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Research Article

GIS-Based Irrigation Dams Potential Assessment of Floating Solar PV System

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The majority of the Ethiopian population lives in rural areas and uses wood for domestic energy consumption. Using wood and fuel for domestic uses accounts for deforestation and health problems, which is also dangerous for the environment. The Ethiopian government has been planning to generate power from available renewable resources around the community. Therefore, determining the water surface potential of energy harvesting with floating solar photovoltaic system by using geographic information system is used to support decision-makers to use high potential areas. To identify useable areas for floating solar photovoltaic, factors that affect the usability were identified and weighted by using Analytical Hierarchy Processes. Thus, weighted values and reclassified values were multiplied to do the final usability map of floating solar photovoltaic with ArcGIS software. Due to the improper location of floating solar photovoltaic, efficiency is dropped. Therefore, the objective of this study was to identify the most usable surface of water bodies in Amhara regional, state irrigation dams for generating electrical power. The usability of the water surface for floating solar photovoltaic power plant was 63.83%, 61.09%, and 57.20% of Angereb, Rib, and Koga irrigation dams, respectively. The majority of the usable areas were found in the middle of the water surface. Nature water surface is a key factor in generating solar energy; it affects the floating solar photovoltaic and irradiance coming to the solar photovoltaic panel surface.

1. Introduction

Currently, using promising alternative energy technology to extract maximum power from solar photovoltaic source is a reasonable choice for electrification in Ethiopia. Thus, floating solar PV on the water surface is an ideal solution to improve the technical and economic issue. Solar PV floating is currently emerging technology which uses the surface of the water for power generation. Water bodies like irrigation dams, canals or remediation, water reservoirs, lakes, and ocean are used for floating [1, 2]. Due to the water surface cooling effect, the floating PV system on the water surface has a lower temperature that reduces the cell temperature of the solar PV panel. Thus, floating solar panel is 11% more efficient than the land-based solar panels [3–5].

The scarcity of land, efficiency drop at high operating PV cell temperature, and lack of researches on the area are dominant factors that limit the growth of PV penetration in the world and particularly in Ethiopia. Therefore, the combination of solar PV and floating technology on the water surface is the best solution to overcome the above problems [6–8].

Solar PV floating system has environmental benefits like reducing evaporation and improving water quality in addition to the efficiency of the power plant. Panels shading water surface also reduce the growth of algae [3, 9].

A country like Ethiopia, where agriculture leads the economy, scarcity of land and food insecurity is critical issues. Floating solar PV technology on the surface water bodies is not a choice. Therefore, the aim of this paper was to assess floating solar PV potential in Amhara regional state [10, 11].

2. Literature Review

There are different solar floating-related studies in which the work focused on design concepts of solar floating on water surfaces. And researchers also argued that temperature and

Table 1: Solar PV floating system related studies without multicriteria decision-making perspectives.

No.	Attempt	Method	Weakness	Year	Reference
1	Design and construction of floating PV generation structure PV	GIS approach	There was multicriteria decision-making approach to identify the usable surface of water.	2017	[14]
2	Floating PV system analysis by considering environmental impacts	Comparison approaches were used with some mathematical modeling	It was not georeferenced	2019	[15]
3	Floating and floating tracking system	Dynamic technoeconomic optimization model	GIS system analysis was not considered	2019	[16]
4.	Floating periodization solar PV system to land-based installation	GIS based	Multicriteria decision-making approach was not considered	2019	[17]
5.	Economical floating feasibility	Mathematical modeling approaches	There was no georeferenced system	2019	[18]
6.	Technical floating potential assessment	Floating system design approach	There was no specific cases study area	2019	[19]

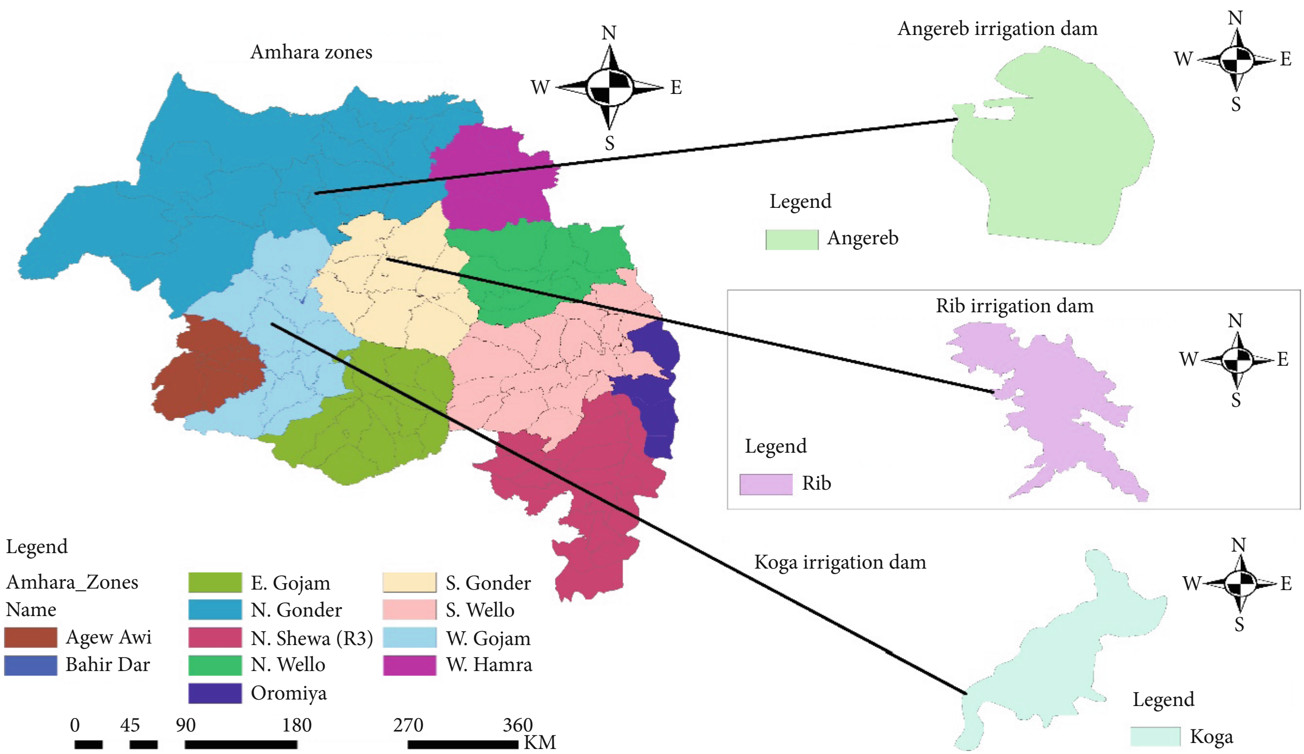

Figure 1: Map of Amhara Region and the irrigation dams.

wind speed are the main factors that affect the panel efficiency. However, there is no usable part of water surface selection related studies. Despite there are different site, suitability-related studies in which multicriteria decision-making have been used for different perspectives. Multicriteria decision-making has been used for energy planning and the selection of suitable sites for power plants installation. This multicriteria decision-making method was used to identify usable/suitable parts of water surface in this study.

The multicriteria weights method has been used to sustainable energy development [12, 13]. Most of the researchers have argued that MCDM approaches are well-suited to address strategic decision-making on multicriteria problems. MCDM methods provide a systemic and actual way to enclose multiple conflicting objectives. Multicriteria decision-making based on multiattribute value functions are used to support sustainable renewable energy development and select usable parts of water bodies for solar panel floating.

Indre Siksnelyte-Butkiene et al. review provided an application of MCDM with GIS methods in photovoltaic potential assessments and suggested that AHP is the most popular method for multiobjective functions.

Table 2: Fundamental scale for pairwise comparisons [25, 26].

Degree importance	Definition	Explanation
1	Equal importance	Criteria equally important to the objective
3	Moderate importance	One criterion slightly importance over another
5	Strong importance	One criterion strongly importance than another
7	Very strong importance	One criterion very strongly importance than another
9	Extreme importance	One criterion extreme importance than another
2,4,6,8	Intermediate values	A compromise is needed

Table 3: Decision maker matrix of floating solar PV power plant.

Criteria		1 Distance from land	2 Surface area	3 Forest distance	4 Depth
1	Distance from land	1	3	2	4
2	Surface area	1/3	1	1/2	2
3	Forest distance	1/2	2	1	3
4	Depth	1/4	1/2	1/3	1

Pilar Díaz-Cuevas et al. used the AHP method to map the potential of solar and wind for home system in Spain.

All the researchers (Table 1) have developed solar PV floating system to obtain optimal power from the solar panels. However, some of the raised approaches require knowledge to adapt multicriteria decision-making. The problem of unconstrained solar PV placement on the water surfaces has been observed. In this study, efficient power harvesting option from solar panel was developed by considering constraints like distance from land, surface area of water body/shape, distance from forest, and depth of water bodies.

Table 4: Normalized decision matrix of floating solar PV power plant.

Criteria		1 Distance from land	2 Surface area	3 Forest distance	4 Depth
1	Distance from land	0.480	0.462	0.522	0.4
2	Surface area	0.160	0.154	0.130	0.2
3	Forest distance	0.240	0.308	0.261	0.3
4	Depth	0.120	0.077	0.087	0.1

Table 5: Eigenvector and weights of the criteria floating solar PV attributes.

Criteria for suitability analysis		Eigenvector	Weight
1	Distance from land	1.863	0.466
2	Surface area	0.644	0.161
3	Forest distance	1.109	0.277
4	Depth	0.384	0.096

3. Methods

The meteorological data is collected from NASA surface meteorology. The criteria are set to find the usable area to assess the solar energy potential of those irrigation dams, and finally, ArcMap 10.4.1 is used to show optimal usable area for solar energy generation based on the given criteria [20, 21].

3.1. Study Area. Irrigation dams in Amhara regional state were selected for this study. Amhara regional state is one of the nine regional stats located in the north-west part of Ethiopia between 9°20′ and 14°20′ north latitude and 36°20′ and 40°20′ east longitude. The area of the region is estimated about 170,000 square kilometers [22–24]. The region consists large water bodies which are currently using for generating hydroelectric power and for irrigation. Koga, Rib, and Angereb are the irrigation dams constructed in the region (Figure 1).

Koga dam and irrigation project lies in the Tana Basin in the west Gojjam Zone at 11°24′31″ north latitude and 37°9′ 39″ east longitude. It is located adjacent to the town Merawi in Mecha Woreda, 35 km from Bahir Dar which is the capital city of Amhara Regional State. It covers an area of 13.9995 km^2 [25].

Rib dam and irrigation project is situated in the South Gondar Zone of Amhara Regional State at 12.031° north latitude and 38.008° east longitude, and it covers an area of 10.6858 km^2 [26].

Angereb dam is situated in the Central Gondar Zone of Amhara Regional State at 12.613° north latitude and 37.486° east longitude near to the town of Gondar, and it covers an area of 0.3701 km^2 [27]. The primary use of the dam is for drinking water, and its secondary use is for irrigation.

3.2. Analytic Hierarchy Process (AHP) for Criteria Evaluation. Analytic Hierarchy Process (AHP) is one of the multicriteria decision-making method [28, 29]. It is a method to derive ratio scales from paired comparisons. Thus, a pairwise comparison method was used to make complex decision problems in this study. The input was obtained from the actual measurement and subjective opinion like satisfaction feelings and preference [30–32]. Pairwise comparison of the attributes makes it easy to decisions for complex problems. With this method, the importance of the two attributes is compared at one time (Table 2).

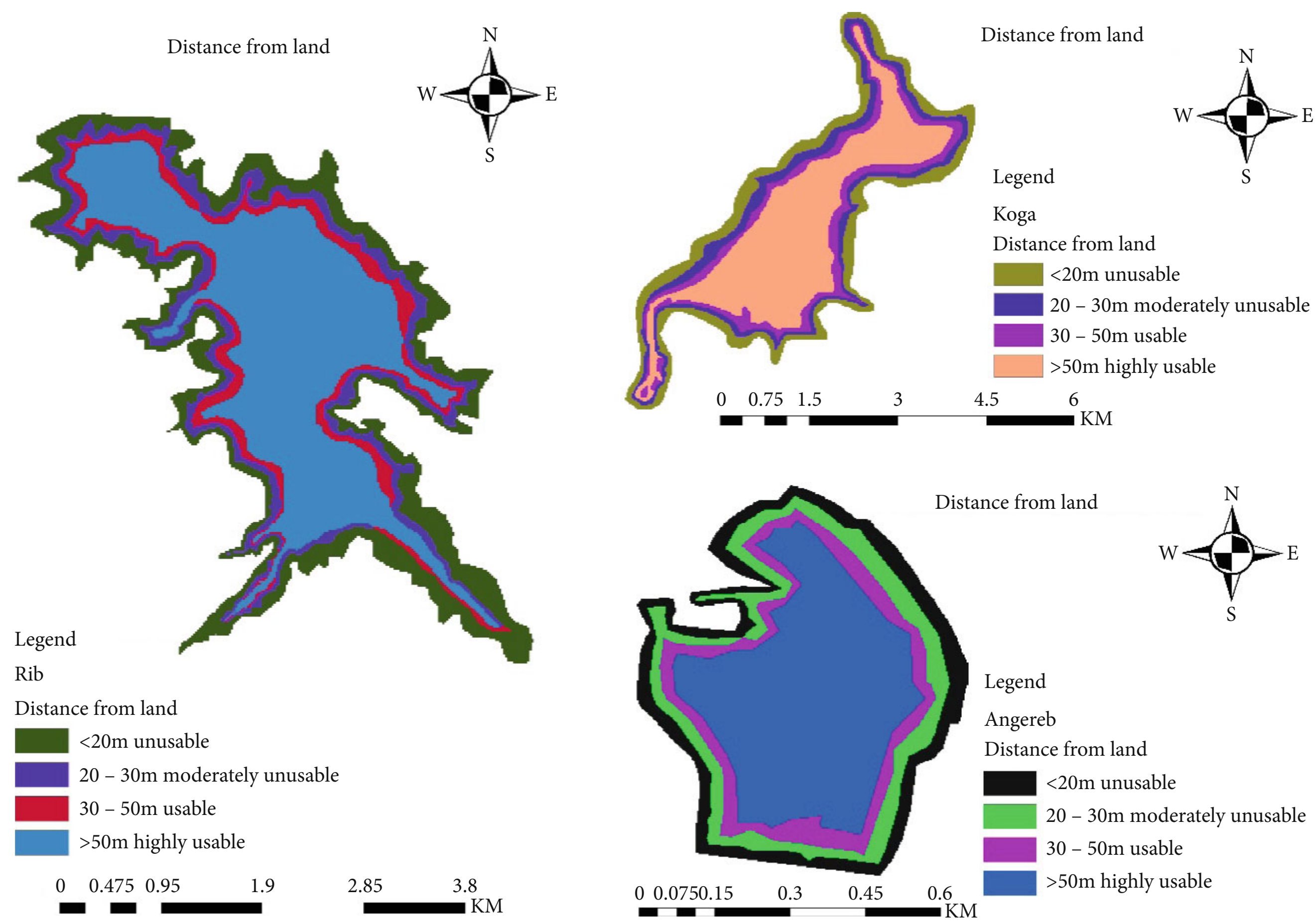

Figure 2: Suitable distance from land.

3.3. Selecting Criteria for Solar PV on Water Bodies

3.3.1. Selection Criteria for Floating Solar PV on Water Surfaces. In determining the usable and suitable locations for floating solar PV power plant, location to float panel is depending on the weights of each layer [32, 35, 36]. Experts' opinions were used to determine each location criterion for locating floating solar PV on the water surface. Area, depth, distance from land, and distance from the forest were used to formulate a model to determine usable and suitable locations for floating solar PV as per the nature of the water surfaces (Table 3).

A normalized decision matrix of floating solar PV power plant is obtained by summing up the column and divides it to each cell value (Table 4). The normalized values are calculated from the decision-making matrix (Aij) as:

$$N = \frac{\sum j}{c} \tag{1}$$

where N is normalized value. J is the column of the matrix. C is the values of the column of the decision.

In identifying the potential location for solar PV power plant, location selection was depending on the weights of each layer (Table 5). The weights of the criteria were calculated from the normalized matrix (Anm) as:

$$W = \frac{\sum n}{X} \tag{2}$$

where W is the weights of the criteria. n is the row values of normalized matrix. x is the number of criteria for suitability analysis.

3.3.2. Useable Surface of Water Body Analysis of Floating Solar PV. Geographic information system (GIS) is used to indicate the appropriate locations for floating solar PV power plant. ArcGIS prioritizes the location on the surface of the water to determine the most usable surface based on the relative importance [7, 21, 37]. GIS is used to model, store data, analyze data, and display spatial data with the map.

To identify the most usable areas for floating solar PV placement, four data sets were taken as a layer. Thus, dataset were area, depth, distance from land, and distance from forest. The water surface was ranked to identify the most usable locations, and the potential locations for floating solar PV placement were ranked, as highly usable, usable, moderately usable, and unusable.

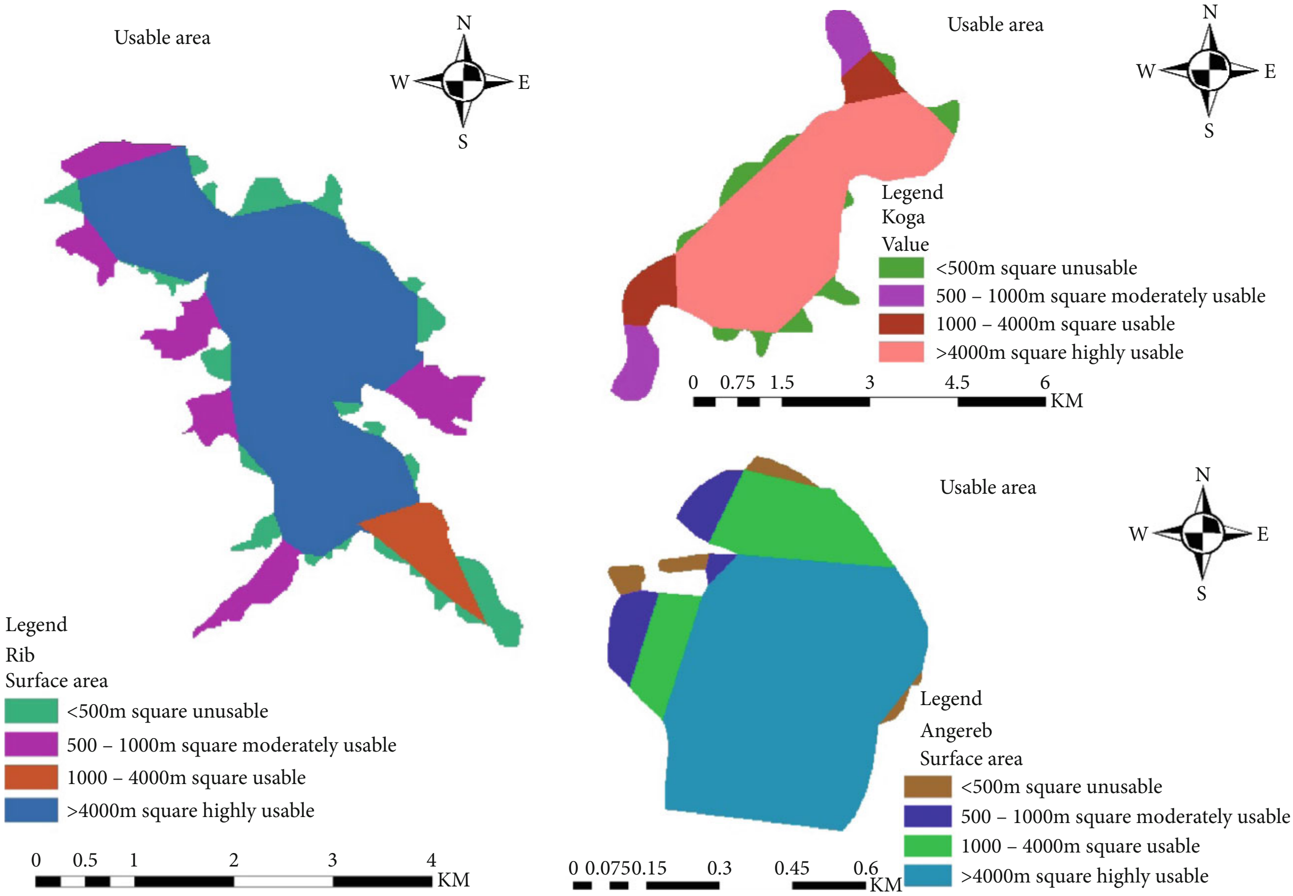

Figure 3: Suitable surface area of water for floating solar PV.

3.3.3. Distance from Land Reclassified. Deconstructive actions are important factors that affect any solar PV power plant [20, 31, 38, 39]. On land installation, solar PV power plant is protected by a fence; it is difficult to build the fence on the surface of water. Thus, the areas near to land are technically and infeasible and unusable. Therefore, areas less distance than 20 m was selected as unusable locations for floating solar PV. Water body areas with distance (20-30 m) moderately usable, (30-50 m) usable, and greater 50 m highly usable were prioritized, respectively (Figure 2).

3.3.4. Surface Area Water Bodies Reclassification. The surface area of the water bodies was the most important factor in deterring usable locations for floating solar power plant. The surface irregularity affects the receiving radiation from the sun and power plant installation [3, 5, 20, 40]. Thus, regular surface areas receive more radiation and produce more energy from floating solar PV. In addition to the irregular surface, there is no enough area to install solar panels.

Surface areas greater than 4000 meters square were reclassified as highly usable, 1000-4000 meters square were usable, 500-1000 meters square were moderately usable, and less than 500 meters square were unusable (Figure 3).

3.3.5. Forest Distance from Water Bodies Reclassification. Water surface distance from the forest was the most important factor for floating solar PV power plant location selection. Forest shadow highly affects solar radiation [29, 40–42]. Thus, far distance from the forest was considered as the most usable, and the nearest distance was considered as unusable locations.

The forest dataset was reclassified into four classes in this study, greater than (60 m) highly usable, (40-60) usable, (20-40 m) moderately usable, and less than (20 m) unusable (Figure 4).

3.3.6. Depth Water Surface Reclassification. The depth of water surface affects floating of panels on the surface of the water [38, 43, 44]. The most depth locations were the most usable locations to float panels easily. The depth was reclassified into four main categories. The more depth locations were taken as more usable locations (Figure 5). The depth greater than (4 m) highly usable, (3-4 m) usable, (2-3 m) moderately usable, and less than 2 m was unusable, respectively.

3.4. Weighted Overlays of Floating Solar PV Usability Analysis. ArcGIS10.4.1 weight overlay tool was used to combine the weights of all criteria. Distance from land, surface area, distance from forest, and depth of water surface dataset were overlaid to the aggregate base on its weight (Figure 6).

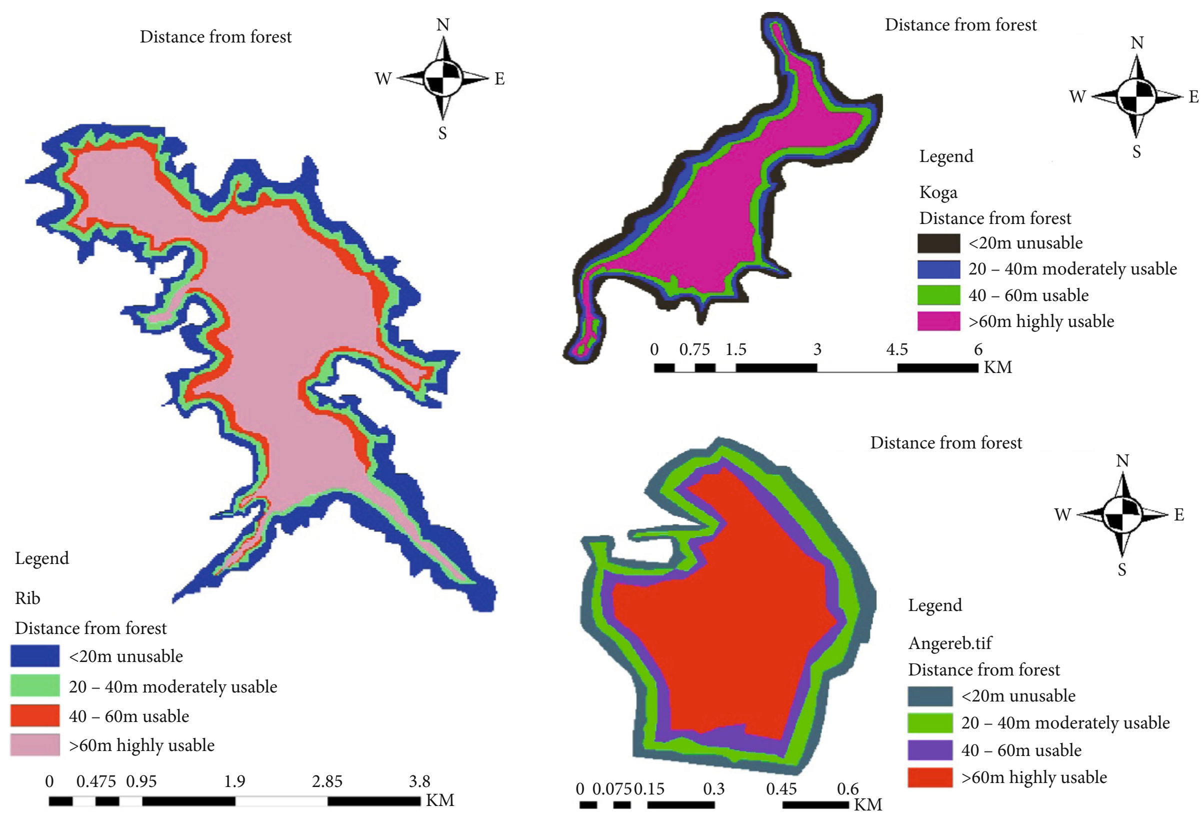

Figure 4: Suitable distance of forest floating solar PV.

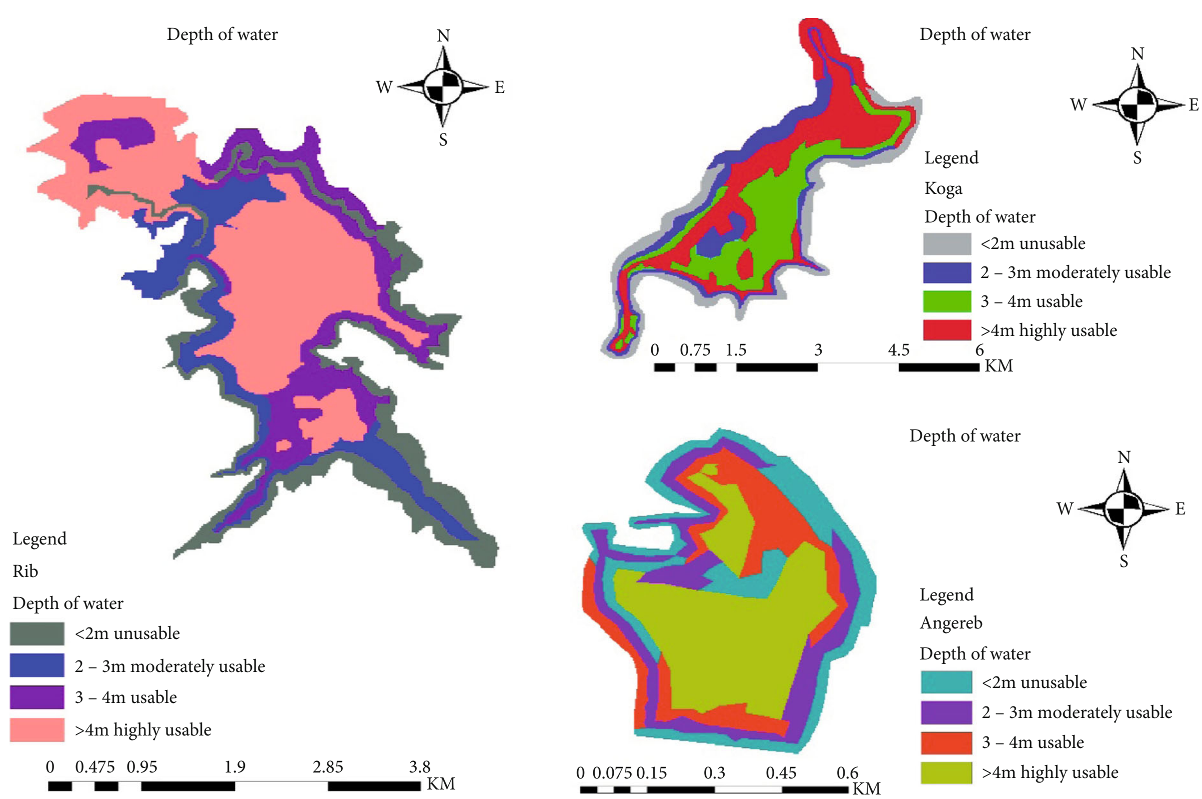

Figure 5: Suitable depth of water surface for floating solar PV.

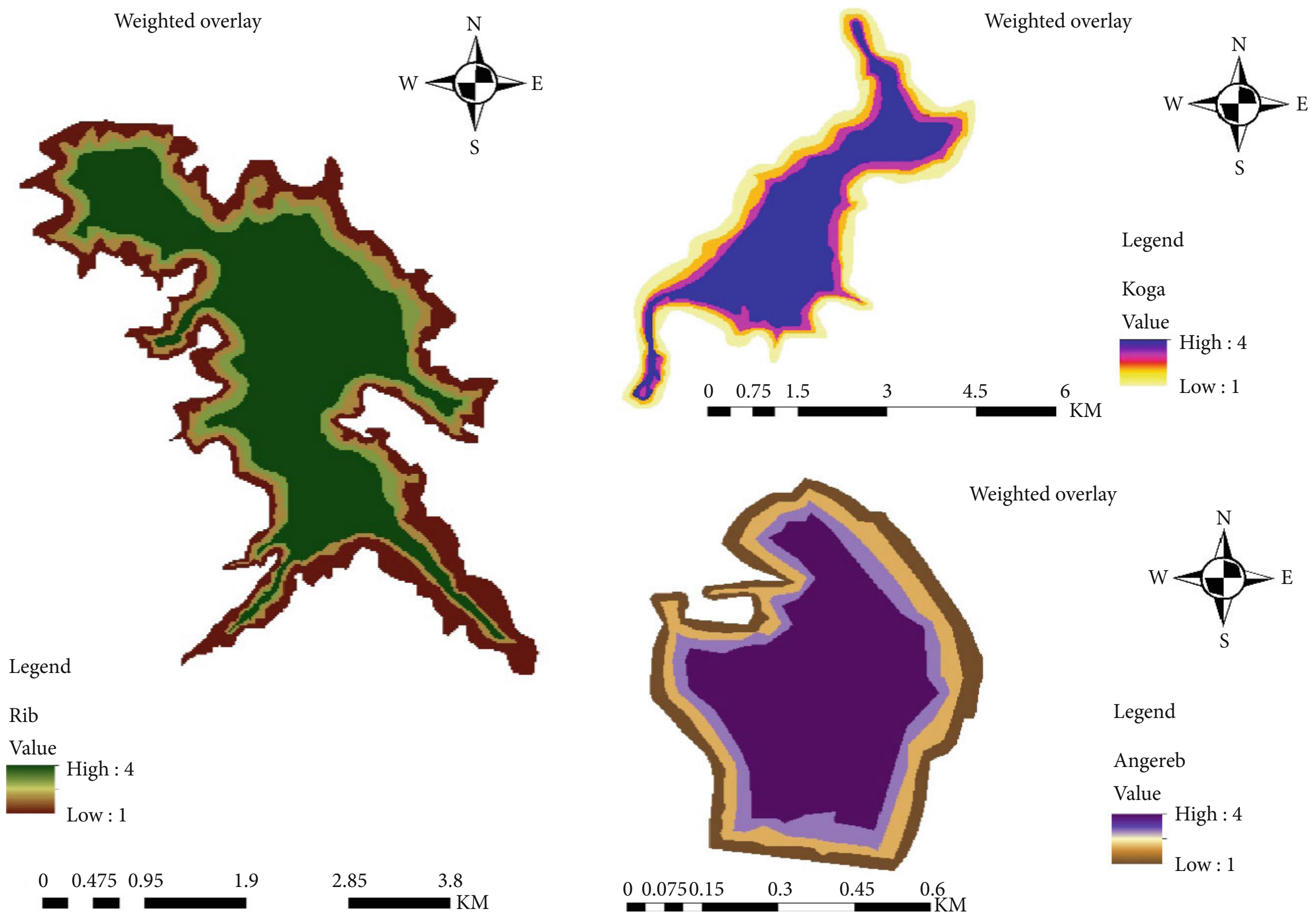

Figure 6: Overall suitability map of floating solar PV.

Table 6: Water surface area usability for floating solar photovoltaic in percent.

Suitability rank	Area (m^2) Angereb	Area (%) Angereb	Area (m^2) Rib	Area (%) Rib	Area (m^2) Koga	Area (%) Koga
Unusable	69921.89	18.89	3375597.89	24.11	3084778.60	28.87
Moderately usable	63973.87	17.28	2072640.31	14.80	1487507.06	13.92
Usable	55726.45	15.05	2118449.10	15.13	1082442.05	10.13
Highly usable	180592.32	48.78	6434451.26	45.96	5028777.965	47.07
Total	370214.53	100.00	14001138.55	100.00	10683505.68	100.00

The final map of usable surface area water was obtained by multiplying reclassified value with each weight value and adding up all layer products [35, 45–48]. The rank of floating solar PV usability was from one to four. Thus, surface water was divided into four main categories, and a highly usable water surface for placing floating solar PV value was one (Table 6).

3.5. Solar Photovoltaic Potential Analysis. Three irrigation dams were selected in Amhara regional state (Figure 1) for this study. To obtain the irrigation dam potential values of power generation, Monocrystalline silicon module HCP78X9-400 W (Table 7) was selected. The dimension ($L \times W \times T$) of selected PV panel is $2172 \times 1002 \times 40\ mm$.

The highly usable and usable area (Table 6) of water surface was considered as a suitable area for floating PV power generations (Table 8). Thus, power output was determined by dividing usable area to single panel area and then multiplied by panel power rating the efficiency of the selected panel.

4. Result and Discussion

The middle parts of water surface were usable for floating solar PV from the eligible water surface. This is due to the long distance from land, large and irregular area of water surface, far distance from forest, and far from forest, and more depth of water. In addition to middle part of water surface,

Table 7: Solar photovoltaic specification [41, 42].

Module type	HCP78X9-400 W
Maximum power P_{max}	400 W
Open-circuit voltage V_{oc}	51.6 V
Maximum power voltage V_{mp}	42.0 V
Short-circuit current I_{sc}	9.95 A
Maximum power current I_{mp}	9.53 A
Module efficiency (%)	18.38%
Power tolerance	$0\sim+5\ W$
Temperature coefficient of I_{sc}	0.05%/°C
Temperature coefficient of V_{oc}	-0.31%/°C
Temperature coefficient of P_{max}	-0.38%/°C
Standard test environment	Irradiance 1000 W/m^2, cell temperature 25°C, Spectrum AM 1.5

Table 8: Usable water surface area in percent generation power potential of each irrigation dam.

Place	Usable area (m^2)	Usable area (%)	Pout (MW)
Angereb	236318.78	63.83	7.9832
Rib	6111220	57.20	206.4457
Koga	8552900.35	61.09	288.9292

there were some floating solar potential areas nearest to the land. The majority of unusable areas were found near to land due to short distance from the forest and low depth (Figure 1).

63.83%, 61.09%, and 57.20% of water surface areas were highly usable (Table 5) and usable water surface of Angereb, Rib, and Koga irrigation dams, respectively. 17.28%, 14.80%, and 13.92% were moderately usable, and 18.98%, 24.11, and 28.87 were unusable areas for Angereb, Rib, and Koga, respectively.

5. Conclusion

There were higher potentials of floating solar power generation in the Amhara region, irrigation dams, particularly in Rib, Angereb, and Koga. This potential contributes to fill the need of energy the country. It bridges the energy gap of rural and urban communities, if the country uses this high green floating solar photovoltaic potential to generate power.

The majority of water surface fulfilled the usability analysis criteria. Distance from land, distance from forest, water surface area, and depth were the dominant factors for floating solar PV power location usability analysis. To increase rural electrification by finding the optimal locations for floating solar PV, educating the community and stakeholders to change their perception were on renewable energy and related traditional practices like deforestation, and it is on the environment.

Data Availability

Data to support this study are available, and correspondence author can be contacted for further.

Ethical Approval

Ethical approval of the study was obtained from Bahir Dar University, Faculty of Electrical and Computer Engineering of Electrical power ethical review committee. The ethical letter was submitted to Bahir Dar, Ethiopia, electric power Utility (Main office), and permission was obtained to conduct the study. To ensure confidentiality, employee's information was kept and was not exposed to third body. Verbal consent was taken, and it was approved by an ethical review committee.

Conflicts of Interest

The authors declare that there no conflict of interest in regards to the publication of this paper.

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