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RESEARCH ARTICLE

DIAGNOSIS OF WATER NEEDS AND IMPROVED SOLAR PUMPING SOLUTION: CASE OF MARKET GARDENERS IN THE PLATEAUX REGION TOGO

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Abstract

Market gardeners face significant challenges, exacerbated by the growing impacts of climate change. Young farmers and women, who play a crucial role in this sector, are among the most severely affected. This study examines their key difficulties, particularly in water management, using survey data. Thefindings were analysed to develop an improved solar-powered pumping system. Results reveal that 64% of market gardeners are under 40, with women representing49% of respondents. 98% report drought impacts, while99% cite manual watering (using cans and buckets) as exhausting and harmful to their health. The proposed system features a portable solar pump delivering2.72 m³/h, supplying21.6 m³ daily, enough to irrigate4,320 m² between8 AM and 4 PM.

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Introduction:-

Togo spans an area of 56,000 km² and 60% of this area is arable land. Its exploitation would ensure the country's food self-sufficiency and elevate it among agricultural exporting countries [1]. Unfortunately, only 45% of this arable land is exploited [2].Furthermore, this cultivated area is the sum of small, fragmented farms [3], which are unevenly distributed and influenced by factors such as gender. In recent years, small farms have been facing the consequences of climate change, including irregular rainfall and increasingly frequent droughts.

The result is a deterioration in the socio-economic conditions of the most vulnerable groups engaged in agriculture [4] [5].This article presents the technical study of the pumping solution proposed in the context of a project to develop the Mono river basin in southern Togo, the technical implementation of which is being carried out by the Dargatech-Togo company. The project aims to contribute to poverty reduction and improved food security in rural communities by promoting the emergence and appropriation of sustainable pumping methods to strengthen the capacities of small market gardens. The project places great importance on young people and women.

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Methodologies:-

The study covers 194 sites that are candidates for the installation of a solar pump, 75 of which have already been installed in the Plateau region of Togo. Table 1 presents the average climate parameters for the Plateaux region. The collection of hydraulic data, irrigation methods and crop management practices in the study area is facilitated by the Kobo Toolbox software. The data are subsequently processed and analysed. An analytical assessment of the water requirements of the various crops grown by market gardeners is carried out. Water requirements are specific to each plant. Water requirements vary according to the specific characteristics of each plant.

They are assessed using formula (1):

$$B_{EI} = ET_C - Pui - RS \quad (1)$$

Where,
B_{EI} Is the plant's daily water requirement (mm),
ET_C Evapotranspiration,
Pui useful rainfall availability,
RS soil water reserve

Evapotranspiration ET_C Is obtained using formula (2) [6] :

$$ET_C = K_c \times ET_0 \quad (2)$$

ET_0 Is equivalent to the sum of transpiration from vegetation cover and soil evaporation that could occur. This value takes meteorological parameters into account. Among the approaches used to determine ET_0, the most recommended is the Penman Monteith approach, formulated (3) as follows:

$$ET_0 = \frac{0.408 \times \alpha \times (1 - 0.23)R_n + \gamma \frac{900}{T_{moy} + 273} \times ff_{2m} \times max(e_s - e_a; 0)}{\alpha \times \gamma(1 + 0.34 \times ff_{2m})} \quad (3)$$

ET_0 (mm/day)
R_n Net radiation from the canopy surface (MJ/m^2.day
T_{av} Average daily temperature at 2 m (°C)
ff_{2m} Wind speed at 2 m (m/s)
e_s Saturation vapour pressure (kPa)
e_a Actual vapour pressure (kpa)
α Saturation curvature loss (kPa/°C)
γ Psychrometric constant (kPa/°C)

The calculation of RS depends on factors such as grain size and soil permeability. The soils at the various sites in this study are mostly sandy loam. In fact, almost all of the sites are located in areas that are often flooded during high water periods, which promotes the deposition of silt and sand. The study's specifications are to formulate a solar solution to address the difficulties faced by market gardeners, as expressed in the Kobo Toolbox surveys. The proposed solution should be robust and easy for market gardeners to use. The system components and their operation must be environmentally friendly. The components of the proposed system are sized taking into account local parameters obtained at the various installation sites (194 sites), as illustrated in Figure 1.

Based on these parameters, the manometric height of each site, which is the sum of the static height (H_s) and the dynamic height (H_{ds}), is calculated as follows:

$$HMT = H_s + H_d et H_s = H + H' \quad (4)$$

The dynamic head H_d Represents the sum of the linear pressure losses (H_{dL}) and the singular pressure losses (H_{ds}) in the piping.

These pressure losses are expressed by:

$$H_{dL} = f\frac{L}{D}\frac{V^2}{2g} \quad (5)$$

$$H_{ds} = K_{ac}\frac{V^2}{2g} \quad (6)$$

Where $L, D, V,\ K_{ac}$ Are respectively the length and diameter of the pipe, the fluid flow velocity and a singular pressure loss coefficient.

Hydraulic energy is obtained by simplifying Bernoulli's equation:

$$E_H = \frac{\rho g Q_i HMT}{3600} \, or E_H = 2{,}725 Q_i HMT \quad (7)$$

With Q_i The daily water requirement.

The efficiency of the motor pump reaches 86 % [7] and is expressed by:

$$R_{mp} = \frac{E_H}{E_{elec}} \, or E_{elec} = \frac{E_H}{R_{mp}} = 2{,}725\frac{Q_i HMT}{R_{mp}} \quad (8)$$

This electrical energy is supplied by the panels and can also be determined by formula (9):

$$E_{\mathrm{E}lec} = K_p P_c H_i \quad (9)$$

K_p Is an efficiency factor, P_c Is the power of the solar module, and G_{global} Is the irradiation.

The power of the photovoltaic module supplying the motor pump is then obtained by:

$$P_c = \frac{2{,}725 Q_i HMT}{K_p R_{mp} G_{global}} \quad (10)$$

The cross-section of the power cables is selected in accordance with formula (11):

$$S \geq \frac{2LI}{\Delta V_L(\%)U} \quad (11)$$

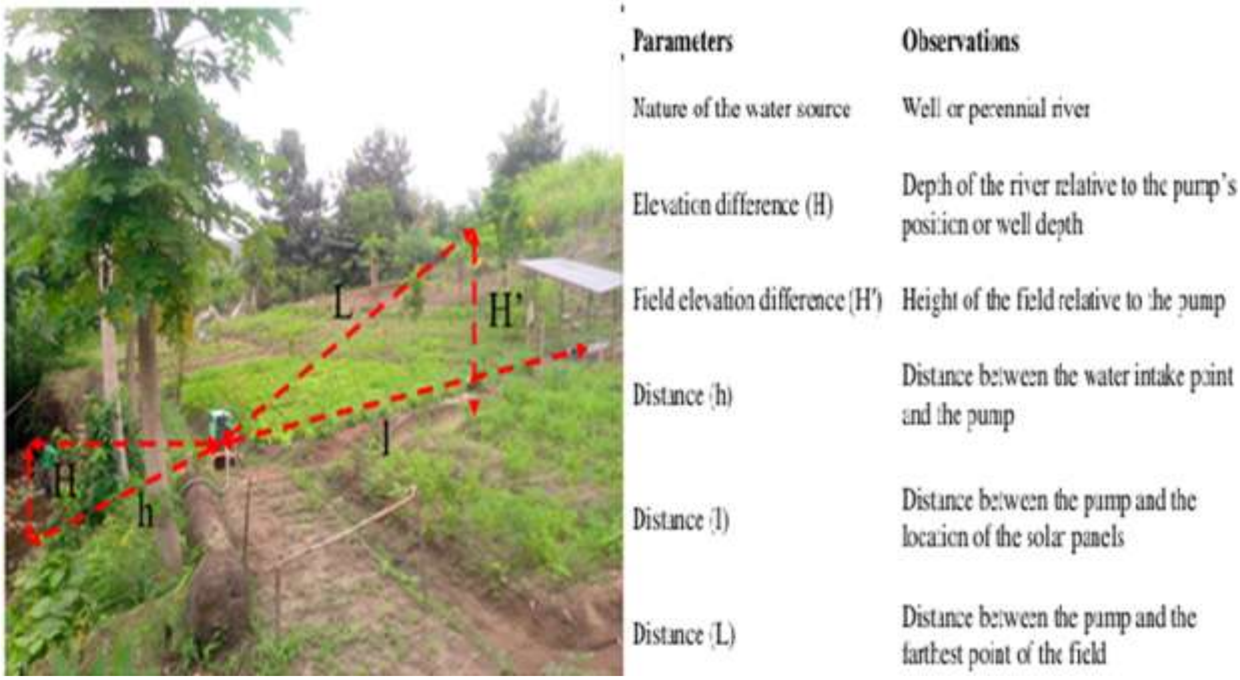

Figure 1. Parameters measured at the 194 sites.

Table of climatic parameters for the Plateaux region extracted from NASA data using retscreen Expert software [8]

	Air temperature (°C)	Soil temperature (°C)	Relative humidity (%)	Solaire radiation (Mj/m²/j)	Wind speed at 2m	Vapor pressure at T_{av} (kPa)	Effective vapor pressure (kPa)	Pressure curve slope (kPa/°C)	Psychometric constant (kPa/°C)	Precipitation (mm)
January	25,6	25,8	59,1	20,196	1,68	3,32	1,96	0,19	0,06	9,3
February	27,5	28,3	59,3	21,168	1,82	3,84	2,28	0,22	0,06	17,92
March	27,7	28,7	68	20,88	2,03	3,93	2,67	0,22	0,06	53,94
April	27,4	28	75,4	20,376	2,1	3,77	2,85	0,22	0,06	112,5
May	26,6	27	80,3	19,44	1,89	3,56	2,86	0,20	0,06	140,43
June	25,4	25,7	83,7	17,424	1,89	3,30	2,76	0,19	0,06	184,5
July	24,5	24,7	85,7	15,984	2,03	3,11	2,66	0,18	0,06	237,46
August	24,4	24,6	86	15,192	2,03	3,09	2,66	0,18	0,06	230,02
September	24,7	24,9	86,2	16,488	1,61	3,14	2,71	0,18	0,06	243
October	25,2	25,4	84,9	18,648	1,47	3,24	2,75	0,19	0,06	135,16
November	25,6	25,7	76,7	19,8	1,47	3,30	2,53	0,19	0,06	19,5
December	25,3	25,1	65,4	19,908	1,47	3,18	2,08	0,18	0,06	9,3

Results Et Discussions:-

Survey data analysis: The survey questionnaires enabled the collection of useful information for the study on the project's target population, namely: age, gender, area cultivated, difficulties encountered, type of crops grown, accessibility to water, means of water extraction, type of water source, daily amount of water extracted, months of irrigation and harvest, etc. The histogram in Figure 2 (a) shows the age distribution of the surveyed population. Of the 194 market gardeners surveyed, over 64% are aged 40 or under: 26% are aged between 20 and 30, while 38% are aged between 30 and 40. 45% of market gardeners are women.

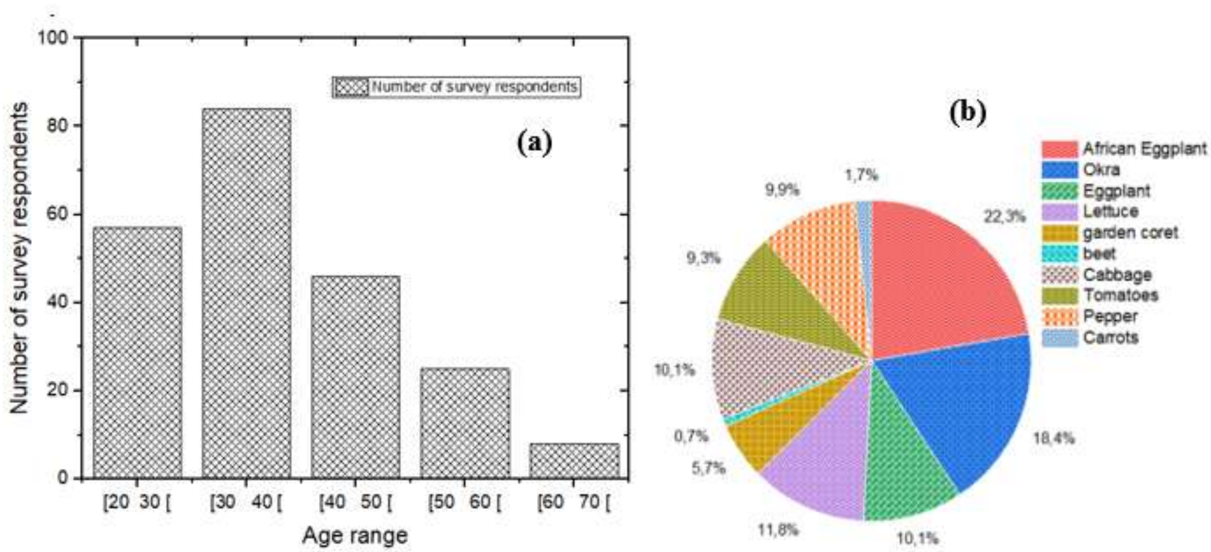

Figure 2: (a) Proportion according to the age of the market gardeners involved in the project, (b) percentage of different crops grown

Among the crops grown by market gardeners, it appears (Figure 2 (b)) that African aubergine, okra, lettuce, and cabbage are the most widely grown, with percentages of 22.3%, 18.4%, 11.8% and 10.1% respectively. Market gardening is not without its challenges for smallholders. One of their difficulties is the availability of agricultural inputs. 98% of market gardeners say they have difficulty obtaining these inputs. This difficulty is taken seriously by the authorities, who have created the National Plan for Agricultural Investment, Food Security and Nutritional Security (PNIASAN) for the period 2017-2026, which includes measures to encourage the establishment of seed producers and companies in the country [9].

Climate change, which is forcing insects to adapt and change their feeding habits, is now impacting market gardeners [10]. 99% of those surveyed report that their plants have been destroyed by insects and that there are new plant infections that did not exist a few years ago. 98% say they are affected by drought. Although they use rivers, the drought, which is exacerbated by climate change, increases the water requirements of plants and requires additional time for watering. Figure 3 (a) illustrates the results of the questionnaire regarding the amount of time spent watering plants. It is easy to see that 62% of market gardeners spend more than four (4) hours watering their gardens. This result confirms that 99% say that watering is tiring and causes back pain and limits the space they can use.

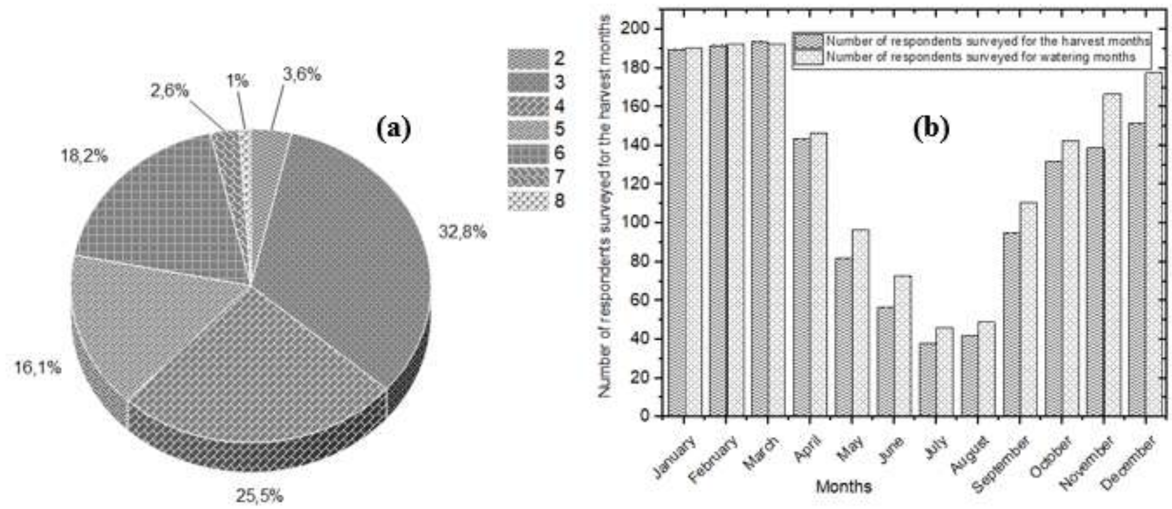

Figure 3: (a) Distribution of the population of market gardeners surveyed according to the time spent on water drainage, (b) distribution of watering and harvesting activities throughout the year.

The Plateaux region covered by the study has two seasons: the rainy season, which is the period from March/April to October, and the dry season, from November to February/March. Between May and August, the number of market gardeners who water their crops and those who harvest them decreases, falling from 42% in May to 26% in August. It is surprising to observe watering activities during this period, which coincides with the rainy season (Figure 3 (b)). However, this observation is justified by the irregularity of rainfall and the droughts observed during the rainy season, as mentioned by Ali et al. [11]. On the other hand, during the period from September to December, the number of market gardeners who irrigate is much higher than those who harvest. This period therefore constitutes the start-up period for market gardening activities.

The geographical area covered by the study is crossed by several rivers, most of which do not dry up. 96% of market gardeners use surface water from rivers, compared with 4% who use wells, which justifies the choice of surface pumps for solar pumping. The difference in elevation between water sources is in most cases between 2 and 4 metres. More than 80% of market gardeners say they draw water using watering cans and buckets (equivalent to 15 litres).Considering the differences in elevation, the means of water extraction, the distance between the fields and the water points, the watering time (mostly more than four hours) and the area to be watered, this activity, although the main source of income for these market gardeners, could only lead to their exhaustion and health problems.

Assessment of plant water requirements inmarket gardening inthe Plateau Region:

Each plant has specific water requirements. Analysis of the survey results shows that the crops most commonly grown by market gardeners are African eggplant, okra, lettuce and cabbage, at 22.3%, 18.4%, 11.8% and 10.1% respectively. Water requirements are evaluated in relation to these main crops. The results are compared with the water requirements of the plants as reported by market gardeners in the survey (Figure 4). The various crops require watering from mid-October to mid-March. Statistical analysis reveals that 18% of market gardeners provide more water (horizontal line in Figure 4) than the 5 mm of water required by plants for the different stages of their growth. As this percentage is high, there is a need to train market gardeners in water management. Between mid-March and mid-October, theoretically, there is no need to water, as shown in Figure 7. However, in practice, market gardeners are observed to water sporadically during this period. During the rainy season, there may be a lack of rain for one or more weeks, followed by heavy rainfall after this short period of drought[12] [13]. As precipitation values are monthly averages, the forecast does not indicate the need for spraying during the short dry spell [14] [15]. The improved solar irrigation solution will enable adaptive water management to mitigate the impacts of these droughts.

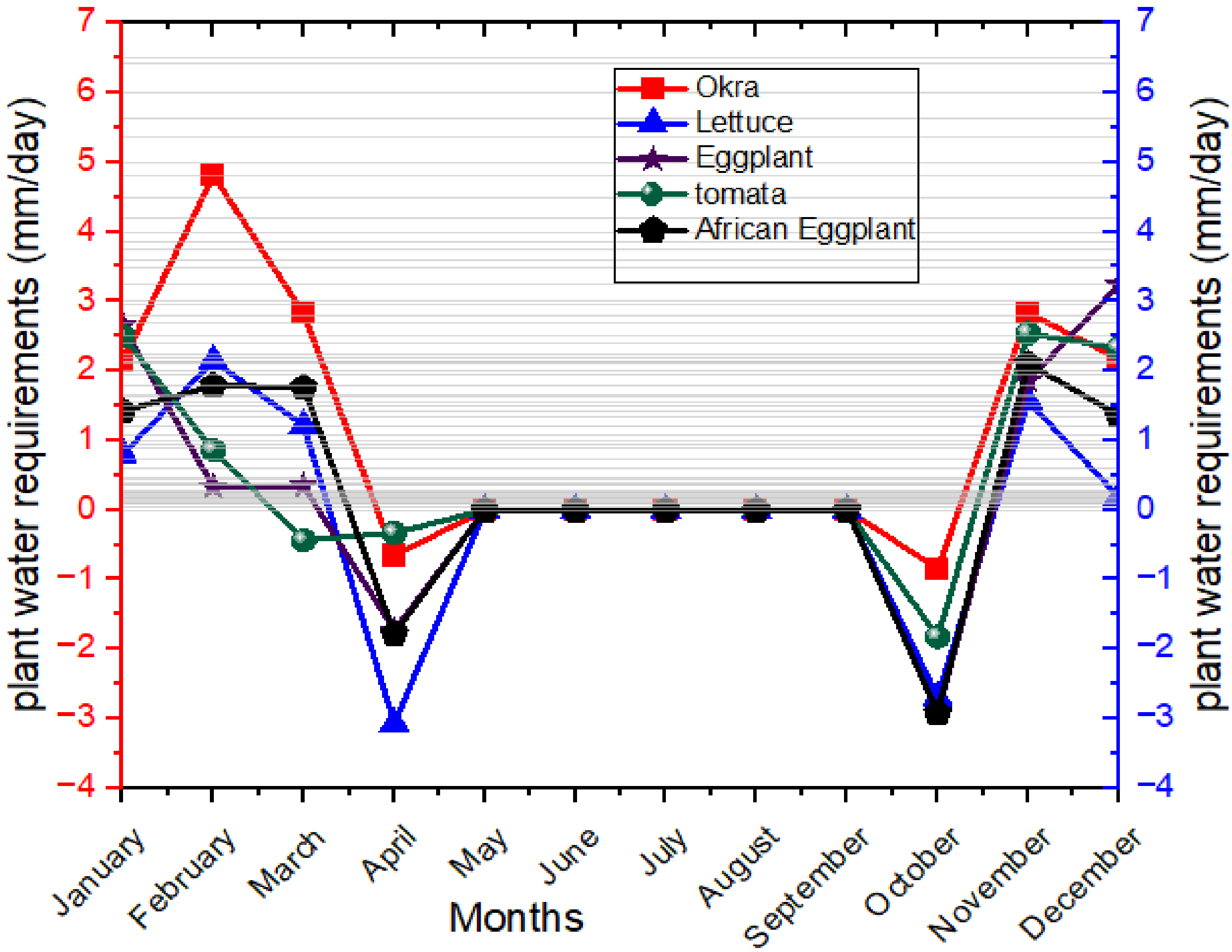

Figure 4. Distribution of water requirements for various crops.

Solar irrigation system proposed:

The superposition of hydraulic data [16]and irradiation data [17] enabled us to produce the map illustrated in Figure 8. Analysis of this map reveals an abundance of rivers that do not dry up, unlike in other areas of Togo, and the potential for solar irradiation. Consequently, surface solar pumps are the appropriate choice for irrigation. To determine the pump power, we assumed a maximum suction flow rate of 6 m^3/h. In the specifications, a discharge flow rate of 2 m^3/h is desirable. The manometric height is variable at different sites. For our design, we chose a maximum manometric height of 24 m, which will be sufficient to pump even from wells 7 m deep.

The viscosity μ of water is set at 10^{-3}Pa.s. Taking into account equations (7), we obtain a useful power of the pump equal to 400 W. From equation (8), we obtain an electrical power to be supplied to the pump of approximately 550 W. The duration of sunshine in the study region is estimated at 6.3 hours [18]. Considering the 15% efficiency modules and equation (8), we obtain a power of 588 W for the modules to be installed. In order to cover periods of low irradiation and enable the pump to always operate at its rated power, in practice two 500 W modules were installed and the motor pump was selected in respect of the assumptions of this study.

After testing, the average discharge flow rate at 50 sites was 2.72 m^3/h, with a maximum of 3.43 m^3/h at 12 noon and a minimum of 2.40 m^3/h at 10 a.m. The measurements were taken under precarious conditions, such as uncleaned panels. The average flow rate obtained under these conditions was 2 m^3/h. The robustness of the system was validated after six months of operation without major failures, which enabled the deployment of the first tranche of 75 installations (blue dot in Figure 5). The proposed system meets the specifications. With a flow rate of 2.70 m^3/h between 8 a.m. And 4 p.m., the volume of water pumped will be 21.6 m^3. Given that the water requirement for 1000 m² is 5 m^3, market gardeners will be able to irrigate at least 4320 m².

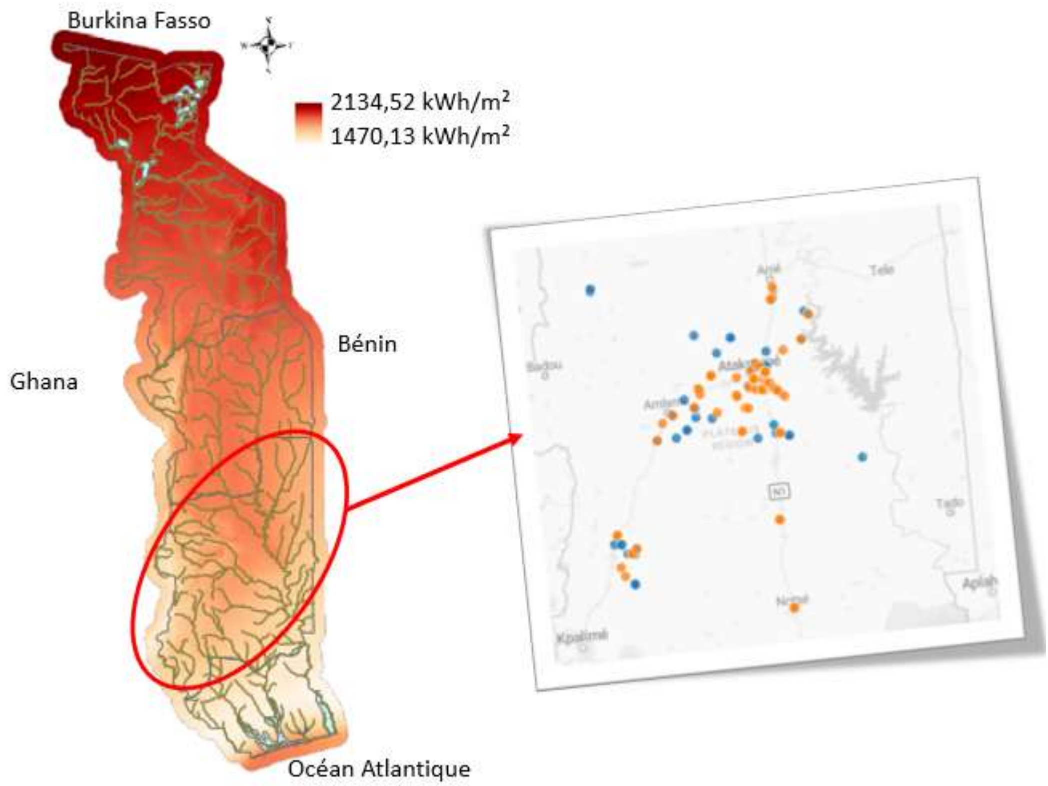

Figure 5. Spatial distribution of installed systems.

Conclusion:-

This article analyses market gardening activities in region of plateau in Togo using questionnaires administered via the Kobo Toolbox application. A solar pumping solution was proposed and the system was sized.The study shows that 99% of market gardeners reported finding it tiring to water crops with watering cans and buckets. This has a direct impact on their health and restricts the size of the area they can cultivate. The solar system, which was installed at 75 sites, has a maximum measured flow rate of 3.45 m^3/h and a minimum of 2.40 m^3/h. The average daily flow rate is 2.72 m^3/h, providing 21.6 m^3 of water per day. Water retention basins have also been installed to store water and compensate for intermittent sunlight.

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