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SUITABILITY OF SOLAR PHOTO-VOLTAIC WATER PUMPING SYSTEM FOR IRRIGATION IN RWANDA

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Abstract

The implementation of SIS project needs the energy from the sun, cultivable land, water for agriculture irrigation and some infrastructures like roads and markets to facilitate the availability of the necessary equipments on the field

The site suitability for photovoltaic water pumping systems has been assessed in this research using different map types from different sources and it has been found that a large part of Rwanda is highly suitable for the application of SIS.

The most suitable areas are located in Eastern and Southern provinces whose solar irradiation varies between 5.25 and 5.55.52 KWh/m²/day.

This research has showed that the maximum temperature in Rwanda varies between 25 and 27.5°C throughout the year which implies a very good suitability of the country for PV irrigation systems.

The slope and elevation maps showed that the eastern and southern parts of Rwanda are the most suitable for surface irrigation as the slope ranges between 0 and 12% and the elevation in these regions is less than 1500m.

The western part is not suitable for surface irrigation and therefore the application of special technique like radical terracing is necessary to ensure a secure drip or sprinkler irrigation without erosion.

1. Introduction

Irrigation is an important part in agriculture that helps tocontrol crop growth and boosts the food productivity. Dieselbased water pumps are used to irrigate farms in many countries around the world. However, rising oil prices and tighter energy restrictions have prompted these countries to seek alternative clean energy sources using pumps [1].

The important reasons of using solar PV irrigation technology are the lower prices of Solar Irrigation System and the availability of power electronic components used in this field.

Moreover, the energy from solar is a good for environment and it is found freely everywhere in the word and therefore it has been considered to replace diesel and other fossil fuel to get a high profitability and sustainability in agriculture [2].

The improvements in solar pumping technologies have enabled the irrigation industry to overcome a number of technical and cost hurdles, resulting in reliable and cost-effective products that have robust and versatile designs, increased efficiency, minimal operating costs, longer lifetimes and lower maintenance requirements [3].

In Rwanda and the surrounding area, topography has a significant impact on spatial precipitation patterns. Mountains that operate as a barrier to moisture-carrying winds, forced convection, Lake Victoria's humidity, and the high altitudes all contribute to the precipitation. The catchment area of Akanyaru has severe seasonal variations in monthly rainfall. The wettest month in Gisagara is November, with an average of 150 mm of precipitations. The driest month is July, with an average precipitation of 12.5mm. The country is subdivided into five provinces and the city of Kigali [4].

The areas that cannot be used for SIS are considered as exclusionary and those with much probability of being used by SWPS are considered as most suitable areas for solar irrigation system. The most important parameters to consider before implementing SWPSs in a region include solar radiation, precipitation, slope of the site, water availability and aquifer recharge, land coverage and load infrastructures[5].

2. Background of the Project

Developers, researchers, and policy makers are promoting photovoltaic solar-based water pumps in developed countries as a "costeffective" and "clean" way of irrigation and drinking watersuply. They claim that solar powered pumps offer an inexpensive alternative to ele ctric or gas powered pumps. At the same time, policy bodies ranging from the CAADP to natioal and municipal plans highlighted the potential of water resources to reduce poverty and support economic growth in Sub-Saharan Africa [6]. Many researches have focused on investing in big projects in the past, but that is changing. Current research shows that the deve lopment of smallscale irrigation has the potential to contribute to local and national food security and improve nutrition and income.

In general, the technology of irrigation used in Rwanda is a traditional irrigation system that is labor rigorous and that allows only small amounts of area to be irrigated. Diesel engine technology is very costly, not accessible at time and it is air pollutant [7].

Till now, a small part of irrigation system is coupled to the network which is also fighting with power outages while SIS technology is still lagging behind.

Rwanda's total grid installed solar power capacity is composed by Jali power plant generating 0.25MW, Rwamagana solar power plant of 0.15MW, Ndera generating 8.5MW, and Nasho whose capacity is 3.3 MW [8].

Solar irrigation pumps should replace traditional irrigation systems and to give the advantages in socio-economic benefits and climate benefits since they are driven using MPPT to boost the extraction of solar energy.

Simulation helps in the optimum designing of the system as per the water requirement, and a well optimum designed Photovoltaic system has the advantage of reducing payback period with a reduction of the overall system cost [9].

3. Problem statement

As solar panels become cheaper, solar photovoltaic pumps have been identified as a promising w ater-lifting technology to meet the needs of the growing basin of SSA.
However, little is known about the geospatial potential of solar photovoltaic pumped irrigation, given not only solar energy but also its water supply and connectivity to the economy.
The request for food in the country is growing because of an increase in Rwanda population although the land of agricultural is declining [10].
Mechanized agriculture involving irrigation systems such as water pumps increases commercial energy consumption per hectare compared to manual systems.Electricity is often the cheapest an d most efficient way to use water in many countries, but may not be available to farmers scattere d over a small area [2].
Rwanda has attempted to enhance access to electricity for its citizens. Over fifty-one percent of the installed capacity comes from numerous hydropower plant projects being developed across the nation. In order to provide universal access to electricity, hydropower potential still needs to be identified and developed. Due to shortage of qualified local hydropower engineers, one of the problems facing is the availability of competent staff for hydropower project implementation. Solar water pump is a better way to solve these problems [4].

The irrigation region suitability is a crucial key factor for estimating the size of the market potentiality and implementation feasibility. A suitably study of appropriate SIS technologies is also very important to attract private sector attention and partnership.

Farmers are supposed to get money facilities from Credit and Savings microfinance cooperatives and therefore, a convincing proof of project potentiality, sustainability and viability is crucial for loan approvals [7].

4. Objectives of the study

4.1. Main Objectives

The main objective of this study is to evaluate the suitability of PVWPS application in different regions of Rwanda.

4.2. Specific Objectives

In the current research, the following analyses have to be done:

- Solar radiation in Rwanda
- Rainfall distribution
- Elevation throughout the country
- Terrain slope
- Water availability and aquifer recharge
- Land use and distance to road maps

5. Literature Review

Rwanda is a landlocked country covering a surface of 26338 km^2 and a population of 13.6 millions. This translates into an average density of 515 inhabitants per km^2, which makes it the most densely populated country in Africa [11].

It is an East Africa country located at latitudes from 1.050 to 2.840^{0}S and longitude from 28.860 to 30.90^{0}E [12].

The approximate average of every month solar radiation changes between 4.3 and 5.2 kWh per m^{2}per day throughout the country, although the most part remains unused [10, 11and 12].

The maximum temperature in Rwanda varies between 25 and 27.5°C throughout the year which implies a very good suitability of the country for PV irrigation systems and the average of annual rainfall of about 1,250 mm [13].

The highest daily GHI ranges from 5.23 to 5.55 KWh/m^2 in some regions of Eastern province, southern parts of Kigali and the areas near Kivu Lake. The lowest daily GHI ranges from 3.52 to 4.52 KWh/m^2 in northern west and southern west of the country [14].

Farm workers have faced many problems planting crops in recent days as there has not been enough rain to help them get a good harvest. Such problems can be solved by using a solar photovoltaic water pump as solar energy is environmentally friendly and freely available [15].

Often it is not possible to connect the pump to nearby mains because it is very expensive to connect to the mains. Using electric pumps to send water for use is both profitable and environmentally problematic. High diesel prices increase utility operating costs and reduce profits. In addition, the use of electric pumps releases a large amount of carbon dioxide, which causes global warms. One solution to these problems is to use solar energy to run water pumps [16].The current pumps using fuel for a generator have the following limitations: inaccessible roads for transportation of oil to the production site, high fuel costs and the needs of regular maintenance.

There are big advantages of using solar energy to pump water because solar energy can be used in many places in Rwanda. The investment cost is low and the maintenance cost is low. It also has the advantage of storing water for use when the sun is not shining. By comparing costs of installation, fuel costs, and maintenance costs to electrical systems in Rwanda, you can see that solar is a financial option and a solution for remote and remote areas. The solar pump is more reliable than other water sources and requires less maintenance [17].

The solar irrigation pump must receive sufficient solar energy and have access to land and water suitable for agriculture irrigation, physical operating infrastructure such as markets and roads. The viability of a region to bring solar pumping technology is important for building a particular business model because it helps to predict market size and scope [18].

The suitability of the soil for crop sustainability depends on the depth of the soil, the texture of the soil, and the drainage specified by the SCI, which explains that the land can be irrigated. Land use patterns in watersheds have a positive impact on water use, water quality and water availability. Insufficient precipitation is a climate security issue that affects agricultural production and suggests the use of irrigation systems to increase productivity. A negative precipitation value indicates that precipitation is more than evapotranspiration, and a high precipitation value indicates no need for additional water. However, negative precipitation value indicates that evapotranspiration is higher than precipitation, as in this study, more water is needed for crops [19].

6. Research method

6.1. Solar radiation

The main parameter in SWPS is solar radiation and the amount of produced electrical energy depends on its irradiance. The performance analysis of SIS and the energy yield calculation in different regions of Rwanda is based on respective received GHI. The map of GHI in different provinces of Rwanda is shown in Figure 1 (Global Solar Atlas).

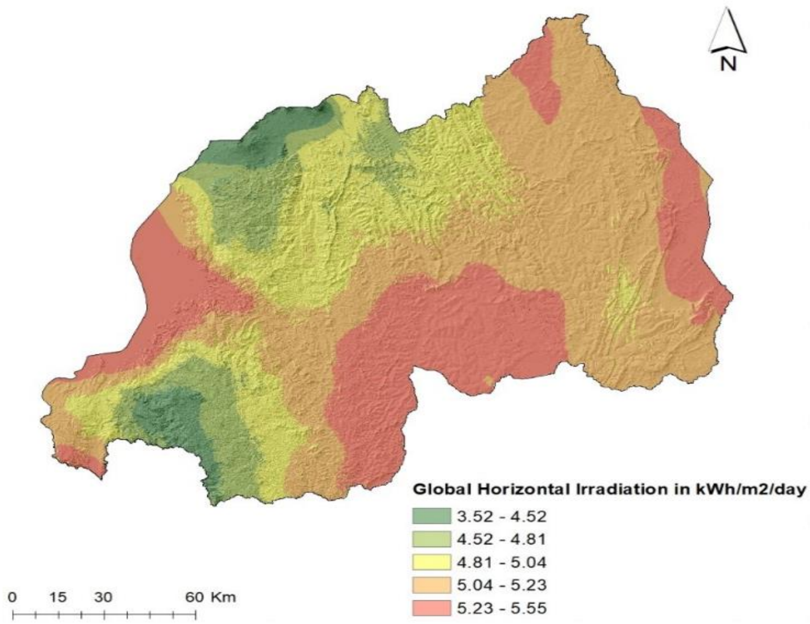

Figure 1: Map of GHI for Rwanda

From the above figure, the highest daily GHI ranges from 5.23 to 5.55 KWh/m^2 in some regions of Eastern province, southern parts of Kigali and the areas near Kivu Lake. The lowest daily GHI ranges from 3.52 to 4.52 KWh/m^2 in northern west and southern west of the country.

The GHI is well distributed throughout the country and 67% of the total area receives the irradiation greater than 5KWh/m^2/day as shown in Figure 2.

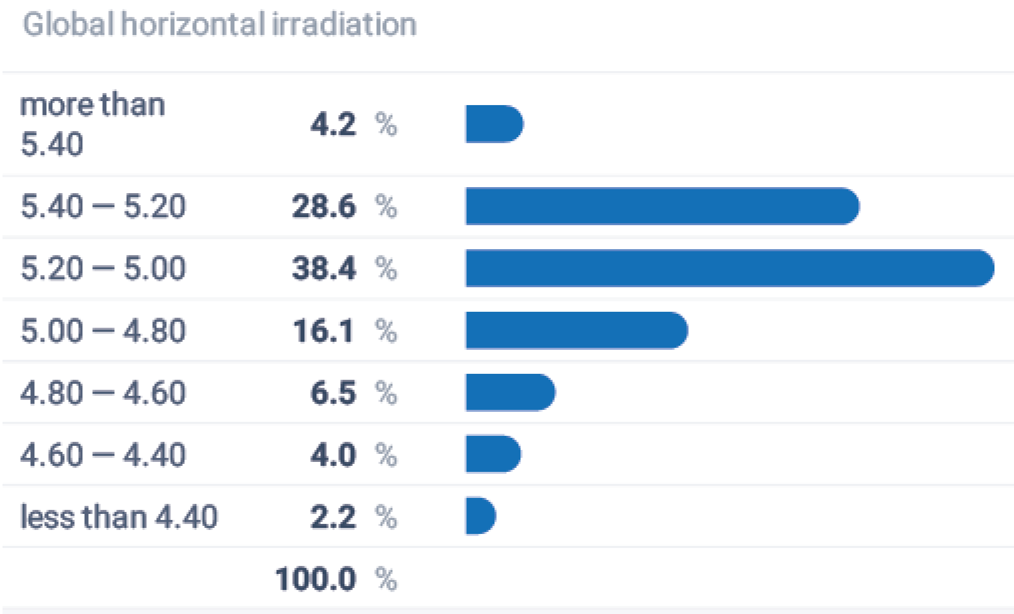

Figure 2: Rwanda GHI distribution (Global Solar Atlas)

6.2. Rainfall distribution

The annual rainfall in the plain of East ranges from 700 to 1100 millimeters, the center part of the countries rainfall is between 1,100 and 1,300 millimeters, volcanic chains of Birunga and Congo-Nile Ridge precipitation is ranging from 1,300 mm and 1,600 millimeters and most of parts near Kivu Lake and plains of Bugarama has precipitations ranging from 1,200 to 1,500 millimeters (MINIRENA). Figure 3 shows the rainfall distribution in Rwanda.

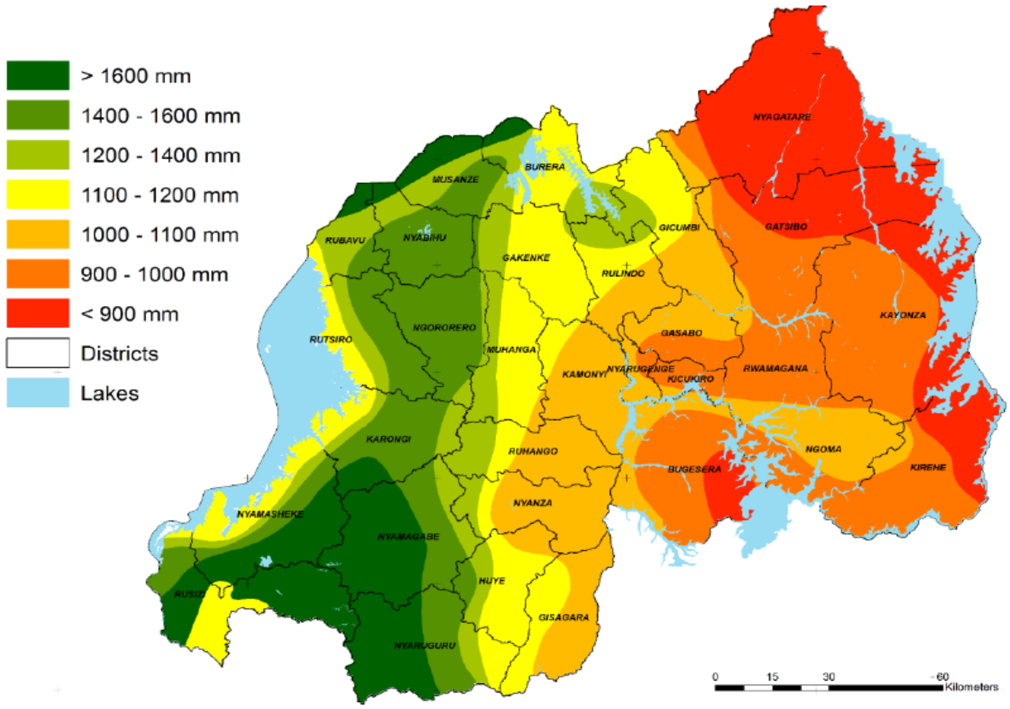

Figure 3: Rainfall distribution map (RNRA)

The monthly mean values of minimum temperature, maximum temperature and monthly mean value of precipitations are shown in Figure 4 (World bank Climate knowledge portal).

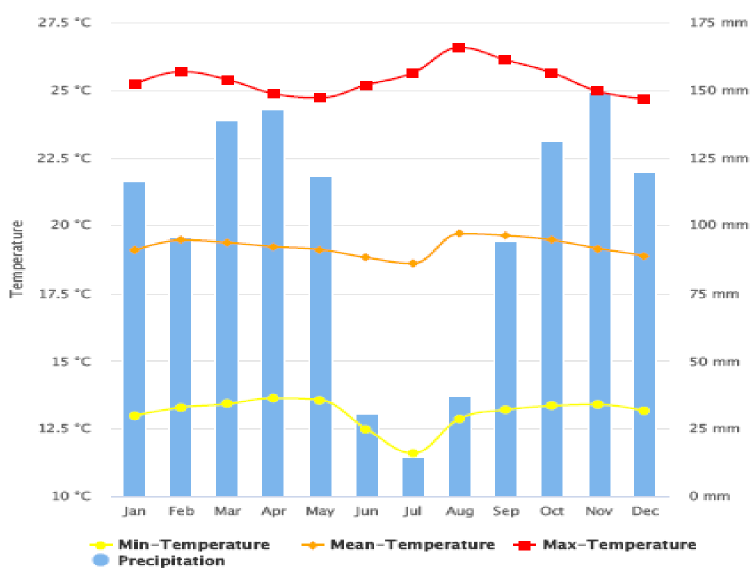

Figure 4: mean temperatures and precipitations

6.3. Terrain slope

The terrain slope is very crucial factor while considering the erodibility of various types of soil and their higher values indicate high likelihood of erosion occurrence. The irrigation system type to be used in a particular region is defined by corresponding slope of its terrain.

A big part in the western regions of Rwanda have the highest slope (greater than 28% and the regions in East and south east have the lowest slope scaling between 0 and 12% as shown in Figure 5.

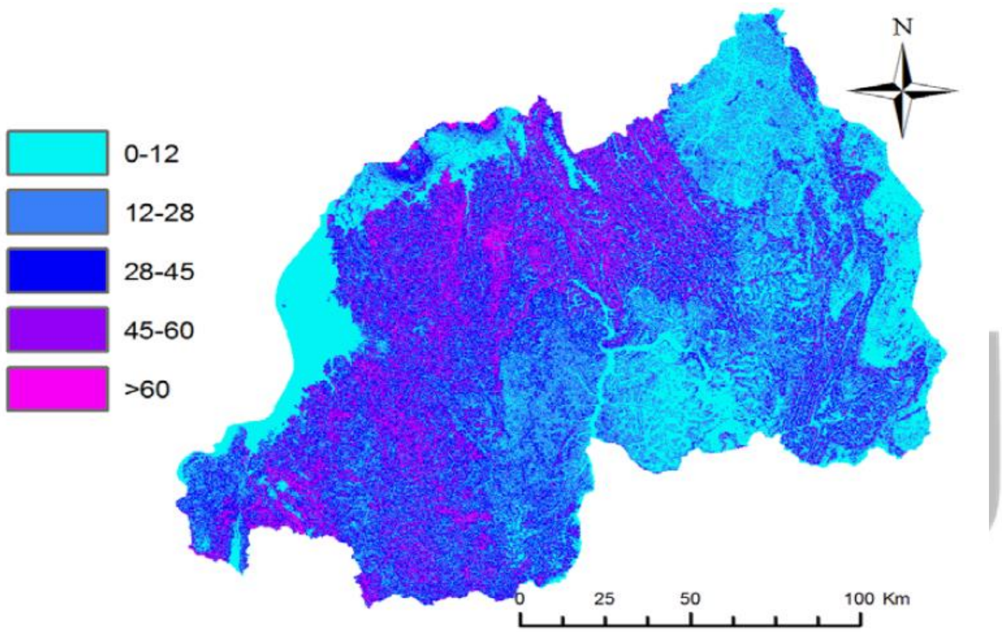

Figure 5: Slope map (Rwanda DEM SRTM)

Radical terracing method is applied on hillsides especially in Western part of the country with slopes of up to 40% to expand the country irrigated area potential.

This method is applied manually by collective group work of many farmers using hoes and shovels as shown in Figure 6.

The technology decreases the soil loss, promote and enlarge the agriculture area on abrupt slopes which favor the land consolidation and rigorously increase the agriculture land.

The impact has been considerable in the regions where radical terraces have been developed resulting in optimal water conservation and soil protection.

Figure 6: Radical terracing technology [20]

6.4. Elevation

The eastern part of the country consists of savanna, plains and swamps at 900 m of altitude, the central region has an elevation angle ranging between 1500 to 1800m and the western regions are dominated by big mountains with an altitude greater than 2000m as shown in Figure 7.

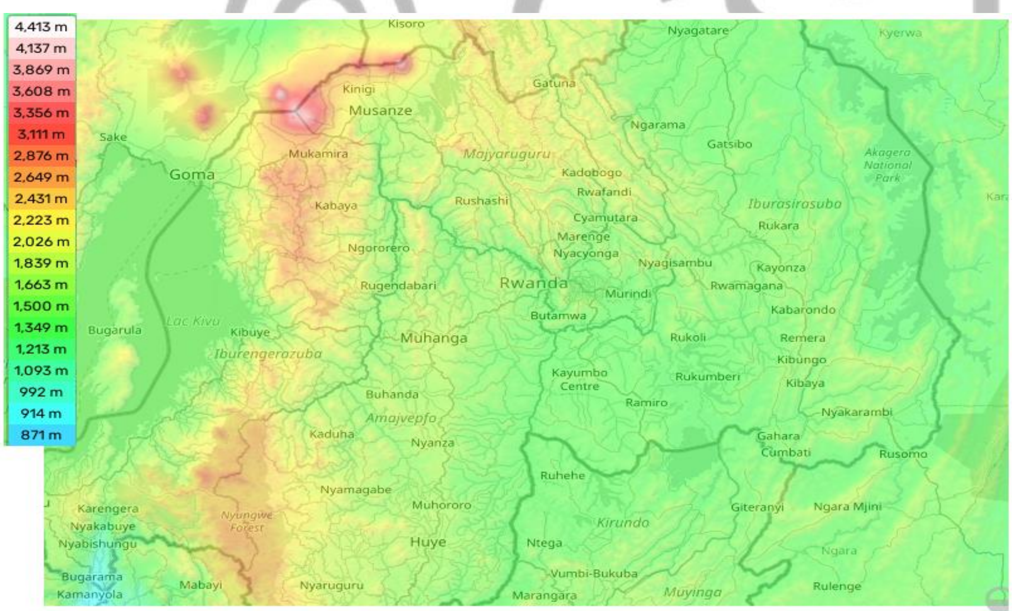

Figure 7: Rwanda elevation map [21]

6.5. Land use and distance to road maps

The structure of coverage of site land is very important to indicate most suitable areas for irrigation. The use of Land depends on multiple factors the incorporating government policies, climate and population culture.

The coverage structure includes: wet land, trees and shrub areas, crop and grass lands, bare and built up areas as shown in Figure 8.

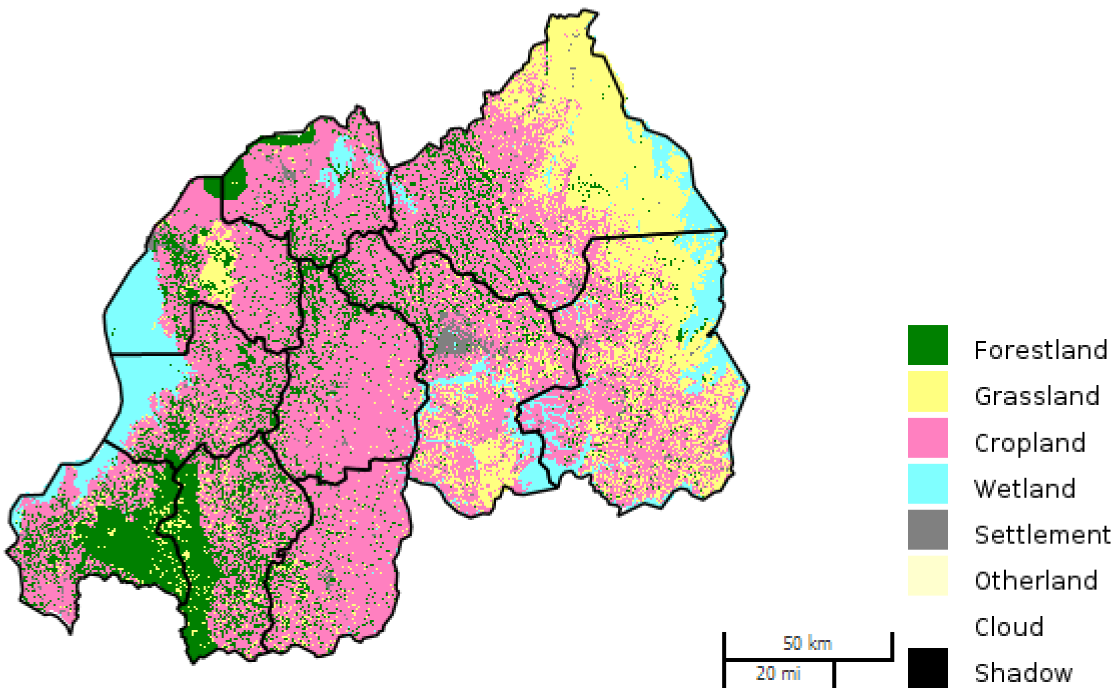

Figure 8: Land coverage map (rcmrd geoportal)

Agriculture sector occupies over 74% of the country area, protected and forests parts occupy over 10% and 6% of national are occupied by lakes (REMA). Figure 9 shows the country land use and land cover percentages in different periods.

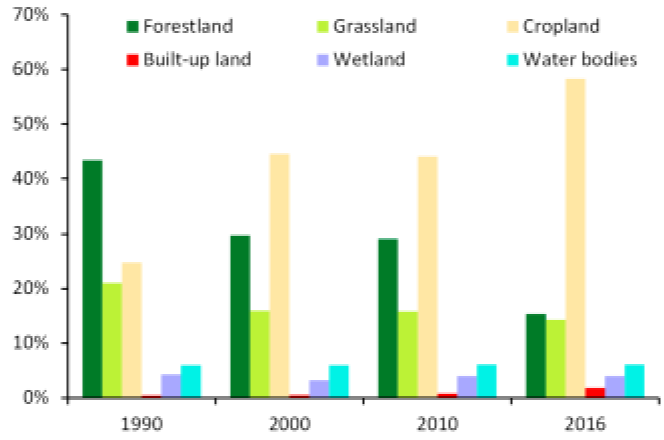

Figure 9: Rwanda LULC [70]

Rwanda's primary transportation system is land transportation ensuring connections between Kigali, different districts and other nearest countries. Transport by roads is Rwanda's main mode of transportation, covering the majority of the country's passenger and freight needs.

The road density of the country is high as shown in Figure 10 and this has the advantage of low operation cost during installation of solar irrigation system and its maintenance.

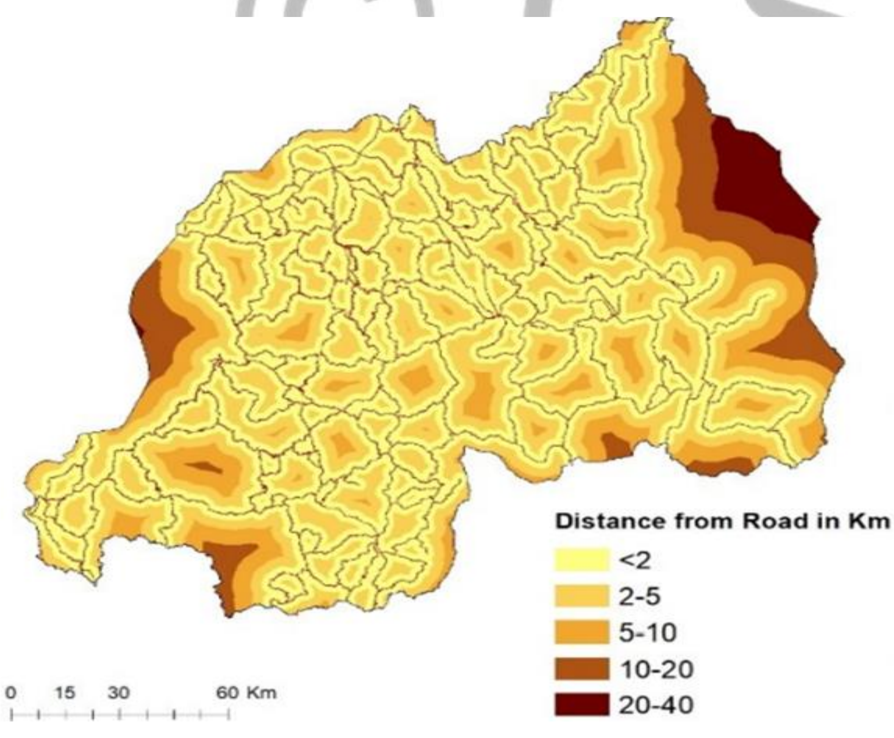

Figure 10: Distance from the road map (RTDA)

6.6. Water availability and aquifer recharge

Rwanda has a heavy water network consisting of many rivers, streams and wetlands that flow into lakes and other ponds.

The level of availability of water in Rwanda is lower in Eastern and Southern Provinces and higher in Western province having the heaviest measure of rail fall.

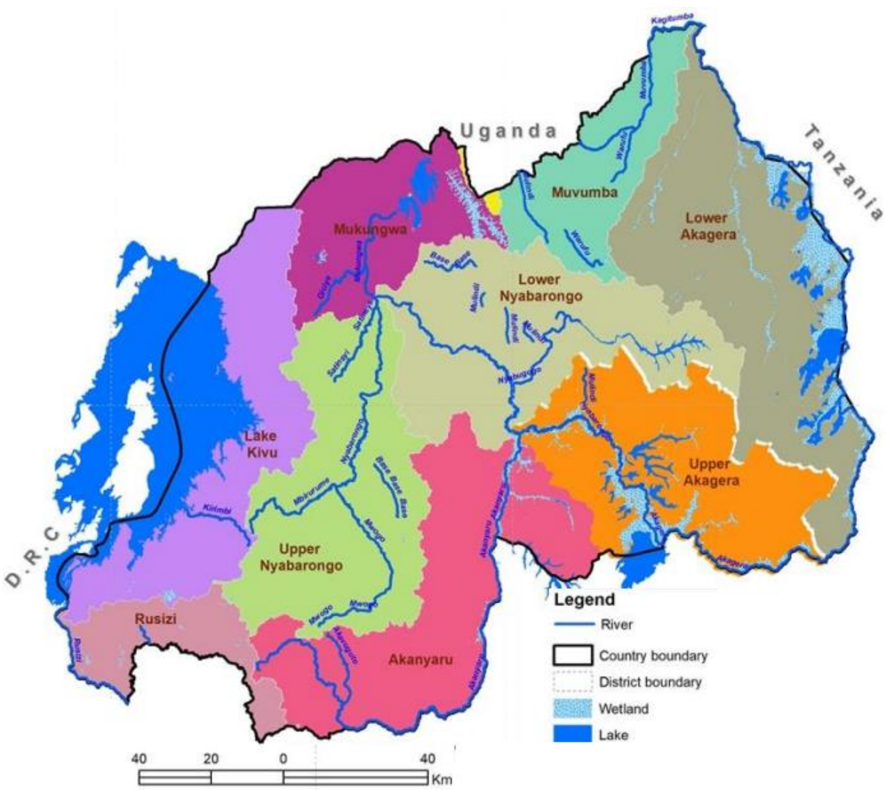

Figure 11: Rwanda waterbodies [22]

Rwanda water distribution is dominated by marshlands occupying about 37% of the total country water as shown in Table 1.

Table 1: Water distribution in Rwanda (MINAGRI)

Water Resources	Area [ha]	Share of Total
Runoff for small reservoirs 21	125.627	21.0%
Runoff for dams	31.204	5.2%
Direct river and flood water	80.974	13.6%
Lake water resources	100.153	16.8%
Groundwater resources	36.434	6.1%
Marshlands	222.418	37.3%

When it rains, the hillside generated runoff flows towards different water bodies
causing economic water shortages due to the poor infrastructure and farming during dry seasons is limited.

The Eastern region of Rwanda receives fewer precipitations but its lowlands are interspersed by a good surface water body system with a remarkable flows and accumulation.

The overview of the country statistics on water availability is shown in Table 2.

Table 2: Rwanda water availability overview (MINIRENA)

Parameter	Quantity
Rainfall	32.4BCM/annum
Ground water recharge	4.554 BCM/annum
Surface water	6.826 BCM/annum
Total renewable water resources	11.38 BCM/annum
Water availability per capita	1O89 m^3/annum

7. Findings and Discussions

This study has analyzed the site suitability using various types of Rwanda maps.

Previous studies have shown that solar power can be effectively deployed, preferably in areas receiving more than 3.6kWh/m^2/day of solar irradiance per annum (Elboshy et al., 2021).

The Map of GHI for Rwanda and land coverage map show that the crop land of the country area is widest and receives more than 4.52 KWh/m^2/day which is satisfactory good for producing the required electrical energy for irrigation purposes.

Considering the solar radiation, Rwanda is suitable for SISs since its irradiance exceeds

3.6 kWh/m^2/day.

The most suitable areas are located in Eastern and Southern provinces whose solar irradiation varies between 5.25 and 5.55.52 KWh/m^2/day.

In addition to the country solar irradiance, solar cell performance also depends on temperature. The maximum efficiency of solar modules can be obtained in the temperature range of 15 to 40°C, but temperatures above this range affect the efficiency of the solar cells [23].

This research has showed that the maximum temperature in Rwanda varies between 25 and 27.5°C throughout the year which implies a very good suitability of the country for PV irrigation systems.

The slope and elevation maps showed that the eastern and southern parts of Rwanda are the most suitable for surface irrigation as they range 0 and 12%. The elevation in these regions is less than 1500m.

The western part is not suitable for surface irrigation and therefore the application of special technique like radical terracing is necessary to ensure a secure drip or sprinkler irrigation without erosion.

The implementation of SIS in Rwanda is also facilitated by a high availability of both surface and ground water that results in 670 m^3/capita/annum and a dense network of county roads.

8. Conclusion and recommendations

8.1. Conclusion

Using solar energy to generate electricity is an important tool for photovoltaic-based water pumps for agriculture and community water. Irrigation with PVWPS is a sustainable and attractive solution that can contribute to the sustainable development of the Agriculture sector.

Solar irrigation systems play an important role in sustainable agriculture by addressing global issues such as greenhouse gas emissions, pollution and sustainable production. A growing body of research is discussing the role of renewable energy in agriculture from a theoretical, economic and environmental perspective. This study adds to the existing literature by providing more ways to analyze the feasibility of solar irrigation from the perspective of small farmers in developing countries. A solar-powered water system is a simple and affordable solution to water shortages in Rwandan communities.

The site suitability for photovoltaic water pumping systems has been assessed in this research using different map types from different sources and it has been found that a large part of Rwanda is highly suitable for the application of SIS.

8.2. Recommendations

Further researches should focus on reuse of water and desalination that will help in various applications such as garden irrigation, toilet cleaning and car washing. Those studies would find very good solutions to decrease waste of water and related costs.

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