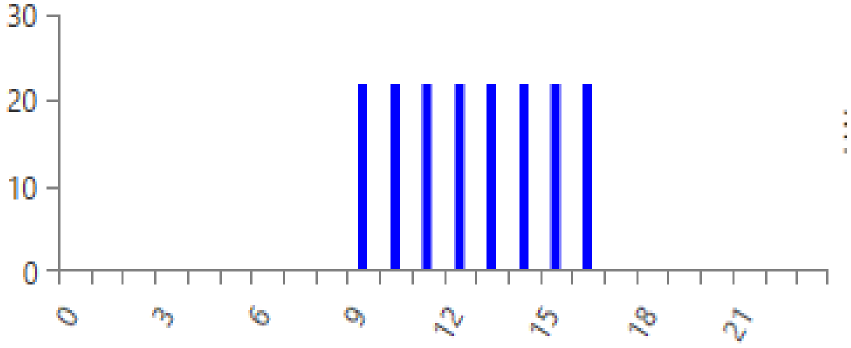
Schematic of the PV system Design with backup Generator

4.3.1 Components

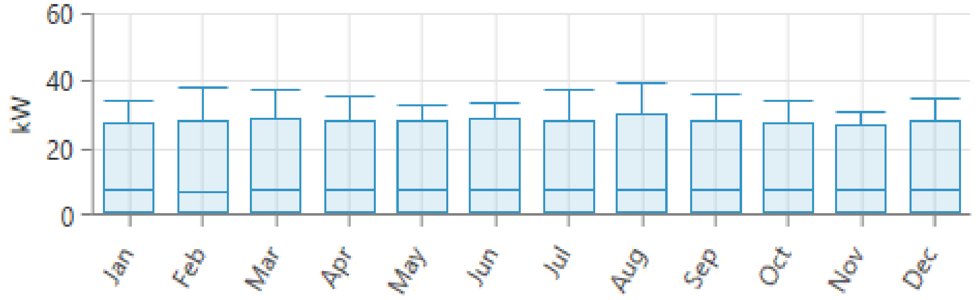
The components selected for the system design are Yingli Solar Panels of capacity 335watts which a BAE SECURA SOLAR battery and Hua40 converter. A CAT-50 generator is also added as a backup. The initial cost of a Yingli solar PV (335) is taken as $134 equivalent to D7000 in the Gambian Market. Operations and maintenance cost of the panel is taken to be $30/year. The solar battery's initial cost is $634 for a 2.41kwh nominal capacity, Replacement Cost is taken to be $500 and the O&M cost is taken to be $20/year(BAE 12V 3 PVS 210 167AH @C10 215AH @C100 – Prism Solar n.d.). The Hua40 converter has a capital cost of $94.4/kw, a replacement cost of $80 and an O&M cost of $10/year(Huawei SUN2000-40KTL-US Price Datasheet Inverter, SUN2000-40KTL-US, Solar Inverter n.d.). The initial cost of the generator is $11,187, the replacement cost was taken to be $10,000 and the O&M cost is $100/op.hour. The cost of Diesel fuel is D50.64 equivalent to $0.97(Gambia Increases Prices of Fuel - allAfrica.com n.d.).

4.3.2 Load Profile

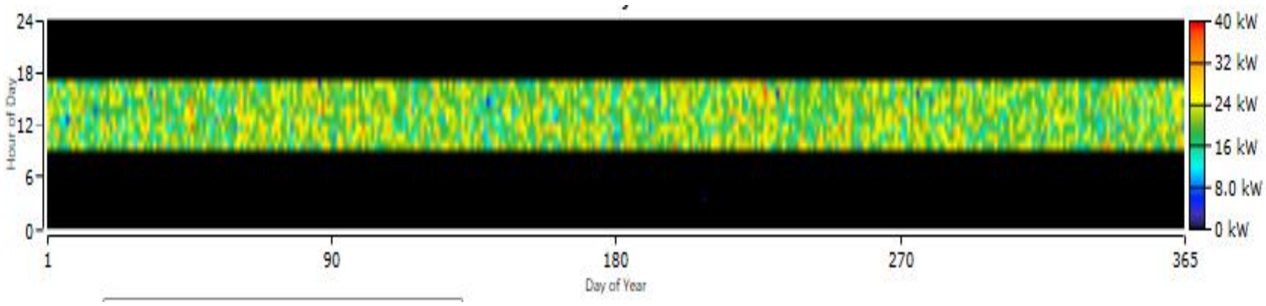
This shows the hourly energy consumed by the load in a day in KW. The load here is the power required to pump the water to the irrigation field and the power required to run the IoT system that monitors and regulate the water supplied to the field. The daily, seasonal and yearly load profile were determined from the simulation from the Homer Software.



Daily Load Profile



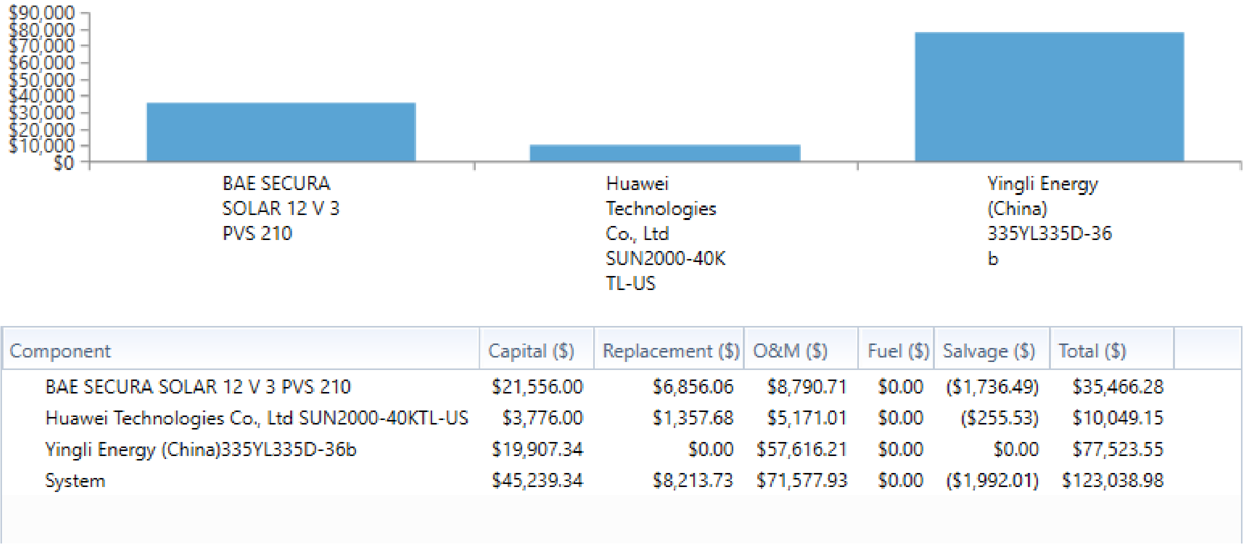
Seasonal Load Profile



Yearly Load Profile

4.3.3 Stand-alone system

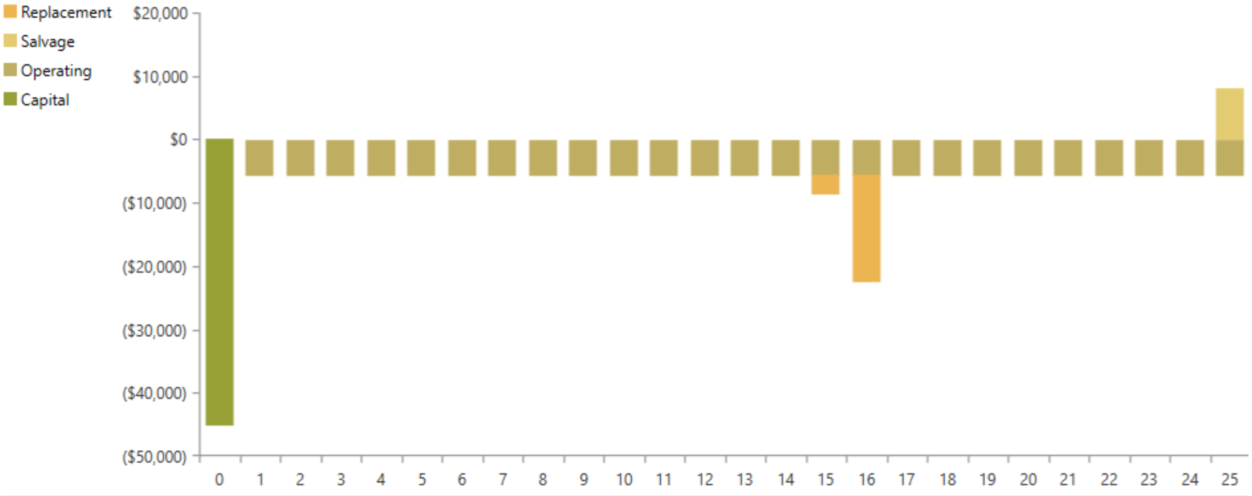
This is a simple design of a mini-grid comprising of a solar PV, a lead acid battery and a converter to convert the DC current from the solar panels to AC current. The figure below shows the cost summary of the stand alone system. The financial output of the system has a Net Present Cost of the system $123,039, Levelized Cost of Energy of $0.1637 and an Operating Cost of $6,018.14



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
BAE SECURA SOLAR 12 V 3 PVS 210	$21,556.00	$6,856.06	$8,790.71	$0.00	($1,736.49)	$35,466.28
Huawei Technologies Co., Ltd SUN2000-40KTL-US	$3,776.00	$1,357.68	$5,171.01	$0.00	($255.53)	$10,049.15
Yingli Energy (China)335YL335D-36b	$19,907.34	$0.00	$57,616.21	$0.00	$0.00	$77,523.55
System	$45,239.34	$8,213.73	$71,577.93	$0.00	($1,992.01)	$123,038.98

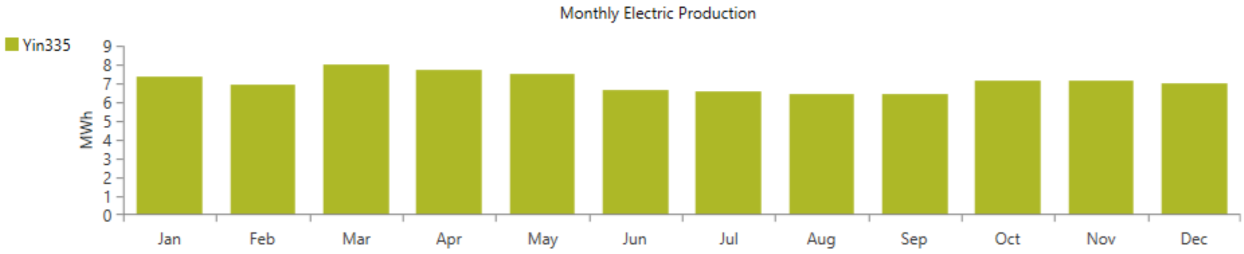
Cost Summary of the Stand Alone System

The cash flow of the cost summary of the system is presented in the figure below over a period of 25 years. It can see from the figure that the capital expenditure at the beginning of the project is $45, 239.34, the replacement cost of $8,213.73 will be expended in the 15th and 16th year during the life of the project. The salvage value at the end of the project is ($1,992.01) and an overall O&M cost is $71,577.93.



Cash Flow Diagram of the Stand Alone System

The Renewable fraction of the project is 100% since all electricity generated by the system in the stand alone system is coming from the PV module. A total of 84,937kWh/yr of electricity is produced every year. The figure below shows the monthly electricity production of the PV modules.

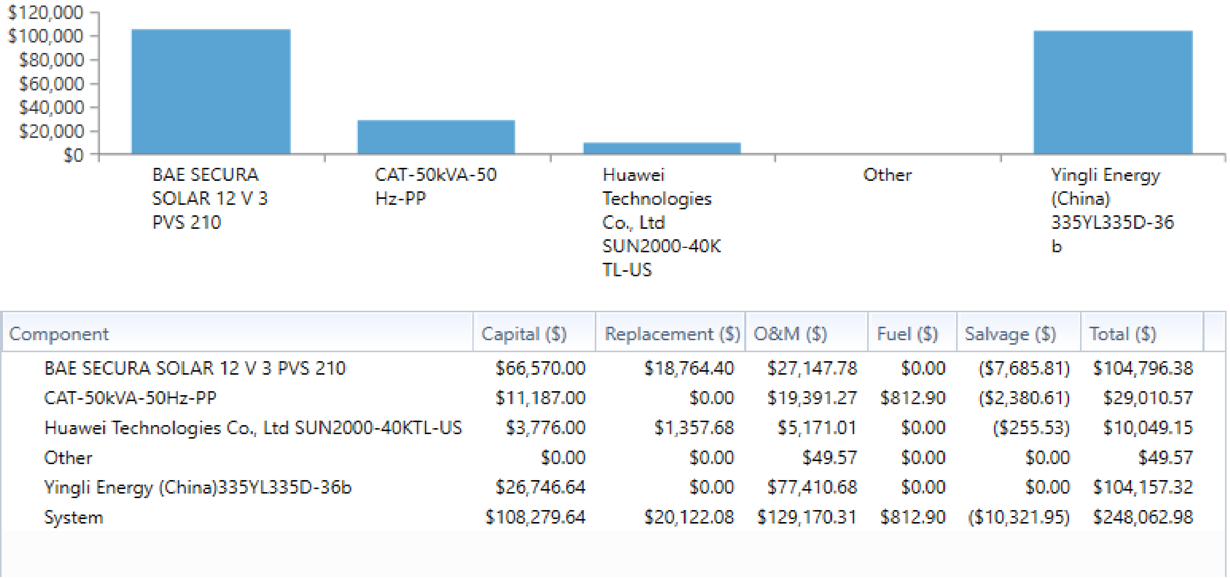


Monthly Electricity Production of the Stand Alone System

4.3.4 Solar PV system with Generator Backup

This comprises of the solar PV system with a Diesel generator as backup to supplement power shortages when the PV system is not producing enough power to run the system. This can be during cloudy days or when the system is put in maintenance mode. An annual capacity shortage of 10% is considered since the clearness index of the region is good.

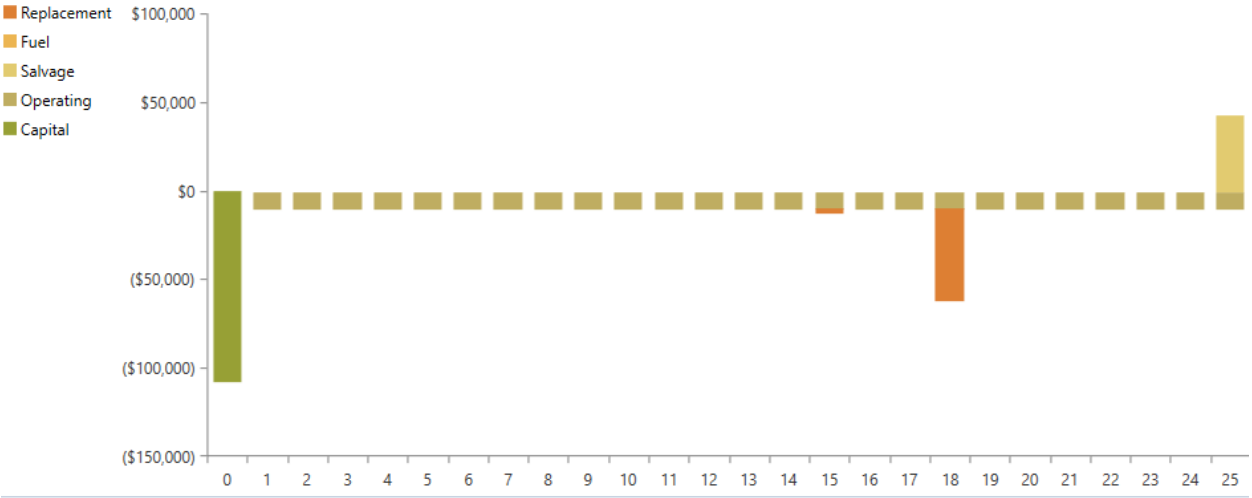
The system has a Net Present Cost of $243,063, a Levelized Cost of Energy of $0.3178 and am Operation Cost of $10, 812.85. The cost summary of the system is presented in the figure below.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
BAE SECURA SOLAR 12 V 3 PVS 210	$66,570.00	$18,764.40	$27,147.78	$0.00	($7,685.81)	$104,796.38
CAT-50kVA-50Hz-PP	$11,187.00	$0.00	$19,391.27	$812.90	($2,380.61)	$29,010.57
Huawei Technologies Co., Ltd SUN2000-40KTL-US	$3,776.00	$1,357.68	$5,171.01	$0.00	($255.53)	$10,049.15
Other	$0.00	$0.00	$49.57	$0.00	$0.00	$49.57
Yingli Energy (China)335YL335D-36b	$26,746.64	$0.00	$77,410.68	$0.00	$0.00	$104,157.32
System	$108,279.64	$20,122.08	$129,170.31	$812.90	($10,321.95)	$248,062.98

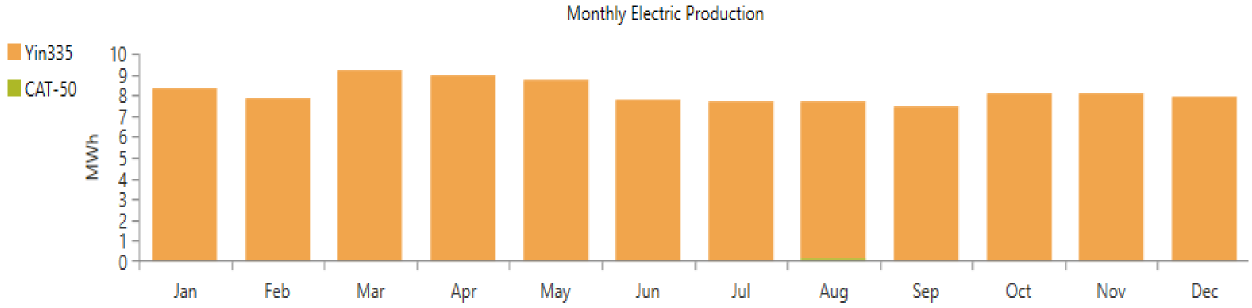
Cost Summary of the System with Backup Generator

The cash flow of the project is shown in the figure below. It is seen that the the capital cost of the system is $108, 279.64 with the bulk of it coming from the purchase of batteries. The replacement cost is $20, 122.08 with 90% of this coming from the replacement of the batteries coming at the 18th year of the project. Under normal circumstancies, the PV systems are not replaced since the life of PV panels spans upto 25 years. The salvage value of the system is at ($10,321.95) which comes from the cost of selling the batteries, generator and the converter at the end of the project.



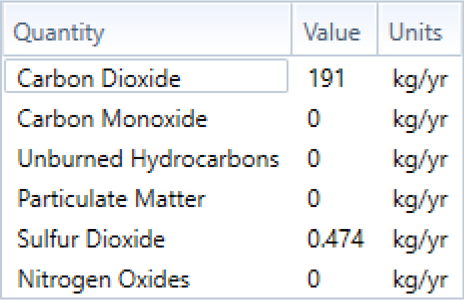
Cash Flow of the System with Backup Generator

The monthly electricity production is also shown in the figure below showing most of the power produced coming from the PV modules (97,736kWh/yr) since it is the main generating component. The Diesel generator only produces 174kWh/yr. The Renewable Fraction of the system is 99.7%.



Monthly Electricity Production of the System with Backup

One concerning issue with the use of a diesel generator as backup is the associated emissions it has. Emissions coming from the use of the generator as presented in the figure below with 191kg/year of carbondioxide and 0.474kg/year of sulphurdioxide emitted.



Quantity	Value	Units
Carbon Dioxide	191	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	0.474	kg/yr
Nitrogen Oxides	0	kg/yr

Associated Emission from the Diesel Generator

The emission penalties were considered in this project with $20/ton charged on to all the emitted gases.

Emissions Penalties

Carbon dioxide ($/t): 20.00

Carbon monoxide ($/t): 20.00

Unburned hydrocarbons ($/t): 20.00

Particulate matter ($/t): 20.00

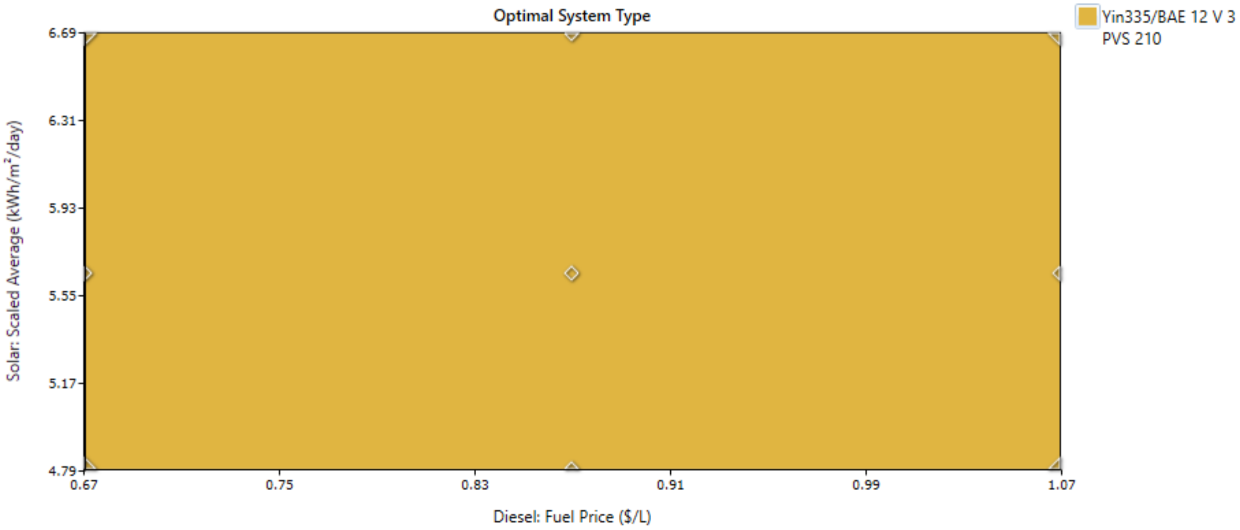
Sulfur dioxide ($/t): 20.00

Nitrogen oxides ($/t): 20.00

Emission penalties

4.3.5 Sensitivity Analysis

A sensitivity analysis was condeucted to study the effects of the volatility of the fuel prices and the scaled average solar radiation of the region on the economics of the system. The systems shows optimum values for the solar PV system only since it is the major electricity producing component amounting to 99.8% of the electricity produced.



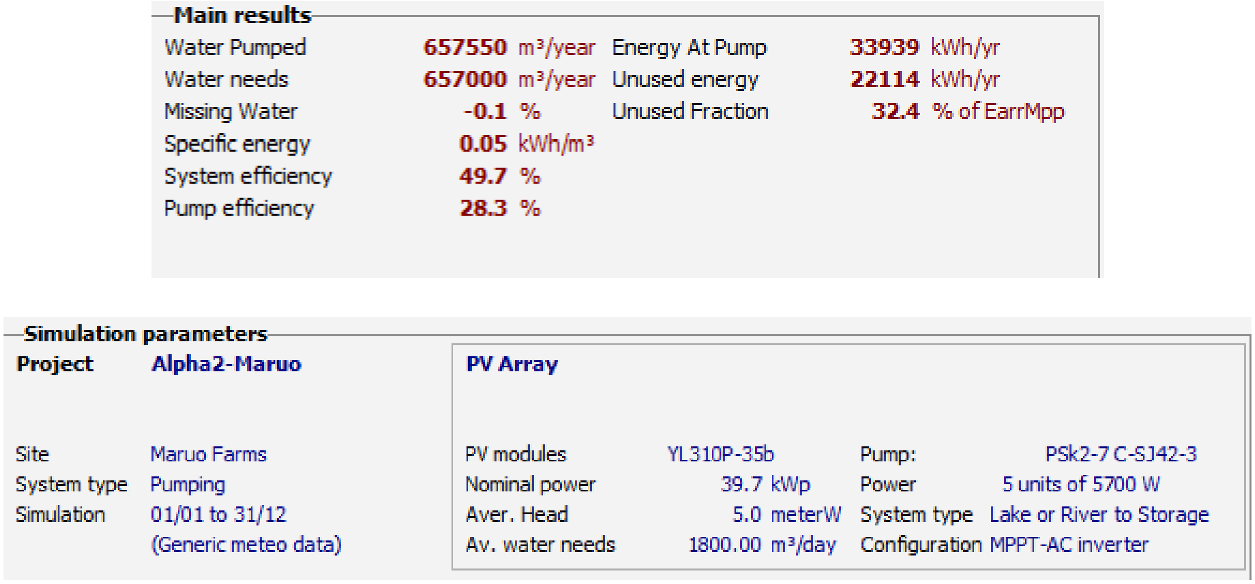
Sensitivity Analysis the system with Backup

4.4 System Sizing and Component Selection Using Pvsyst

The core aim of the study was to size a solar water pumping system and propose a prototypical design of a smart water monitoring and management system. The Maruo farms was identified and assessed for the possibly of installing a solar water pumping system capable of supply the irrigation water needs of the farm and the surrounding community. The Maruo farms which is 30 hectares large is located in Patcharr in the central river region of the Gambia and is engaged in rice production. The water requirement for the cultivation of the 30-hectare rice field was calculated to be 1800m^3/day using reference from the FAO manual on how to determine the water requirement of various crops. The community water need consisting of the domestic water needs and the water demands from the health centre was also calculated to be 85.396m^3/ day. This calculated information was used as input data in the calculation of the energy required to supply the water needed. The system was sized to supply the irrigation water needs since the community is at least 3.5km away from the source. Pumping water from the source to the community will require a lot of pumping power, hence the irrigation supply was considered since it is not far from the source.

The irrigation power needs were calculated to be 27.79Kw. An inverter of 98.4% was proposed to get a system power of 28.24kw. Yingli solar panels (84panels) of capacity 340watts were considered for the sizing. The panels were configured in the (2 parallel, 42 series) panel configuration. Battery storage was considered for the system since there is no tank in the farm. Water from the source is directly allowed to flow to the field and storage for days when the tides are not strong enough for water to flow was not considered by the farm. Rita Batteries of 200Ah capacity and 12V were considered and used to size the system to be able to run the system for two days when there is no enough radiation available to run the system. The number of batteries of the configuration of 3 series by 31 parallel connections were considered to be able to store that much energy capable of supply power to the system for two cloudy days.

The Pvsyst software was also used to design the system considering a storage tank. Input variables in the form of meteorological data, water needs, pumping head were used for the simulation. The results of the simulation are shown in the figures below.



Main results

Water Pumped	657550	m³/year	Energy At Pump	33939	kWh/yr
Water needs	657000	m³/year	Unused energy	22114	kWh/yr
Missing Water	-0.1	%	Unused Fraction	32.4	% of EarrMpp
Specific energy	0.05	kWh/m³			
System efficiency	49.7	%			
Pump efficiency	28.3	%			

Simulation parameters

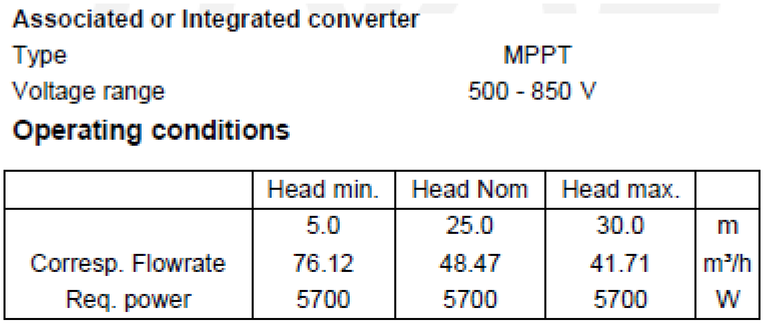
Project	**Alpha2-Maruo**
Site	Maruo Farms
System type	Pumping
Simulation	01/01 to 31/12 (Generic meteo data)

PV Array

PV modules	YL310P-35b	Pump:	PSk2-7 C-SJ42-3
Nominal power	39.7 kWp	Power	5 units of 5700 W
Aver. Head	5.0 meterW	System type	Lake or River to Storage
Av. water needs	1800.00 m³/day	Configuration	MPPT-AC inverter

Figure 42*: *Results of the Pvsyst Simulation

A yearly volume of 657550m^3 of water is pumped into the irrigation field requiring 33939kWh of energy every year. The system and pumped efficiencies are 49.7% and 28.3% respectively. Yingli Solar Panels (128) of the of the model YL310-35b was considered for the simulation to power the whole system. A total of 5 unite of a 5700W capacity pump connected in parallel was chosen to pump the water daily. The pump is of the model PSk-7 C-SJ42-3 with a head ranging from 5-30m was chosen.



Associated or Integrated converter

Type	MPPT
Voltage range	500 - 850 V

Operating conditions

	Head min.	Head Nom	Head max.	
	5.0	25.0	30.0	m
Corresp. Flowrate	76.12	48.47	41.71	m³/h
Req. power	5700	5700	5700	W

Figure 43: ***Inverter Details with Operating condition of the Pump.***

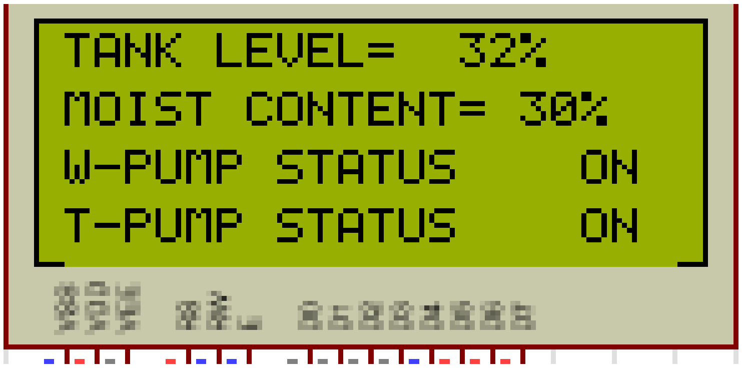
An MPPT inverter was used with voltages ranging from 500-850V was used. The flow rates for when the head is 5m, 25, and 30 m were suggested to be 76.12, 48.47 and 42.71 m^3/h respectively.

Proteus Design Suite Analysis

The results of the irrigation monitoring and management are highlighted in the figures below.

```
IRRIGATION PROJECT
  MARUO FARMS GAMBI
     WELCOME
```

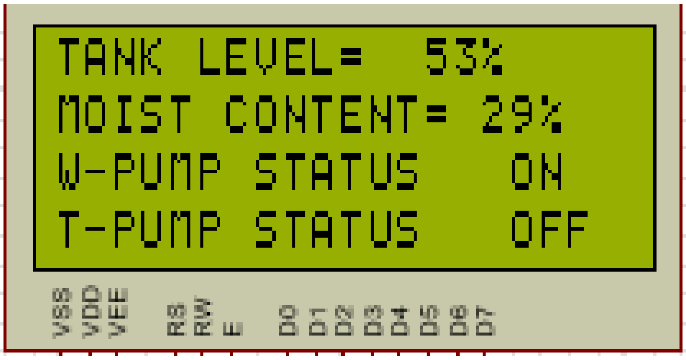
Figure 44: ***Project Introduction on Display***



```
TANK LEVEL=  32%
MOIST CONTENT= 30%
W-PUMP STATUS    ON
T-PUMP STATUS    ON
```

Figure 45: ***Status of the Pumps when they are all running***

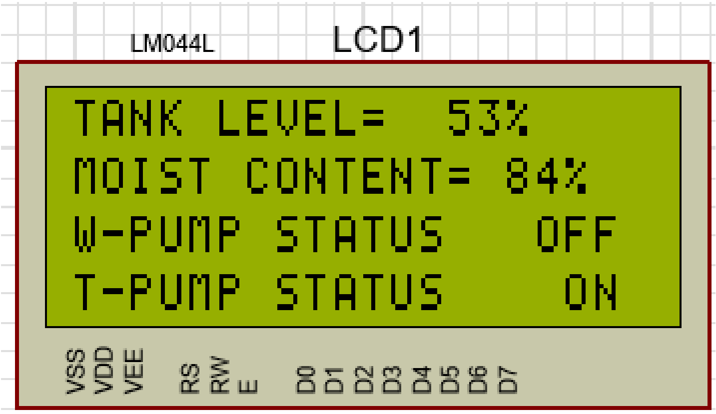
Both pumps are activated since both sensors are below the recommended limits of 65% and 80% for the water level sensor and moisture sensor respectively.



```
TANK LEVEL=  53%
MOIST CONTENT= 29%
W-PUMP STATUS   ON
T-PUMP STATUS   OFF
```

Figure 46*: *When only Watering Pump is Activated

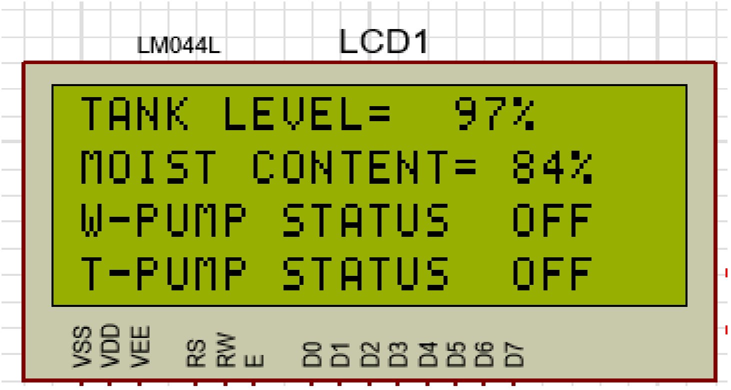
Here, only the watering pump is activated. This is when the moisture in the soil is below the required limit. There is enough water in the tank hence the tank pump is turned off.



```
TANK LEVEL=  53%
MOIST CONTENT= 84%
W-PUMP STATUS   OFF
T-PUMP STATUS    ON
```

Figure 47*: *When only Tank Pump is Activated

In this scenario, the moisture level in the soil is above the minimum required value. The watering pump is therefore deactivated. The water in the tank is below the minimum limit. The tank pump is therefore turned on.



```
TANK LEVEL=   97%
MOIST CONTENT= 84%
W-PUMP STATUS   OFF
T-PUMP STATUS   OFF
```

Figure 48*: *When all Pumps Are Deactivated

All the pumps are deactivated in this case since all the conditions are okay in both the tank and the field. There is enough water to supply the tank when needed and there is enough moisture in the soil. This could also be when the whole system is turned off during breakdown or by the controller during maintenance operations.

Chapter 5: Conclusion and Recommendation

5.1 Conclusions

There is a vast opportunity for growth in the food, water and energy sector in Africa. The continent is blessed with abundant resources which when utilized can improve the socio-economic development of the continent by reducing hunger, increasing access to water and, aiding industrial and agricultural processes thus reducing poverty.

Of the food, water and energy sectors in the Gambia, the increased in water supply is more visible which came as a result of the actions taken against the sahelian drought in the 1970s and 1980s. Food and Energy Supply are still lagging behind compared to water supply.

Energy access can be improved by relying on naturally available energy resources coupled with the application of technological innovations that can help make them available in their usable forms. One problem noticed during this research is the continued use of conventional system for energy generation and food production among Gambians. This is due to little or no knowledge of the existence of new technologies which when adapted can improve the scale of produce and yield of crops.

The existing water supply systems (irrigation Methods) are crude and ineffective and has resulted to low scale production in most of the farms due to challenges in accessing water. There exist Solar Water Pumping Systems but most of them are not in operation due to poor maintenance, theft of parts and lack of proficient technicians. There is little to no training programs implemented to improve the capacities of locals and farmers on the operations of these technologies.

Results of this thesis showed that of all the farms assessed for the APV MaGa project, most of them do not have an efficient method of monitoring and controlling their irrigation systems. There exists no proper method of storing irrigation water for use when there is no water available. The farm used as a case study relies on the tides for irrigation which can be very unreliable. Other farms visited use watering cans to supply water to their farms. Almost all of them do not have access to grid electricity to power their water needs and diesel generators are costly coupled with the running cost attached to them. The use of solar powered water pumps is therefore advised for the long term though it has a high capital investment. When proper interventions are made by governments and NGOs, farmers can be capacitated by installing these systems that can aid them in their activities.

The proposed smart water monitoring and control system when adapted for crop production in Africa has a tendency of managing the available water to be supplied with minimum wastage. The system will help farmers monitor the conditions in their farms and make decisions in response.

The findings are as follows:

- The daily water requirement of the farm is 1800m3/day.
- The Energy needed to pump water to the farms is calculated to be 21.79kW with the power for the electronics as 0.05kw.
- Stand-Alone system is more profitable with a LCOE of 0.1637 as compared to System with generator as backup of 0.2981.
- A storage tank of 3600m3 is suggested to store water with 2 days of autonomy.
- The smart Water Monitoring and Regulation was successfully simulated.

5.2 Recommendations:

- Adequate training programs should be implemented to increase the knowledge of local Farmers on the modern agricultural technologies.
- Training programs aimed at helping farmers with system maintenance and operations should be implemented.
- Financial support from GOs and NGOs to help farmer scale up their production to enhance food security in the country through improvement in Energy and Water access.
- Promotion of Research, Development and Innovation.
- Aiding small and upcoming innovative agri-tech companies

The concept of the APV technology ensures multiple land use to provide energy which can support farm operations, water for agricultural activities as well as increased yield of crops by protecting the crops from intense heat. The results of this thesis when implemented will help solving water management and distribution system issues and can also be used in the design and installation of the solar photovoltaic water pumping system.

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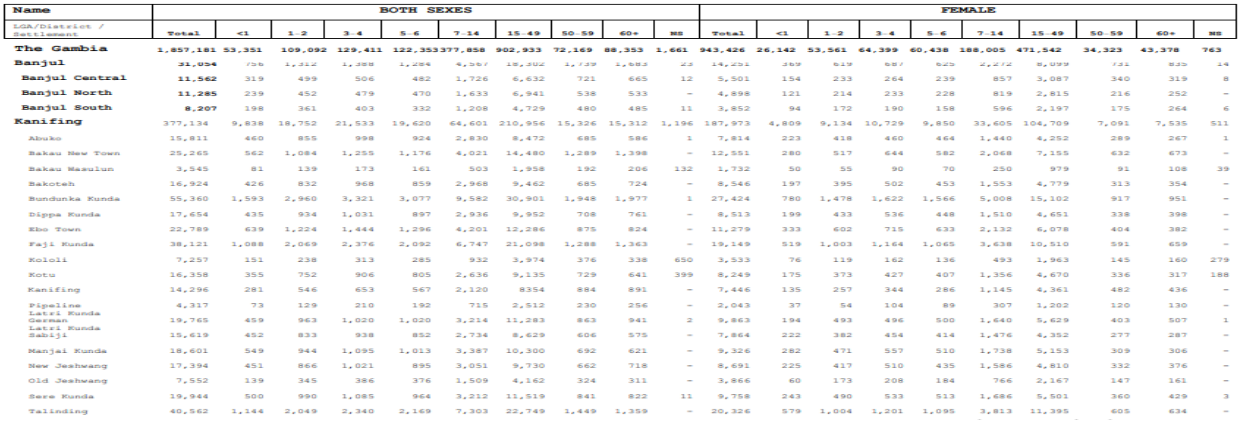
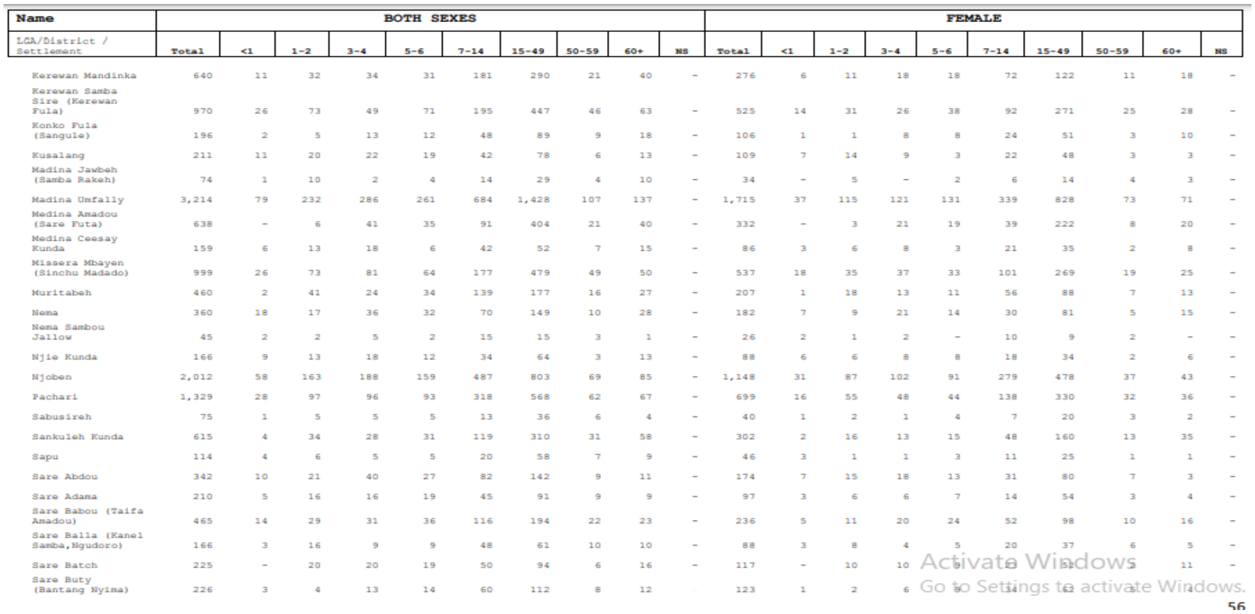
Appendix



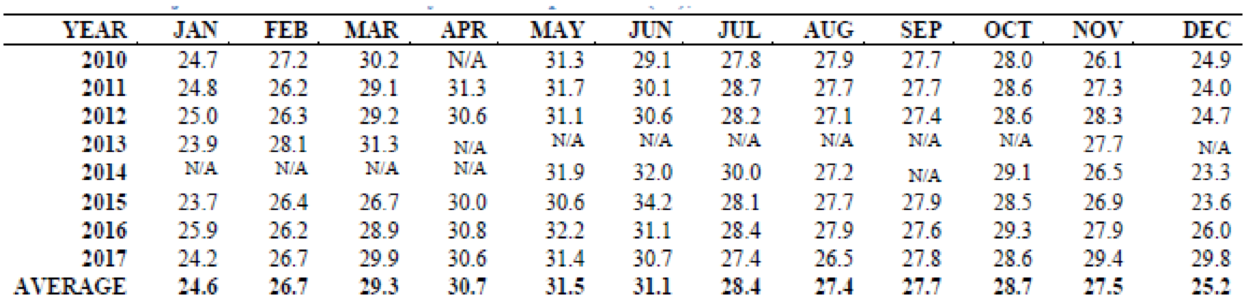
Name	BOTH SEXES										FEMALE									
LGA/District / Settlement	Total	<1	1-2	3-4	5-6	7-14	15-49	50-59	60+	NS	Total	<1	1-2	3-4	5-6	7-14	15-49	50-59	60+	NS
The Gambia	**1,857,181**	**53,351**	**109,092**	**129,411**	**122,353**	**377,858**	**902,933**	**72,169**	**88,353**	**1,661**	**943,426**	**26,142**	**53,561**	**64,399**	**60,438**	**188,005**	**471,542**	**34,323**	**43,378**	**763**
Banjul	**31,054**	756	1,312	1,388	1,284	4,567	18,302	1,739	1,683	23	14,251	369	619	687	625	2,272	8,099	731	835	14
Banjul Central	**11,562**	319	499	506	482	1,726	6,632	721	665	12	5,501	154	233	264	239	857	3,087	340	319	8
Banjul North	**11,285**	239	452	479	470	1,633	6,941	538	533	-	4,898	121	214	233	228	819	2,815	216	252	-
Banjul South	**8,207**	198	361	403	332	1,208	4,729	480	485	11	3,852	94	172	190	158	596	2,197	175	264	6
Kanifing	377,134	9,838	18,752	21,533	19,620	64,601	210,956	15,326	15,312	1,196	187,973	4,809	9,134	10,729	9,850	33,605	104,709	7,091	7,535	511
Abuko	15,811	460	855	998	924	2,830	8,472	685	586	1	7,814	223	418	460	464	1,440	4,252	289	267	1
Bakau New Town	25,265	562	1,084	1,255	1,176	4,021	14,480	1,289	1,398	-	12,551	280	517	644	582	2,068	7,155	632	673	-
Bakau Masulun	3,545	81	139	173	161	503	1,958	192	206	132	1,732	50	55	90	70	250	979	91	108	39
Bakoteh	16,924	426	832	968	859	2,968	9,462	685	724	-	8,546	197	395	502	453	1,553	4,779	313	354	-
Bundunka Kunda	55,360	1,593	2,960	3,321	3,077	9,582	30,901	1,948	1,977	1	27,424	780	1,478	1,622	1,566	5,008	15,102	917	951	-
Dippa Kunda	17,654	435	934	1,031	897	2,936	9,952	708	761	-	8,513	199	433	536	448	1,510	4,651	338	398	-
Ebo Town	22,789	639	1,224	1,444	1,296	4,201	12,286	875	824	-	11,279	333	602	715	633	2,132	6,078	404	382	-
Faji Kunda	38,121	1,088	2,069	2,376	2,092	6,747	21,098	1,288	1,363	-	19,149	519	1,003	1,164	1,065	3,638	10,510	591	659	-
Kololi	7,257	151	238	313	285	932	3,974	376	338	650	3,533	76	119	162	136	493	1,963	145	160	279
Kotu	16,358	355	752	906	805	2,636	9,135	729	641	399	8,249	175	373	427	407	1,356	4,670	336	317	188
Kanifing	14,296	281	546	653	567	2,120	8354	884	891	-	7,446	135	257	344	286	1,145	4,361	482	436	-
Pipeline	4,317	73	129	210	192	715	2,512	230	256	-	2,043	37	54	104	89	307	1,202	120	130	-
Latri Kunda German	19,765	459	963	1,020	1,020	3,214	11,283	863	941	2	9,863	194	493	496	500	1,640	5,629	403	507	1
Latri Kunda Sabiji	15,619	452	833	938	852	2,734	8,629	606	575	-	7,864	222	382	454	414	1,476	4,352	277	287	-
Manjai Kunda	18,601	549	944	1,095	1,013	3,387	10,300	692	621	-	9,326	282	471	557	510	1,738	5,153	309	306	-
New Jeshwang	17,394	451	866	1,021	895	3,051	9,730	662	718	-	8,691	225	417	510	435	1,586	4,810	332	376	-
Old Jeshwang	7,552	139	345	386	376	1,509	4,162	324	311	-	3,866	60	173	208	184	766	2,167	147	161	-
Sere Kunda	19,944	500	990	1,085	964	3,212	11,519	841	822	11	9,758	243	490	533	513	1,686	5,501	360	429	3
Talinding	40,562	1,144	2,049	2,340	2,169	7,303	22,749	1,449	1,359	-	20,326	579	1,004	1,201	1,095	3,813	11,395	605	634	-

Appendix A



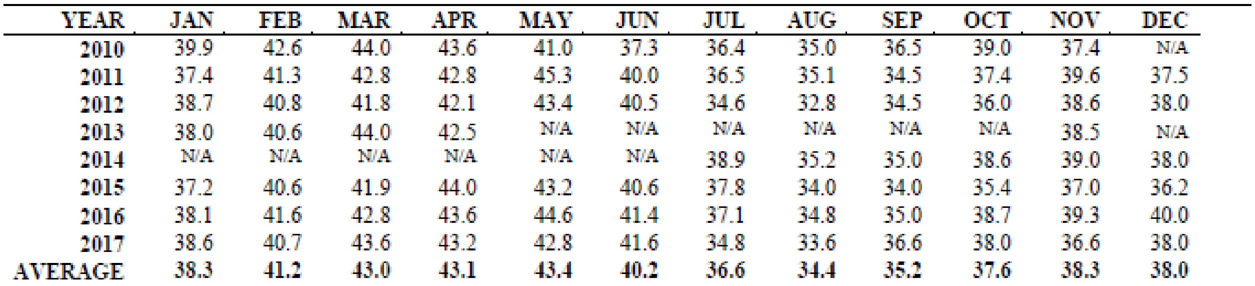
Name	BOTH SEXES										FEMALE									
LGA/District / Settlement	Total	<1	1-2	3-4	5-6	7-14	15-49	50-59	60+	NS	Total	<1	1-2	3-4	5-6	7-14	15-49	50-59	60+	NS
Kerewan Mandinka	640	11	32	34	31	181	290	21	40	-	276	6	11	18	18	72	122	11	18	-
Kerewan Samba Sire (Kerewan Fula)	970	26	73	49	71	195	447	46	63	-	525	14	31	26	38	92	271	25	28	-
Konko Fula (Sangule)	196	2	5	13	12	48	89	9	18	-	106	1	1	8	8	24	51	3	10	-
Kusalang	211	11	20	22	19	42	78	6	13	-	109	7	14	9	3	22	48	3	3	-
Madina Jawbeh (Samba Rakeh)	74	1	10	2	4	14	29	4	10	-	34	-	5	-	2	6	14	4	3	-
Madina Umfally	3,214	79	232	286	261	684	1,428	107	137	-	1,715	37	115	121	131	339	828	73	71	-
Medina Amadou (Sare Futa)	638	-	6	41	35	91	404	21	40	-	332	-	3	21	19	39	222	8	20	-
Medina Ceesay Kunda	159	6	13	18	6	42	52	7	15	-	86	3	6	8	3	21	35	2	8	-
Missera Mbayen (Sinchu Madado)	999	26	73	81	64	177	479	49	50	-	537	18	35	37	33	101	269	19	25	-
Muritabeh	460	2	41	24	34	139	177	16	27	-	207	1	18	13	11	56	88	7	13	-
Nema	360	18	17	36	32	70	149	10	28	-	182	7	9	21	14	30	81	5	15	-
Nema Sambou Jallow	45	2	2	5	2	15	15	3	1	-	26	2	1	2	-	10	9	2	-	-
Njie Kunda	166	9	13	18	12	34	64	3	13	-	88	6	6	8	8	18	34	2	6	-
Njoben	2,012	58	163	188	159	487	803	69	85	-	1,148	31	87	102	91	279	478	37	43	-
Pachari	1,329	28	97	96	93	318	568	62	67	-	699	16	55	48	44	138	330	32	36	-
Sabusireh	75	1	5	5	5	13	36	6	4	-	40	1	2	1	4	7	20	3	2	-
Sankuleh Kunda	615	4	34	28	31	119	310	31	58	-	302	2	16	13	15	48	160	13	35	-
Sapu	114	4	6	5	5	20	58	7	9	-	46	3	1	1	3	11	25	1	1	-
Sare Abdou	342	10	21	40	27	82	142	9	11	-	174	7	15	18	13	31	80	7	3	-
Sare Adama	210	5	16	16	19	45	91	9	9	-	97	3	6	6	7	14	54	3	4	-
Sare Babou (Taifa Amadou)	465	14	29	31	36	116	194	22	23	-	236	5	11	20	24	52	98	10	16	-
Sare Balla (Kanel Samba,Ngudoro)	166	3	16	9	9	48	61	10	10	-	88	3	8	4	5	20	37	6	5	-
Sare Batch	225	-	20	20	19	50	94	6	16	-	117	-	10	10	9	23	52	2	11	-
Sare Buty (Bantang Nyima)	226	3	4	13	14	60	112	8	12		123	1	2	6	9	34	62	5	4	

Appendix B



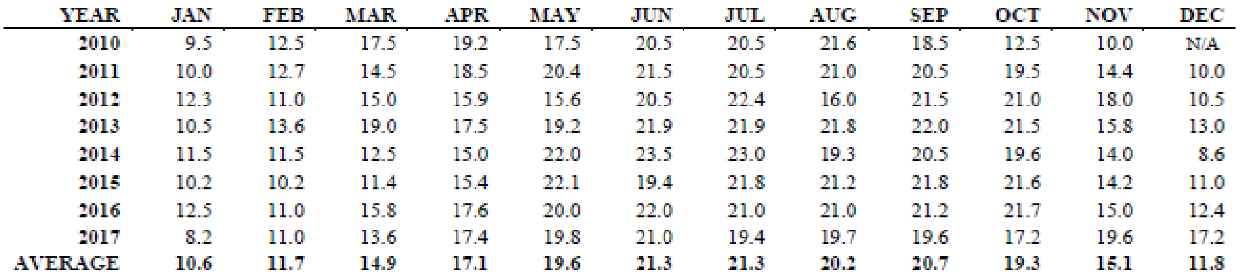
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2010	24.7	27.2	30.2	N/A	31.3	29.1	27.8	27.9	27.7	28.0	26.1	24.9
2011	24.8	26.2	29.1	31.3	31.7	30.1	28.7	27.7	27.7	28.6	27.3	24.0
2012	25.0	26.3	29.2	30.6	31.1	30.6	28.2	27.1	27.4	28.6	28.3	24.7
2013	23.9	28.1	31.3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	27.7	N/A
2014	N/A	N/A	N/A	N/A	31.9	32.0	30.0	27.2	N/A	29.1	26.5	23.3
2015	23.7	26.4	26.7	30.0	30.6	34.2	28.1	27.7	27.9	28.5	26.9	23.6
2016	25.9	26.2	28.9	30.8	32.2	31.1	28.4	27.9	27.6	29.3	27.9	26.0
2017	24.2	26.7	29.9	30.6	31.4	30.7	27.4	26.5	27.8	28.6	29.4	29.8
AVERAGE	**24.6**	**26.7**	**29.3**	**30.7**	**31.5**	**31.1**	**28.4**	**27.4**	**27.7**	**28.7**	**27.5**	**25.2**

Appendix C: Monthly Mean Temperature Data from Janjanburreh Station from 2010-2017



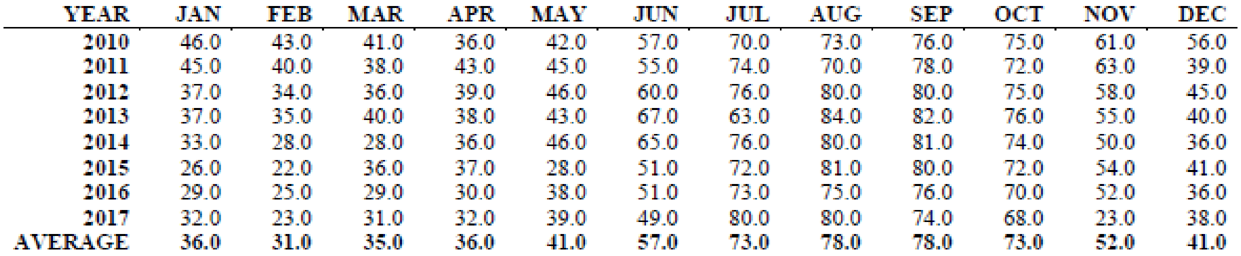
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2010	39.9	42.6	44.0	43.6	41.0	37.3	36.4	35.0	36.5	39.0	37.4	N/A
2011	37.4	41.3	42.8	42.8	45.3	40.0	36.5	35.1	34.5	37.4	39.6	37.5
2012	38.7	40.8	41.8	42.1	43.4	40.5	34.6	32.8	34.5	36.0	38.6	38.0
2013	38.0	40.6	44.0	42.5	N/A	N/A	N/A	N/A	N/A	N/A	38.5	N/A
2014	N/A	N/A	N/A	N/A	N/A	N/A	38.9	35.2	35.0	38.6	39.0	38.0
2015	37.2	40.6	41.9	44.0	43.2	40.6	37.8	34.0	34.0	35.4	37.0	36.2
2016	38.1	41.6	42.8	43.6	44.6	41.4	37.1	34.8	35.0	38.7	39.3	40.0
2017	38.6	40.7	43.6	43.2	42.8	41.6	34.8	33.6	36.6	38.0	36.6	38.0
AVERAGE	**38.3**	**41.2**	**43.0**	**43.1**	**43.4**	**40.2**	**36.6**	**34.4**	**35.2**	**37.6**	**38.3**	**38.0**

Appendix D: Monthly Maximum Temperature (°C) from Janjanburreh station 2010-2017



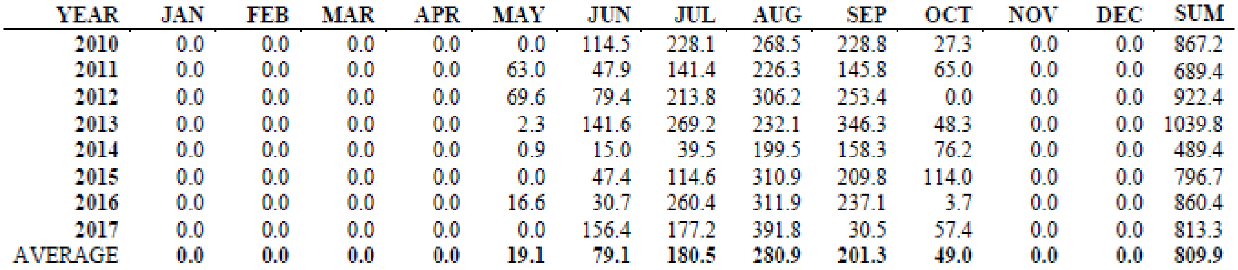
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2010	9.5	12.5	17.5	19.2	17.5	20.5	20.5	21.6	18.5	12.5	10.0	N/A
2011	10.0	12.7	14.5	18.5	20.4	21.5	20.5	21.0	20.5	19.5	14.4	10.0
2012	12.3	11.0	15.0	15.9	15.6	20.5	22.4	16.0	21.5	21.0	18.0	10.5
2013	10.5	13.6	19.0	17.5	19.2	21.9	21.9	21.8	22.0	21.5	15.8	13.0
2014	11.5	11.5	12.5	15.0	22.0	23.5	23.0	19.3	20.5	19.6	14.0	8.6
2015	10.2	10.2	11.4	15.4	22.1	19.4	21.8	21.2	21.8	21.6	14.2	11.0
2016	12.5	11.0	15.8	17.6	20.0	22.0	21.0	21.0	21.2	21.7	15.0	12.4
2017	8.2	11.0	13.6	17.4	19.8	21.0	19.4	19.7	19.6	17.2	19.6	17.2
AVERAGE	**10.6**	**11.7**	**14.9**	**17.1**	**19.6**	**21.3**	**21.3**	**20.2**	**20.7**	**19.3**	**15.1**	**11.8**

Appendix E: Monthly Minimum Temperature (°C) from Janjanburreh Station 2010-2017



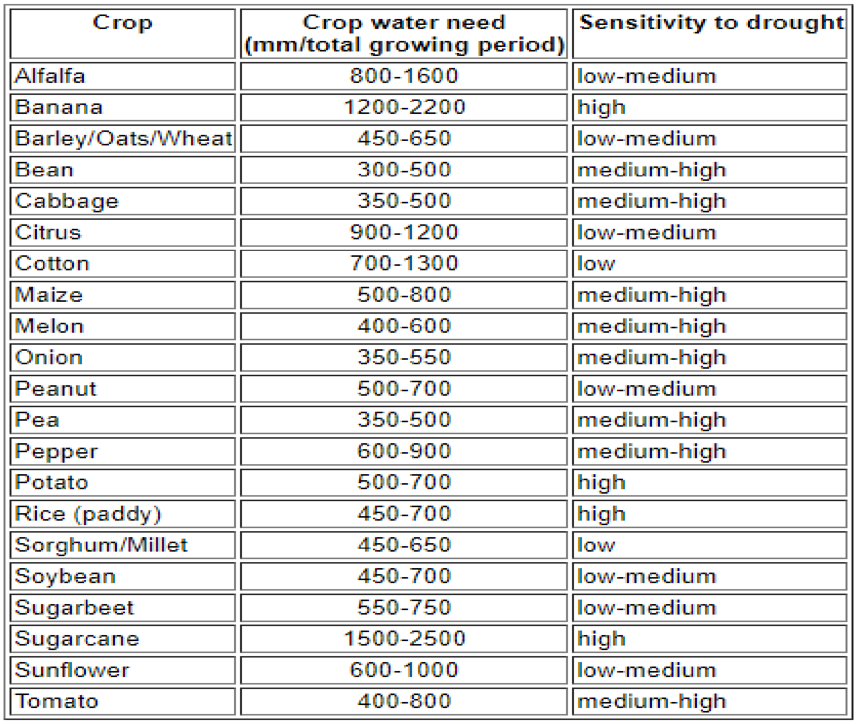
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2010	46.0	43.0	41.0	36.0	42.0	57.0	70.0	73.0	76.0	75.0	61.0	56.0
2011	45.0	40.0	38.0	43.0	45.0	55.0	74.0	70.0	78.0	72.0	63.0	39.0
2012	37.0	34.0	36.0	39.0	46.0	60.0	76.0	80.0	80.0	75.0	58.0	45.0
2013	37.0	35.0	40.0	38.0	43.0	67.0	63.0	84.0	82.0	76.0	55.0	40.0
2014	33.0	28.0	28.0	36.0	46.0	65.0	76.0	80.0	81.0	74.0	50.0	36.0
2015	26.0	22.0	36.0	37.0	28.0	51.0	72.0	81.0	80.0	72.0	54.0	41.0
2016	29.0	25.0	29.0	30.0	38.0	51.0	73.0	75.0	76.0	70.0	52.0	36.0
2017	32.0	23.0	31.0	32.0	39.0	49.0	80.0	80.0	74.0	68.0	23.0	38.0
AVERAGE	**36.0**	**31.0**	**35.0**	**36.0**	**41.0**	**57.0**	**73.0**	**78.0**	**78.0**	**73.0**	**52.0**	**41.0**

Appendix F: Monthly Mean Relative humidity (%) from Janjanburreh Station 2010-2017



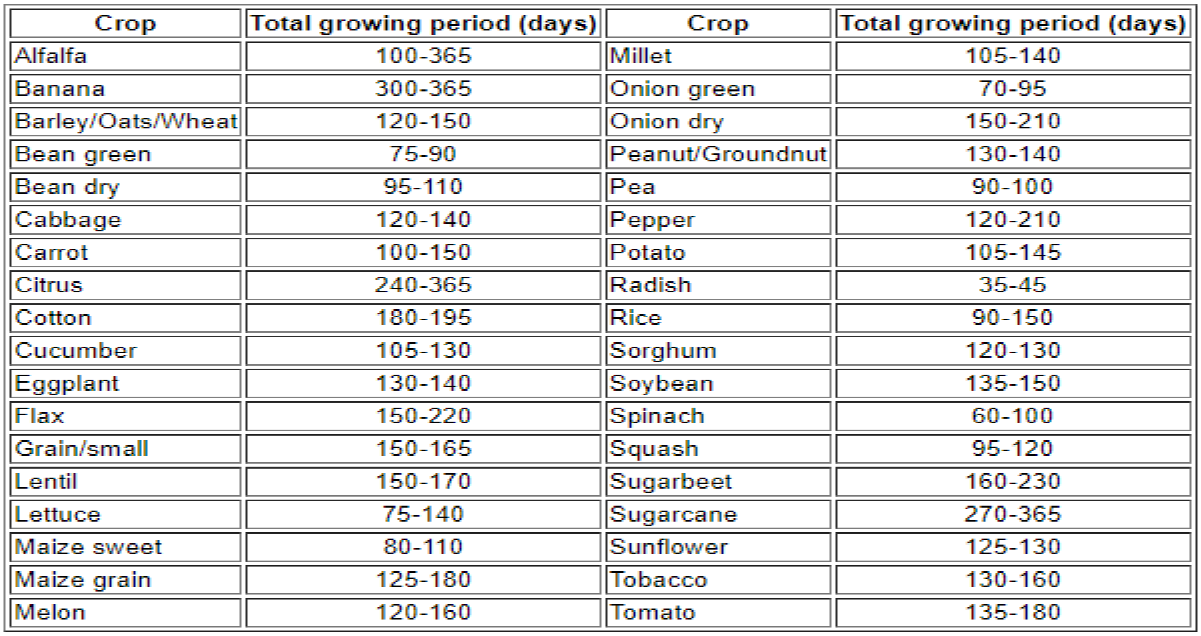
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM
2010	0.0	0.0	0.0	0.0	0.0	114.5	228.1	268.5	228.8	27.3	0.0	0.0	867.2
2011	0.0	0.0	0.0	0.0	63.0	47.9	141.4	226.3	145.8	65.0	0.0	0.0	689.4
2012	0.0	0.0	0.0	0.0	69.6	79.4	213.8	306.2	253.4	0.0	0.0	0.0	922.4
2013	0.0	0.0	0.0	0.0	2.3	141.6	269.2	232.1	346.3	48.3	0.0	0.0	1039.8
2014	0.0	0.0	0.0	0.0	0.9	15.0	39.5	199.5	158.3	76.2	0.0	0.0	489.4
2015	0.0	0.0	0.0	0.0	0.0	47.4	114.6	310.9	209.8	114.0	0.0	0.0	796.7
2016	0.0	0.0	0.0	0.0	16.6	30.7	260.4	311.9	237.1	3.7	0.0	0.0	860.4
2017	0.0	0.0	0.0	0.0	0.0	156.4	177.2	391.8	30.5	57.4	0.0	0.0	813.3
AVERAGE	**0.0**	**0.0**	**0.0**	**0.0**	**19.1**	**79.1**	**180.5**	**280.9**	**201.3**	**49.0**	**0.0**	**0.0**	**809.9**

Appendix G: Monthly Rainfall(mm) from Banjul Station 2010-2017



Crop	Crop water need (mm/total growing period)	Sensitivity to drought
Alfalfa	800-1600	low-medium
Banana	1200-2200	high
Barley/Oats/Wheat	450-650	low-medium
Bean	300-500	medium-high
Cabbage	350-500	medium-high
Citrus	900-1200	low-medium
Cotton	700-1300	low
Maize	500-800	medium-high
Melon	400-600	medium-high
Onion	350-550	medium-high
Peanut	500-700	low-medium
Pea	350-500	medium-high
Pepper	600-900	medium-high
Potato	500-700	high
Rice (paddy)	450-700	high
Sorghum/Millet	450-650	low
Soybean	450-700	low-medium
Sugarbeet	550-750	low-medium
Sugarcane	1500-2500	high
Sunflower	600-1000	low-medium
Tomato	400-800	medium-high

Appendix H: Crop Water Needs (mm/total growing period) of various crops.



Crop	Total growing period (days)	Crop	Total growing period (days)
Alfalfa	100-365	Millet	105-140
Banana	300-365	Onion green	70-95
Barley/Oats/Wheat	120-150	Onion dry	150-210
Bean green	75-90	Peanut/Groundnut	130-140
Bean dry	95-110	Pea	90-100
Cabbage	120-140	Pepper	120-210
Carrot	100-150	Potato	105-145
Citrus	240-365	Radish	35-45
Cotton	180-195	Rice	90-150
Cucumber	105-130	Sorghum	120-130
Eggplant	130-140	Soybean	135-150
Flax	150-220	Spinach	60-100
Grain/small	150-165	Squash	95-120
Lentil	150-170	Sugarbeet	160-230
Lettuce	75-140	Sugarcane	270-365
Maize sweet	80-110	Sunflower	125-130
Maize grain	125-180	Tobacco	130-160
Melon	120-160	Tomato	135-180

Appendix I: Total Growing Periods of Carious Crops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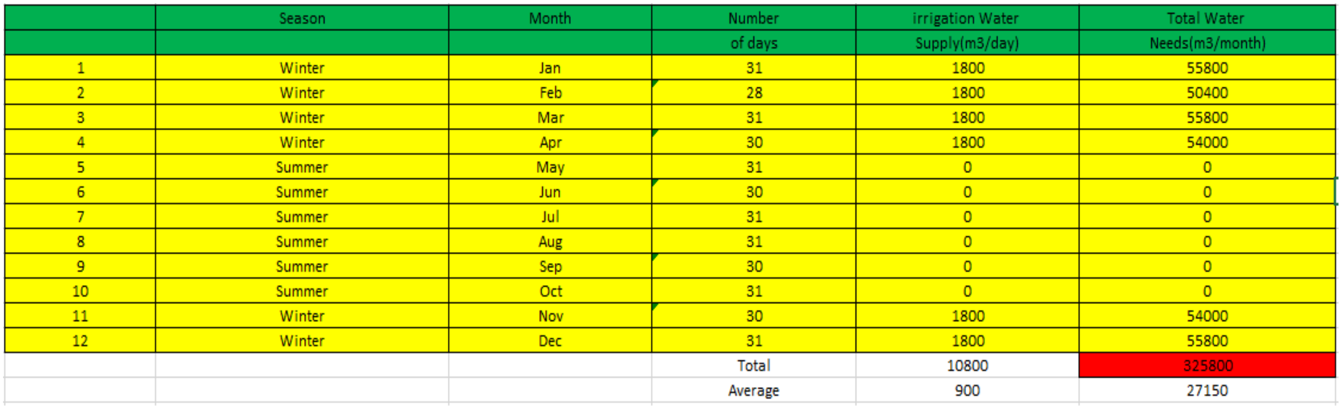
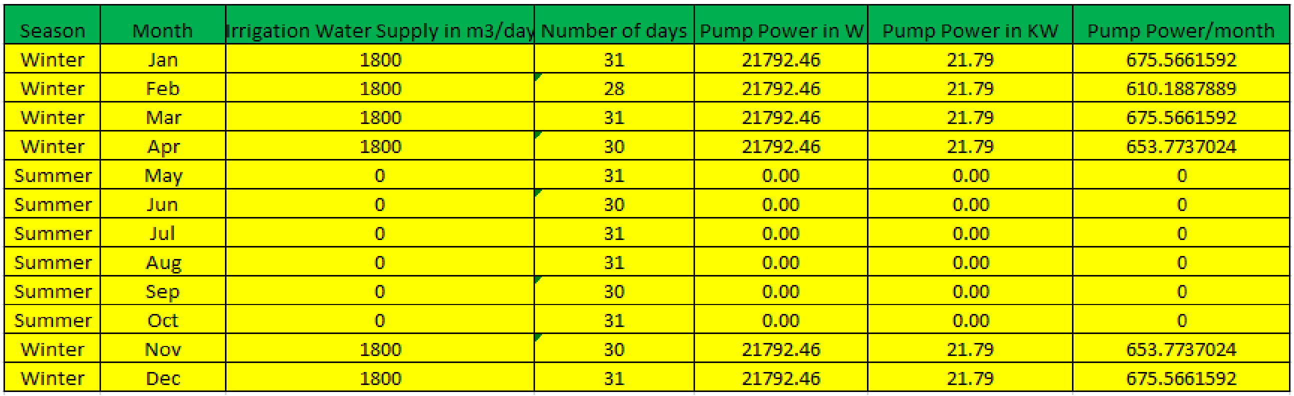


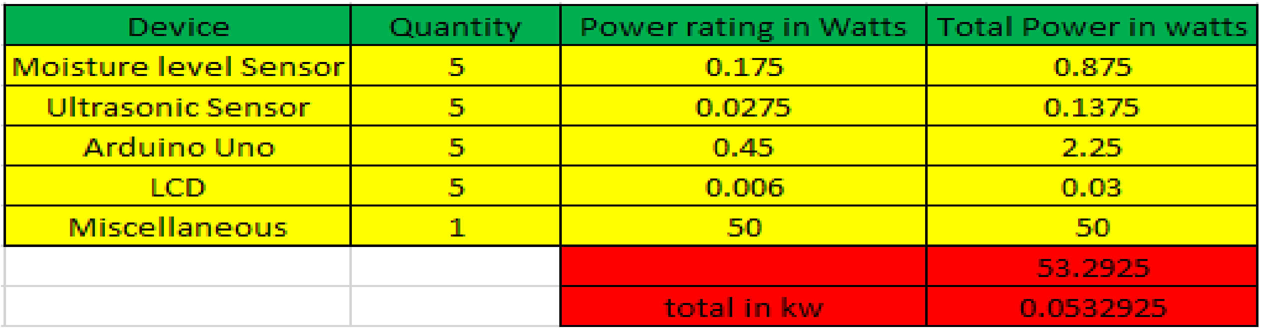
	Season	Month	Number	irrigation Water	Total Water
			of days	Supply(m3/day)	Needs(m3/month)
1	Winter	Jan	31	1800	55800
2	Winter	Feb	28	1800	50400
3	Winter	Mar	31	1800	55800
4	Winter	Apr	30	1800	54000
5	Summer	May	31	0	0
6	Summer	Jun	30	0	0
7	Summer	Jul	31	0	0
8	Summer	Aug	31	0	0
9	Summer	Sep	30	0	0
10	Summer	Oct	31	0	0
11	Winter	Nov	30	1800	54000
12	Winter	Dec	31	1800	55800
			Total	10800	325800
			Average	900	27150

Appendix: Seasonal Water Needs



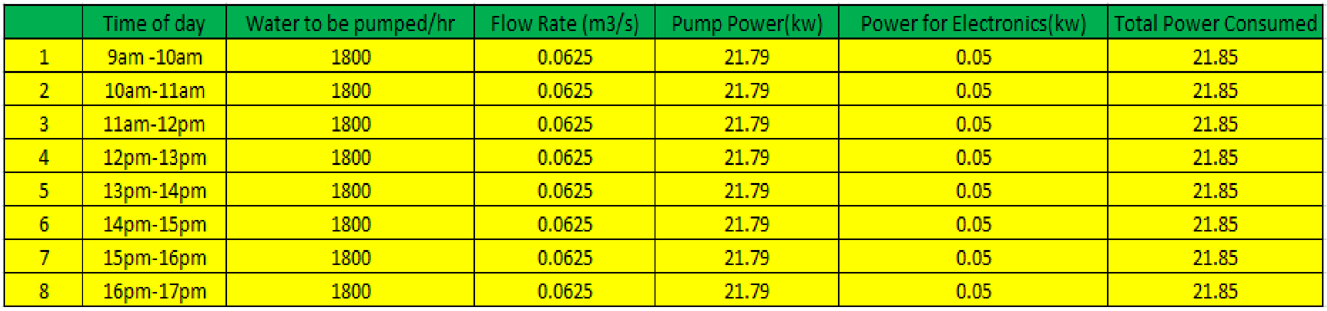
Season	Month	Irrigation Water Supply in m3/day	Number of days	Pump Power in W	Pump Power in KW	Pump Power/month
Winter	Jan	1800	31	21792.46	21.79	675.5661592
Winter	Feb	1800	28	21792.46	21.79	610.1887889
Winter	Mar	1800	31	21792.46	21.79	675.5661592
Winter	Apr	1800	30	21792.46	21.79	653.7737024
Summer	May	0	31	0.00	0.00	0
Summer	Jun	0	30	0.00	0.00	0
Summer	Jul	0	31	0.00	0.00	0
Summer	Aug	0	31	0.00	0.00	0
Summer	Sep	0	30	0.00	0.00	0
Summer	Oct	0	31	0.00	0.00	0
Winter	Nov	1800	30	21792.46	21.79	653.7737024
Winter	Dec	1800	31	21792.46	21.79	675.5661592

Appendix: Pump Power Needed



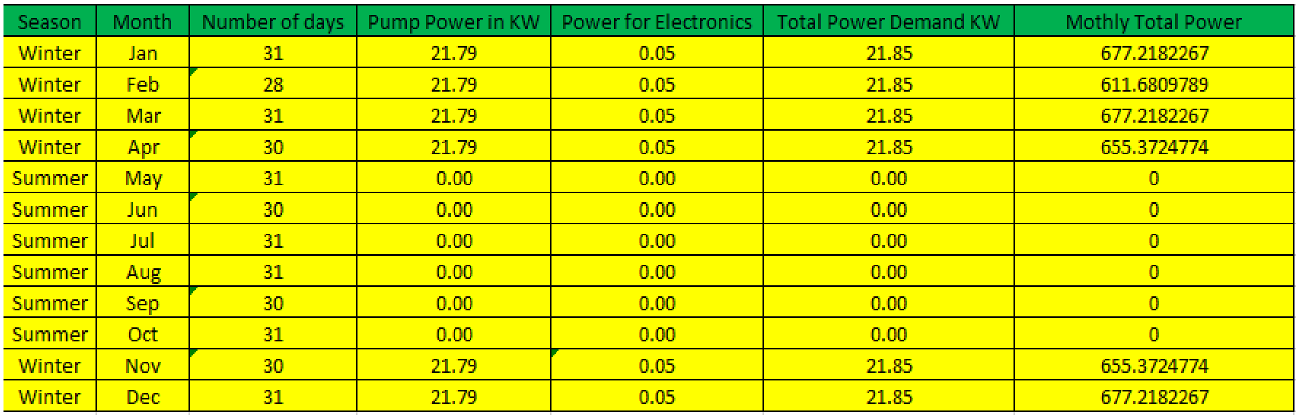
Device	Quantity	Power rating in Watts	Total Power in watts
Moisture level Sensor	5	0.175	0.875
Ultrasonic Sensor	5	0.0275	0.1375
Arduino Uno	5	0.45	2.25
LCD	5	0.006	0.03
Miscellaneous	1	50	50
			53.2925
		total in kw	0.0532925

Appendix: Power for Electronics Devices



	Time of day	Water to be pumped/hr	Flow Rate (m3/s)	Pump Power(kw)	Power for Electronics(kw)	Total Power Consumed
1	9am -10am	1800	0.0625	21.79	0.05	21.85
2	10am-11am	1800	0.0625	21.79	0.05	21.85
3	11am-12pm	1800	0.0625	21.79	0.05	21.85
4	12pm-13pm	1800	0.0625	21.79	0.05	21.85
5	13pm-14pm	1800	0.0625	21.79	0.05	21.85
6	14pm-15pm	1800	0.0625	21.79	0.05	21.85
7	15pm-16pm	1800	0.0625	21.79	0.05	21.85
8	16pm-17pm	1800	0.0625	21.79	0.05	21.85

Appendix: Daily Power Requirement



Season	Month	Number of days	Pump Power in KW	Power for Electronics	Total Power Demand KW	Mothly Total Power
Winter	Jan	31	21.79	0.05	21.85	677.2182267
Winter	Feb	28	21.79	0.05	21.85	611.6809789
Winter	Mar	31	21.79	0.05	21.85	677.2182267
Winter	Apr	30	21.79	0.05	21.85	655.3724774
Summer	May	31	0.00	0.00	0.00	0
Summer	Jun	30	0.00	0.00	0.00	0
Summer	Jul	31	0.00	0.00	0.00	0
Summer	Aug	31	0.00	0.00	0.00	0
Summer	Sep	30	0.00	0.00	0.00	0
Summer	Oct	31	0.00	0.00	0.00	0
Winter	Nov	30	21.79	0.05	21.85	655.3724774
Winter	Dec	31	21.79	0.05	21.85	677.2182267

Appendix: Seasonal Power Requirement

Interview Questions and Site Assessment

APPENDIX A

Questions on field Parameters survey for the Design and Sizing of the Solar Water Pumping System for Irrigation.

Message to the Respondent:

Dear Respondent,

Greetings, I am a Master Degree student at the Pan African University Institute of Water and Energy Sciences Including Climate Change(PAUWES). As a requirement for the honour of this degree, I am carrying out a Research Titled: Conceptual Analysis and Prototypical Design of a Smart Solar Water Pumping System for Irrigation and Community Water Supply Case Study of the Gambia. The research is also under the purview of the APV MaGa hence I am using Maruo Farms which is one of the identified APV MaGa sites in the Gambia as the case study area. This questionnaire is geared towards data collection specific to the research and is purely for academic purposes. Sensitive details and particulars about the farm from the responses and observations will be kept classified. Your participation and responses which are to the best of your knowledge will help in making this research a success.

Yours Sincerely,

Modou Alpha Jallow

QUESTIONS

Personal Information

1. Name: ………………………………………
2. Age: ....
3. Sex: ....

Farm Details

1. The Farm is owned by?
2. Where is the farm Located?
3. How long has the farm been operated?
4. What is the primary crop grown on your farm?

Source of Water

5. Where do you get your water from? Rive☐ La☐ Well/Bo☐ole
6. If there is a Well what is the depth of the well?
7. Is there a water pumping system?
8. What is the type?
9. How do you power the system?
10. How much water do you pump to the field in a day?
11. How many times in a day do you irrigate your field?
12. Do you have a water tank? YE☐ ☐O
13. What is the Volume(dimension) of the water tank?
14. How high is the tank from the ground?
15. How often do you fill the water tank?
16. What type of pipes do you use to supply water to the field if there is any? PVC☐ Welded Ste☐ ☐st Iron Co☐r or Brass

Community Details

17. What is the name of the Community?
18. Where is it located?
19. How do people access water in this communit☐ River ☐ La☐ Well/Borehole
20. What is the cost per liter of water in this community?
21. Is there a water Pumping System?
22. How is this system powered?
23. What are the economic activities of people in this community?

Site and Resources Assessment for the Researcher only

1. Average annual sunshine of the site
2. Population of the community

3. Distance between the source of water and the field (farm and community).
4. Size and water requirement
5. Water supply period (operating period of the pump)

APPENDIX B

Message to the Respondent:

Dear Respondent,

Greetings, I am a Master Degree student at the Pan African University Institute of Water and Energy Sciences Including Climate Change(PAUWES). As a requirement for the honor of this degree, I am carrying out a Research Titled: Conceptual Analysis and Prototypical Design of a Smart Solar Water Pumping System for Irrigation and Community Water Supply Case Study of the Gambia. The research is also under the purview of the APV MaGa hence I am using Maruo Farms which is one of the identified APV MaGa sites in the Gambia as the case study area. This questionnaire is geared towards data collection specific to the research and is purely for academic purposes. Sensitive details and particulars about the farm from the responses and observations will be kept classified. Your participation and responses which are to the best of your knowledge will help in making this research a success.

Yours Sincerely,

Modou Alpha Jallow

Internet Details (Farm and Community)

24. Does your farm have any form of monitoring system?
25. Is the system smartly operated?
26. What is your understanding of what a smart system is?
27. Do you think your farm needs to be smartly operated?
28. Do you have access to the internet?
29. How much of internet data do you consume?
30. How much do you spend on internet data?

31. Will you be able to operate a smart system?

32. Do you have a technician to operate the system for you?