

Estimation of the Stability of a River Island and Its Suitability for Installing Solar Based Power Plant in Bangladesh

Md. Golam Muktedir^{1*}, Md. Muhtasim Billah¹, Anika Samm-A², Farzana Rahman³,
Nusrat Jahan Shimu⁴, Mahmudul Hasan⁴, Intehum Taufique Aurnab¹, Mehedi Hasan Peas⁵

¹Department of Environmental Science, Bangladesh University of Professionals (BUP), Dhaka, Bangladesh

²Department of Disaster Science and Climate Resilience, University of Dhaka, Dhaka, Bangladesh

³Development & Production Division, Bangladesh Oil, Gas & Mineral Corporation (Petrobangla), Dhaka, Bangladesh

⁴Department of Oceanography, University of Dhaka, Dhaka, Bangladesh

⁵Bangladesh Space Research and Remote Sensing Organization (SPARRSO), Dhaka, Bangladesh

Email: *golam.muktadir@bup.edu.bd

How to cite this paper: Muktedir, M. G., Billah, M. M., Samm-A, A., Rahman, F., Shimu, N. J., Hasan, M., Aurnab, I. T., & Peas, M. H. (2024). Estimation of the Stability of a River Island and Its Suitability for Installing Solar Based Power Plant in Bangladesh. *Journal of Geoscience and Environment Protection*, 12, 51-72.

<https://doi.org/10.4236/gep.2024.1211004>

Received: October 19, 2024

Accepted: November 16, 2024

Published: November 19, 2024

Copyright © 2024 by author(s) and Scientific Research Publishing Inc.

This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

Bangladesh, situated in tropical and subtropical regions, receives significant amount of solar energy, making it an ideal location for solar energy production. However, determining suitable sites in the country for solar based power plant establishment turns out to be a difficult task given its dense population. This study aims to the identification of such a potential site by assessing the stability of the Jamuna river Island to be proposed as a site for developing solar based power plant. The research concentrates on Fulchhari union of Gaibandha district, one of the three major islands in the Jamuna river, utilizing two GIS-based multi-criteria decision-making (MCDM) techniques. One is Digital Shoreline Analysis System (DSAS) for stability analysis, and another is Analytical Hierarchy Process (AHP) for suitability evaluation. For the stability analysis of the island, Landsat satellite imagery of 1990, 1995, 2000, 2005, 2010, 2015 and 2020 covering a long term of 30 years period were investigated. Based on average change rates, the bankline of the island was divided into 2 accretion zones in the south and south-eastern direction, and 8 erosion zones. Along with the bankline changes, climatological, geomorphological, and environmental factors have been adopted to modeling process for suitability analysis. The optimal locations for solar based power plants have been demonstrated by a suitability map, where high and standard potential area is about 60% of the area of Fulchhari union. Production may be enhanced up to 5 times more with the consideration of utilizing the moderate optimum zone.

Keywords

Jamuna River Island, GIS-DSAS, GIS-AHP, Stability, Suitability

1. Introduction

Energy provision is of utmost importance in fulfilling the spectrum of human needs, ranging from basic electricity to large-scale industrialization (Gulagi et al., 2017). The origin of this energy is a critical concern, as 75% of it is currently derived from fossil fuel combustion in Bangladesh. This process emits anthropogenic greenhouse gases, contributing significantly to pollution and climate change (Ahiduzzaman & Islam, 2011; Dogan & Seker, 2016; Apergis et al., 2018). According to Kumar and Majid (2020), around one-third of the world's greenhouse gas emissions are attributed to traditional fossil fuel-based power generation methods. This noteworthy contribution poses substantial risks to the safety and security of current and future environmental, as well as global health and social concerns (Mahbub & Islam, 2023). As global energy consumption grows, addressing these emissions becomes paramount. In response, developing countries like Bangladesh are increasingly turning to sustainable energy sources to meet their energy needs (Ul-Haq et al., 2020).

Bangladesh heavily relies on its own declining natural gas reserves, imported oil, and coal for energy production, significantly contributing to greenhouse gas emissions. Additionally, the country experiences an annual energy consumption growth rate of 5.83%. The Government of Bangladesh (GoB) has initiated efforts to enhance the capacity for environmentally sustainable renewable energy generation. This move aligns with addressing the growing need for energy while also emphasizing the urgency to reduce greenhouse gas emissions. These initiatives involve integrating renewable sources with conventional energy to create a more balanced and eco-friendly energy landscape. This strategic approach is expected to be beneficial. Harnessing renewable energy resources may fulfill the nation's energy requirements. The production of renewable electricity is expected to increase to 5% by 2015, 10% by 2021, and 100% by 2050 (PSMP, 2016).

Bangladesh, situated in tropical and subtropical regions, holds significant solar energy potential due to substantial sun irradiation. Alongside wind, hydropower, and bioenergy, solar energy stands out to be a critical renewable source. The country has effectively generated 723.26 MW of electricity from renewables, with a notable 489.03 MW originating from over 6 million solar photovoltaic systems as of mid-April 2021. Current efforts involve implementing 569.49 MW of solar projects, including 108 individual systems, while 1257.813 MW is in the planning stage, covering 21 individual systems (Hussain et al., 2024). Despite progress, identifying suitable sites for solar plants remains a challenge in a densely populated nation, requiring consideration of meteorological, environmental, social, and economic factors (Mahbub & Islam, 2023). Therefore, suitable sites for solar

plants should be identified and assessed to contribute significantly to this continuous effort.

There are many techniques available to evaluate a suitable site for a particular purpose. Among many methods, Multi-Criteria Decision Making (MCDM) is considered an analytical technique specifically designed to facilitate complex decision-making processes. It allows decision-makers to thoroughly consider the issues and problems from various perspectives. A flexible methodology like this can embrace a range of techniques such as the Weighted Linear Combination (WLC), the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), the Analytic Hierarchy Process (AHP), and the Fuzzy Analytic Hierarchy Process (FAHP) (Yildiz, 2024; Islam et al., 2020; Habib et al., 2024). The AHP, developed by Prof. Thomas L. Saaty in 1977, is widely used in decision making in various domains like business, engineering, healthcare, and public policy. It assists people in making decisions by breaking down complex situations into feasible levels, evaluating alternatives, and ranking them based on both qualitative and quantitative factors. It has become a very useful practical tool due to its flexibility and adaptive capacity to address subjective decision making. (Colak et al., 2019).

AHP has emerged as a highly popular method in suitable site determination studies for solar power installation conducted around the world (Al Garni & Awasthi, 2017; Khazael & Al-Bakri, 2021; Colak et al., 2019; Habib et al., 2020). In contrast to the global landscape, Bangladesh has limited studies regarding this field. Existing research in the country has primarily focused on bankline dynamics and land utilization, leaving a significant knowledge gap. This research aims to fill this gap by investigating the feasibility of deploying river islands for solar power production. The primary goal is to enhance knowledge of solar power potential in Bangladesh and establish a foundation for forthcoming renewable energy initiatives.

2. Study Area

To conduct this research, a braided river in Bangladesh, Jamuna, was chosen, which is a downstream distributary of the Old Brahmaputra. Jamuna river is one of the largest braided rivers in the world (Ashworth et al., 2000) and has different size braided islands (Meshkova & Carling, 2013; Peters, 1993). Among the various river islands studied, three major islands were identified as having the highest potential for solar power generation. These islands were selected based on their vegetation, stability, and the fact that they are submerged only during high magnitude floods (Hasan, 2018; Bristow, 1987; Thorne et al., 1993). Subsequently, only one of the islands was chosen (Figure 1) for further analysis after visual analysis and a meticulous selection process. The other two eliminated islands were: the one situated near Daulatpur upazila and the another in proximity to Kajipur upazila. The island near Daulatpur upazila was decided to be skipped due to its pronounced exposure to erosion and low stability found during the study period. The island in the vicinity of Kajipur upazila was not taken into account because it

contains two working solar energy plants, one of which currently under construction. The Kajipur upazila site also had hardly changed morphologically; aside from a few minor changes, the island had not undergone any prominent morphological changes since 2010. The southern part of the morphological properties also did not change significantly. Subsequently, the presented island was chosen due to its invariance for further geographic analysis of the potential of a solar plant. The study area is located between latitude ($25^{\circ}14'9.02''$ to $25^{\circ}2'4.02''$) North and longitude ($89^{\circ}35'7.50''$ to $89^{\circ}43'57.58''$) East covering 126 square kilometers in total. The upazilas of Gaibandha in the northwest, Dewanganj in the east, Islampur in the southeast and Shaghata in the southwest encircle the island (Banglapedia, 2023).

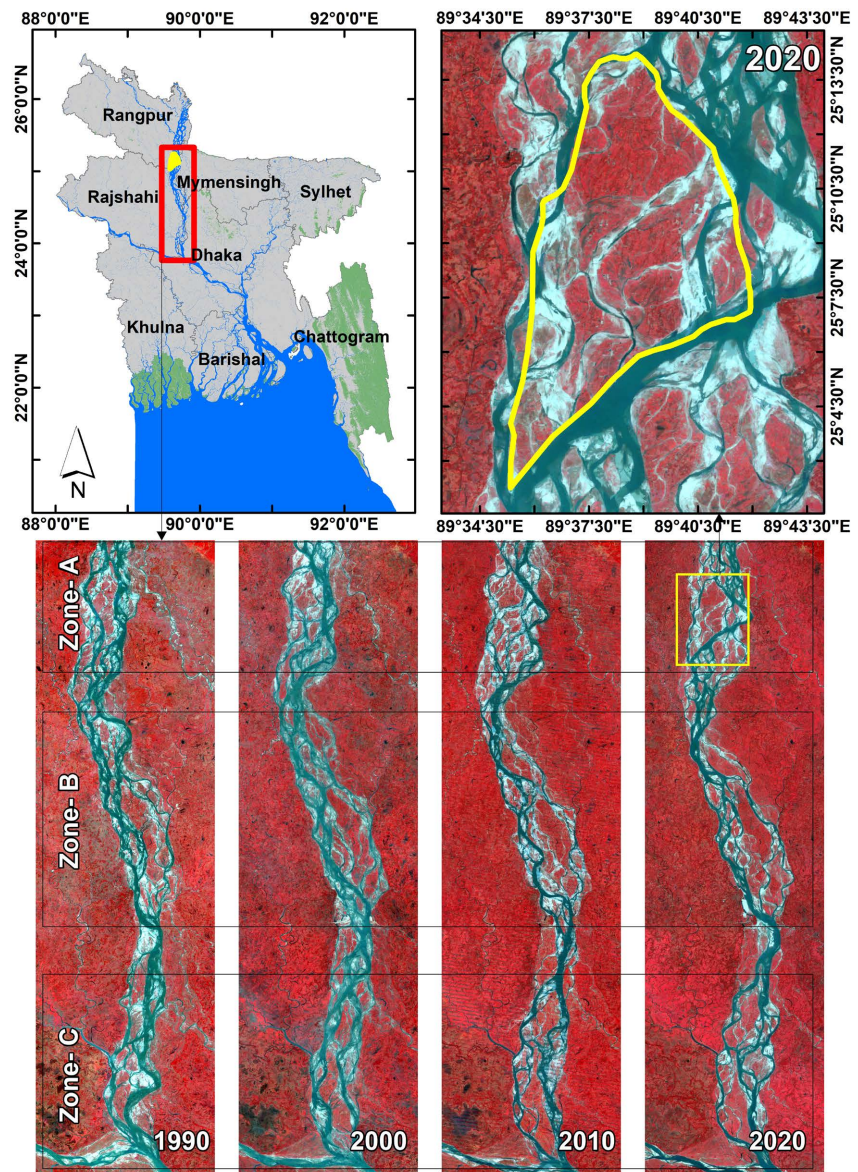


Figure 1. Geographic extent of study area and the visual comparative analysis of the stability of islands in the Jamuna River over recent decades.

3. Materials and Methods

A summary of the collected data is provided in **Table 1**, while **Figure 2** illustrates the research methodology applied to meet the study's objectives. This includes a detailed description of the data sources and collection methods, as well as the specific techniques used to analyze and evaluate the suitability of the island for solar power plant installation.

3.1. Research Methodology

The study utilized a combination of two Geographic Information System (GIS) tools, one was Digital Shoreline Analysis System (DSAS), and another was Analytical Hierarchy Process (AHP) as a methodology to analysis the stability and obtain suitable areas respectively for solar power plant (**Figure 2**) (Al Garni & Awasthi, 2017). The rate of change statistics was computed from a time series of vector bankline position by using the DSAS (5.1v) software which is an add-in to Esri ArcGIS Desktop (10.7v) (Mirdan et al., 2023). The AHP method incorporates the choice of elements to develop paired matrices and allow for capturing both qualitative and quantitative features (Settou et al., 2020). The optimal result was mapped as an output after modification and filtering by using DSAS tools and AHP method.

3.2. Data Collection

Bankline dynamics and site suitability analysis require a large set of data gathered from different sources. These datasets were prepared through the acquisition and processing of satellite images, climatic data, and digital elevation model (DEM). **Table 1** represents the data sets utilize for this research. Landsat images from several time periods (1990-2020) were acquired from the USGS website. The images include TM, ETM+, and OLI/TRIS sensors. From 1990 data, the bankline was drawn in combination with multiple small islands, which are now connected as per 2020 satellite data. Climatic data spanning thirty years with spatial references for the study area was collected from the NASA Power and BARC website. Digital elevation model data was acquired from the USGS website using "SRTM 1 arc second global" to generate morphological criteria models like elevation and slope. All data utilized in this study were georeferenced to the WGS 1984 geographic coordinate system, with the projection specifically defined as UTM Zone 46N, ensuring spatial accuracy within the specified region. The banklines were processed into vector files (polylines) using satellite imagery in ArcGIS Desktop software (version 10.7). The evolution of the island's bankline was conducted in order to understand how it has changed over time. A geodatabase was developed as well to store the bankline data obtained from DSAS (version 5.1). Climatic data was imported into the study geodatabase to produce climatic raster models. The Inverse Distance Weighted (IDW) analysis tool was applied for creating spatial representations of climatic variables based on the collected data.

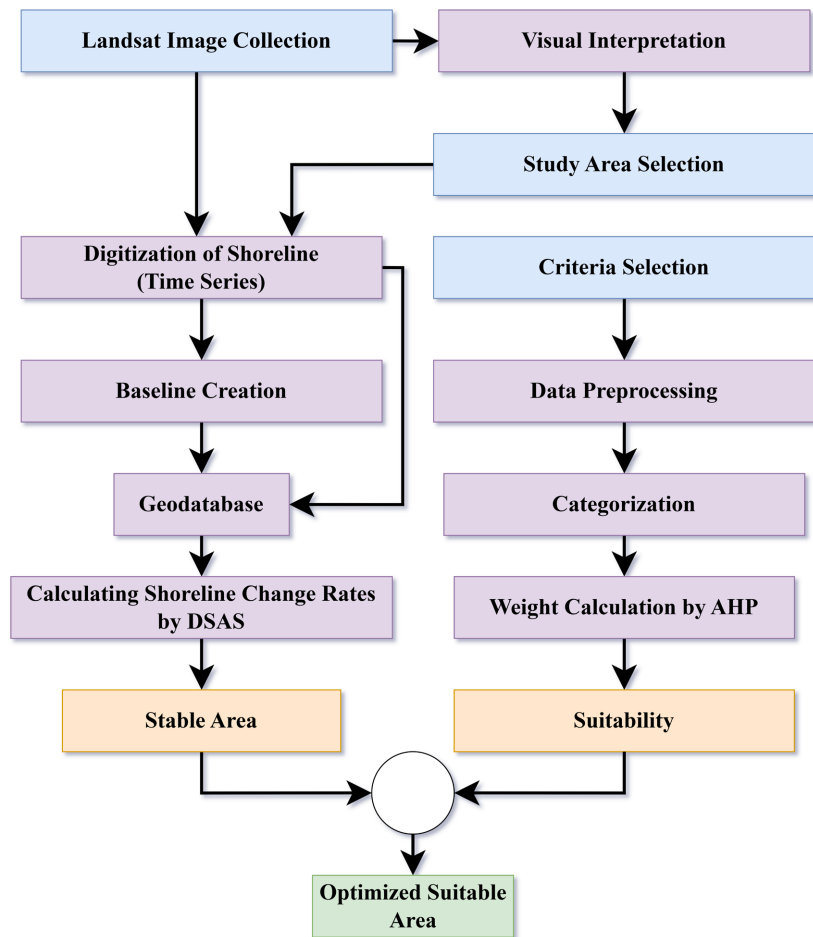


Figure 2. Flowchart of the research methodology.

Table 1. Data sources for the study.

Data Source	Data Type	Data Format
NASA Power and BARC Website	Solar Radiation	Measurements Sheet
	Temperature	Measurements Sheet
	Cloud Coverage	Measurements Sheet
	Sunshine	Measurements Sheet
Modified from Satellite Image	Study Area Data	Shapefile/Polygon
	DSAS Data	Shapefile/Polygon
Esri Land Cover—Living Atlas Website	Landcover	Raster Model
United States Geological Survey (USGS)	DEM / SRTM	Raster Model

3.3. Stability Analysis

Stability analysis of the river island is the preliminary and most important activity for site suitability analysis. This study deployed the DSAS for stability analysis of the island. At first, the automated technique was applied to identify measurement locations. After processing the rate computation, the statistical information was

generated which evaluated the accuracy of the rates. Along with these activities, a beta model for prepared for bankline position forecasts. Five statistical procedures in DSAS were utilized to obtain bankline accretion or erosion characteristics. These were Endpoint Rate (EPR), Linear Regression Rate (LRR), Weighted Linear Regression Rate (WLR), Shoreline Change Envelope (SCE), and Net Shoreline Movement (NSM) (Al-Zubieri et al., 2020; Nassar et al., 2018; Islam et al., 2022). Among these, the metrics: SCE and NSM provided information on the net shoreline changes distance (meters) over the long period between 1990 and 2020. Additionally, EPR, LMS, and LRR statistical methods were employed to quantify change rate per year over a short period of time.

The distance between the banklines that are closest to and furthest from the baseline at each transect was computed to determine the SCE. The SCE function is expressed in Equation (1):

$$S_d = d_f - d_c \quad (1)$$

where, shoreline change distance S_d was the distance between baseline to farthest shoreline d_f at specific transect x_n ; and baseline to nearest shoreline d_c at the same transect x_n . All the parameters measure in same unit meter (m). Here, shoreline represents bankline of the river. At the same way, for each transects intersection, NSM was used to determine the bankline movement distance between the oldest and youngest banklines. The NSM was calculated using Equation (2) and is expressed as:

$$S_{nm} = f_o - f_y \quad (2)$$

where, net movement of shoreline S_{nm} was the distance between baseline and shoreline in oldest date f_o and shoreline in youngest date f_y at a particular transect x_n . All the parameters measure in same unit meter (m). The EPR was computed by dividing the difference at a given transect, between the first (closest) and last (farthest) banklines by the total number of years. For analysing DSAS, the EPR statistic was calculated by dividing the distance of NSM by the entire amount of times that had passed between the oldest and most recent banklines at transects x_n . The trend of erosion and accretion process is represented by the magnitude and cyclical trends of the EPR values. The bankline change per year rate was calculated by using Equation (3), which is expressed as:

$$S_r = (f_o - f_y) / n \quad (3)$$

where, the per year rate of bankline change S_r measured in m/year unit and calculated by dividing the distance between baseline and bankline in oldest date f_o and recent date f_y at a particular transect x_n ; by the total number of years n . By matching a least squares regression line to bankline points along specific transects, the LRR for banklines was determined. The slope of the regression line was measured in this process and it minimized the sum of the squared distances from each data point to the line. Each distance is squared and then summed up to find the best fit (Dolan et al., 1991). However, this method frequently underestimates the real

trend of bankline changes over the observation period and it is susceptible to anomalies (Genz et al., 2007). The slope of regression line was estimated by using Equation (4), which is expressed as:

$$y = S_{LR} x + \alpha + e \quad (4)$$

Here, y was the dependent which was predicted and x was the independent variable what was predicting using square residuals of baseline distance at a specific date; S_{LR} was the slope of the regression line which was measured in m/year unit; α is constant coefficient of x ; and e is the predicting error. The LMS is a reliable estimation method for regression estimation that was developed by an adaptive process that computed all potential slope values within a constrained range of angles (Rousseuw & Leroy, 1987). For a given set of dates, the point where the transects and the bankline overlaps determines the slope of angle (x values). The y intercept (y value) is the distance measured at those points from baseline. This computation process is carried out repeatedly until the laws of significant figure indicate the slightest difference in offset values between consecutive rounds is insignificant. The slope related to best fitted regression line and is returned as LMS value once the minimum offset has been determined. The relationship between the distance from baseline on various dates to derive the lowest median of square values.

Table 2. Bankline classification according to the rate of bankline change (m/yr).

Bankline Classification	Rate of Bankline Change (m/yr)
Very High Erosion	>-2
High Erosion	>-1 to <-2
Moderate Erosion	>-1 to <0
Stable	0
Moderate Accretion	>0 to <1
High Accretion	>1 to <2
Very High Accretion	>2

Applying these methods, the changes of bankline position shifting was automatically calculated along user-defined transects. First, a 150-meter landward baseline was created according to the island's common area from polylines of the years 1990-2020. A total of 7 polylines were created in intervals of 5 years. As Jamuna is a flowing river, the intervals taken were very minimal to quantify every little change of the study area. The baseline was parallel to the island's bankline, where no erosion occurred. At 25 m intervals, total 1772 transects were automatically created. For every available bankline position, the overall shifts in bankline movement were mapped. Additionally, the erosion and accretion rate of the island was assessed with respect to the baseline positions according to **Table 2**, providing a comprehensive understanding of the island's bankline dynamics. Bankline positioning data on 2020 was also visually analyzed to validate the outputs from the

DSAS. The bankline those were shifted to landward were interpreted as erosion and assigned a negative sign, while those were shifted to riverward were identified as accretion and marked with a positive sign (Anders & Byrnes, 1991, Islam et al., 2022).

3.4. Analytical Hierarchy Process (AHP)

Among Multi Criteria Decision Making (MCDM) methods, the AHP method, developed by Saaty (1980), is one of the most popular. There are three steps in AHP method like the hierarchy determination, pairwise comparison matrix creation, and finally weight calculation (Solangi et al., 2019). A comparison table is applied to figure out the weights main and sub criteria for binary comparison after the hierarchy is established because it is important to determine the level of importance among them. Then the consistency test is performed normalizing the weights of the criteria. The consistency index (CI) and consistency ratio (CR) value is calculated using following Equations (5) and (6) (Solangi et al., 2019).

$$CI = (\lambda_{\max} - n) / (n - 1) \quad (5)$$

$$CR = CI / RI \quad (6)$$

λ_{\max} in equation is the highest given value determined from decomposition of the consistency vector. The suitable random consistency index (RI) value is chosen based on the number of criteria. Binary comparisons are acceptable as long the CR value is less than 10% (Solangi et al., 2019, Habib et al., 2024).

3.5. Potential Criteria for AHP

It is imperative to select appropriate parameters for AHP. To determine the main and sub criteria, literatures related to GIS-based MCDM method between 2013 and 2022 were analyzed. Most of these shown that topographical, geomorphological, hydrological, socio-economic and infrastructural factors were as main criteria (Alam & Ahamed, 2022). Sub-criteria were global horizontal irradiation, aspect, slope, land use/cover, bird migration routes, faults, rivers, water surfaces, power line, road transportation network, and transformer centre. Sub-criteria can be classified under different main criteria. Firstly, the climatological factor includes variables such as solar radiation, sunshine, temperature, cloudy days, and lightning strike rates which directly affect the efficiency of energy generation by influencing the amount and strength of sunshine. The suitability of a location and the resilience of its infrastructure are influenced by many geomorphological factors, such as elevation, slope, stability, and closeness to fault lines. Factors like proximity to urban centers, main transportation routes, and population density are important considerations for assessing the feasibility of a project and engaging stakeholders. Environmental Factor factors such as land cover assess the ecological consequences, appropriateness of land use, and connectedness of infrastructure. Every metric carries importance, either because of its direct impact on energy

production or its consequences for project operations, community approval, or environmental sustainability. Hence, utilizing the AHP enables a thorough assessment of these elements and criteria, facilitating well-informed decision-making when choosing the most suitable location for a solar power plant. As each region has unique topography with distinct features, structures and characteristics, the suitable site for solar power plant should be selected based on the region-based criteria (Günen, 2021). So, all the criteria derived from literature review were not utilized in this research rather the main and sub criteria were developed by several decisionmakers so that it would reflect the characteristics of the study area better. Three different main criteria and a total of seven sub criteria associated with their datasets related to solar power plants have been short-listed to conduct the AHP analysis as shown in **Table 3**.

Table 3. Types of data collected from different sources.

Climatological Factor	Geomorphological Factor	Environmental Factor
Solar Radiation	Elevation	Land Use Land Cover
Sunshine		
Temperature	Slope	
Cloudy Coverage		

3.6. Criteria Priority and Factor Weight Determination

This study deployed the AHP to develop an optimal algorithm for thoroughly selecting a site for a solar-power installation. Initial stages involved geoprocessing tools to convert diverse components within the geodatabase into raster models. Subsequently, climatic data, encompassing temperature, solar radiation, cloud coverage, and sunshine, were derived using the Inverse Distance Weighted (IDW) method for these raster models. 3D analyst tools, specifically the Slope tool, were employed to develop slope raster models. The reclassify tool was then applied to recategorize raster data, which underwent further processing in the weighted overlay tool. The AHP methodology was instrumental in ascertaining the weights assigned to each class within the raster data, with the land cover raster layer serving as a foundational element for informed decision-making through the overlay tool (Islam et al., 2020).

The study opted for an extensive questionnaire session to ascertain expert opinion and prioritize the factors. Additionally, a possible value of priority has been allocated to the seven criteria that impact the selection of solar-based power plants. The subsequent comparison matrix was utilized in the Microsoft Excel software with the AHP method to establish the weights for the main and sub-criteria. This methodology was validated through Consistency Ratio calculation, following the approach outlined by Colak et al. (2020). Preserving strict adherence to a CR threshold below 0.1 ensured the accuracy and reliability of the procedures were ensured (Habib et al., 2024).

3.7. Sustainability Index Formulation

To estimate the site priorities for installing solar based power plant, the suitability index has been formulated as illustrated in Equation (7). This index depends on the weighted outcomes of the AHP results as well as the ranked values of several suitability criteria.

$$\text{Suitability Index}(SI) = \sum_{i=1}^n (w_i R_i) \quad (7)$$

Here, SI is suitability criteria; n is the total number of criteria; w_i is the relative weight; and R_i represents the rank score. Reviewing previous literatures, several criteria were categorized into 5 categories (i.e., Very Low, Low, Moderate, High, and Very High) (Habib et al., 2024).

3.8. Determination of Optimum Area

The final output of DSAS analysis was applied to optimum area of the study area and the exclusion of unsuitable areas for establishing solar based power plant. The final output was an area shapefile generated in ArcGIS environment and utilized it to clip the classified raster output from AHP analysis. These may exclude the area prone to erosion and not so stable during high magnitude flood events.

4. Results and Discussion

4.1. Island Bank Change Findings

The study reveals that the bankline of the island has undergone significant changes over time, with both erosion and accretion occurrence as shown in **Figure 3**. The island's location in the middle of the river makes it particularly vulnerable to these changes, as the river's flow and sediment transport can greatly impact the rates of erosion and accretion. In the south, south-eastern, and eastern parts of the island, accretion occurred in a significant manner. The rest of the parts might be susceptible to river flow action, and continuous erosion or accretion. The geomorphology of the island has undergone significant changes due to variation in the input of sediments and water. The accretion observed on the eastern bankline may be attributed to the combined effects of river flow currents and sediment movement from the middle to the south-eastern part of the study area. The northern, north-eastern, and north-western parts of the bankline experienced more significant changes. However, some of the erosional and accretional activities along the island are likely to be influenced by human interventions (Habib et al., 2020). A low accretion rate was observed in the northern region of the island, where human activities such as settlement and agriculture are prevalent. This northern side has already become heavily settled. In contrast, the southern part remains largely barren, with minimal settlement and agricultural activities.

The SCE from the study period of 1990-2020 indicates that the maximum accretion occurred in a distinct area on the eastern part of the bankline, specifically between 3894 meters and 5290 meters. The dense blue area shown in **Figure 3(b)**

represents the accretion zone. The center baseline area, as depicted, is the region where there is neither accretion nor erosion happened in the study period.

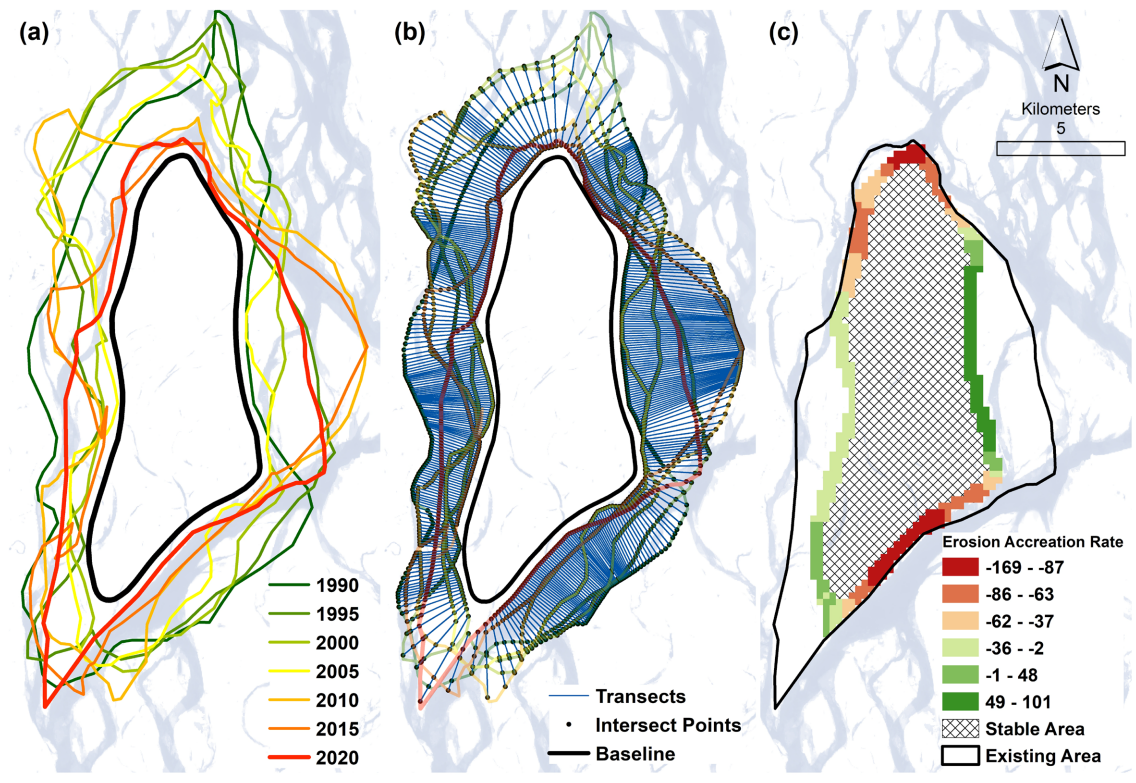


Figure 3. The change of the study area over 1990 to 2020; (a) Morphological variations of the island, (b) Bankline Change Envelope and (c) Zonal division of Fulchhari Island.

The bankline had been divided into different distinct zones based on fluctuations in bankline changes, as shown in **Figure 3(c)**. **Table 4** represents bankline change statistics for different zones of the island. The average bankline accretion and erosion rates were classified into three distinct categories based on the EPR, LRR, and WLR, and expressed in meters per year (m/yr). According to Mahapatra et al. (2014), the classifications are as follows: Low Erosion: (0 to -25 m/yr), Moderate Erosion: (-25 to -50 m/yr), High Erosion: (less than -50 m/yr), as well as Low Accretion: ($+1$ to $+25$ m/yr), Moderate Accretion: ($+25$ to $+50$ m/yr), and High Accretion: (more than $+50$ m/yr). Two of the ten zones of the bankline were found to be accretion dominant. Zone 1 and Zone 2, classified as high accretion zones, have gained much land. On the other hand, zones 3, 4, 8, 9, and 10 were classified as a high erosional zone. Zone 5 and Zone 6 were low erosional, and only Zone 7 was considered a moderate erosional zone.

4.1.1. High Accretion Zones (1 and 2)

Zone 1 and Zone 2 exhibited a mean EPR of 57.69 ± 14.75 and 62.69 ± 18.12 , respectively indicating substantial accretion and a significant net gain in sediment deposition along the bankline. The positive mean valued of LRR averages $84.37 \pm$

9.67, WLR 84.37 ± 9.67 , NSM 1736.29 ± 350.12 , and SCE 4067.22 ± 725.63 for Zone 1 and comparable valued with LRR at 63.64 ± 24.37 , WLR 63.64 ± 24.37 , NSM 1886.77 ± 243.64 , and SCE 3354.52 ± 788.95 for Zone 2 further supported the notion of significant sediment buildup. This findings from **Table 4** suggested significant sediment deposition and bankline stabilization in these zones over the past three decades. These zones served as sediment sinks, likely driven by sediment supply from riverine inputs, alluvial transport, and wave-induced sediment transport processes. The stability and expansion of landforms in high accretion zones were crucial for buffer areas against erosion, and contribute to sediment budget dynamics, promoting bankline stabilization, landform expansion, and sustainable development project like solar power plant.

4.1.2. High Erosion Zones (3, 4, 8, 9, and 10)

Zones 3, 4, 8, 9, and 10 have consistently experienced erosional trends from 1990 to 2020. The negative values of EPR, LRR, WLR, NSM, and SCE underscore the vulnerability of these zones to erosion. For example, Zone 3 demonstrates EPR (-76.84 ± 23.52), LRR at -82.64 ± 29.15 , WLR -82.64 ± 29.15 , NSM -2313.6 ± 389.78 , and SCE 2561.83 ± 195.45 , indicating significant lateral retreat and net bankline degradation. Similar patterns are observed in Zones 4, 8, 9, and 10, with mean EPR values ranging from -65.87 to -71.167 , showcasing substantial erosion. Despite varying degrees of erosion intensity, the bankline change data underscores the persistent vulnerability of these zones to natural and anthropogenic stressors, including wave action, sediment deficits, and human interventions.

4.1.3. Moderate and Low Erosion Zones (5, 6, and 7)

Zones 5, 6, and 7 display heterogeneous bankline change patterns, reflecting variable erosion and stability trends since 1990. While Zone 5 initially experienced erosion in the 1990s with a negative mean EPR (-25.75 ± 18.5), it transitioned to a combination of accretion and stability in subsequent years, indicating dynamic bankline processes influenced by sediment availability, and wave climate. Zones 6 and 7 exhibit mixed responses, slightly negative to near-zero mean values across parameters, suggesting relatively stable bankline conditions with minor erosion tendencies over the study period. These zones may be influenced by local geomorphological features, anthropogenic activities, and climate variability, contributing to the observed variability in bankline dynamics.

Table 4. Summary of zone-wise bankline statistics for Fulchhari island.

Zone	Parameters	No. of Transect	Mean	Maximum	Minimum	Remarks
Zone-1	EPR	239	57.69	75.07	0.62	High Accretion
	LRR		84.37	101.71	10.26	
	WLR		84.37	101.71	10.26	
	NSM		1736.297	2259.31	18.8	
	SCE		4067.226	4669.78	1618.73	

Continued

Zone-2	EPR		62.69	77.33	-29.58	High Accretion
	LRR		63.64	111.68	-41.03	
	WLR	140	63.64	111.68	-41.03	
	NSM		1886.77	2327.41	-890.2	
	SCE		3354.522	4930.47	1631.96	
Zone-3	EPR		-76.84	-33.7	-92.8	High Erosion
	LRR		-82.64	-43.62	-101.43	
	WLR	180	-82.64	-43.62	-101.43	
	NSM		-2313.6	-1014.36	-2792.93	
	SCE		2561.83	2956.09	1772.81	
Zone-4	EPR		-71.167	-26.57	-94.27	High Erosion
	LRR		-77.23	-23.36	-98.26	
	WLR	180	-77.23	-23.36	-98.26	
	NSM		-2141.85	-799.65	-2837.25	
	SCE		2374.768	2837.25	1902.72	
Zone-5	EPR		-25.75	8.03	-51.96	Low Erosion
	LRR		5.58	38.44	-25.14	
	WLR	140	5.58	38.44	-25.14	
	NSM		-774.94	241.78	-1563.69	
	SCE		2260.8	2831.43	1450.36	
Zone-6	EPR		-21.41	-5.79	-37.79	Low Erosion
	LRR		-10.35	17.99	-23.32	
	WLR	190	-10.35	17.99	-23.32	
	NSM		-644.275	-174.29	-1137.19	
	SCE		1817.42	2994.08	1334.73	
Zone-7	EPR		-50.43	-25.96	-77.72	Moderate Erosion
	LRR		-18.6	-8.17	-31.57	
	WLR	230	-18.6	-8.17	-31.57	
	NSM		-1517.72	-781.18	-2338.91	
	SCE		2819.2	3249.3	2066.03	
Zone-8	EPR		-63.26	-53.9	-76.45	High Erosion
	LRR		-59.35	-18.83	-75.59	
	WLR	160	-59.35	-18.83	-75.59	
	NSM		-1903.78	-1622.3	-2300.77	
	SCE		2727.26	3430.98	2117.66	
Zone-9	EPR		-54.17	-33.94	-173.89	High Erosion
	LRR		-85.48	-55.07	-201.64	
	WLR	160	-85.48	-55.07	-201.64	
	NSM		-1630.292	-1021.48	-5233.39	
	SCE		3497.38	5289.95	2306.44	

Continued

	EPR		-65.87	-4.17	-79.23	
	LRR		-56.9	-3	-75.24	
Zone-10	WLR	152	-56.9	-3	-75.24	High Erosion
	NSM		-1982.52	-125.49	-2384.41	
	SCE		2201.21	2384.41	1660.72	

Table 5 illustrates the bankline change by the 1990 baseline, with ten distinct zone's bankline changes every 5-year intervals. We can visualize every reported year whether land is being added or eroded. In that context, a significant portion of land was identified as unaffected by erosion/accretion.

Table 5. Bankline changes in accordance with year 1990 baseline.

Zone	1990	1995	2000	2005	2010	2015	2020	Remarks
Z1	Baseline	A	A	NC	A	A	A	Accretion in accordance with Baseline
Z2	Baseline	A	NC	NC	A	A	A	
Z3	Baseline	E	E	E	E	E	E	Erosion in accordance with Baseline
Z4	Baseline	E	NC	E	E	E	E	
Z5	Baseline	NC	E	NC	A	A	E	
Z6	Baseline	E	NC	NC	A	A	E	
Z7	Baseline	E	E	E	A	NC	A	
Z8	Baseline	E	NC	E	A	E	E	
Z9	Baseline	A	A	A	E	E	A	
Z10	Baseline	E	E	NC	E	E	E	

Accretion = A; Erosion = E; No Change = NC.

4.2. Sustainability of the Solar Power Plant Project

The findings of the climatic factor assessment showed that solar radiation was the most crucial climate sub-criteria, while cloud coverage was the least important. In the geomorphological sub-factor, the slope criterion had the highest weight. Also, the weights of the sub-factor data for land cover were given a lower weightage value. **Table 6** shows a summary of the weights for each class. Here, the susceptibility class ratings tell us how significant the positive effects are. Value 5 shows the most positive effect, and value 1 shows the most negligible positive effect.

Table 6. Solar causative susceptibility rating and weight description.

Causative Criterion	Unit	Class	Class Range	Ratings	Weight (Total 100%)
Solar Radiation	kW-hr/m ² /day	4.558 - 4.570	Very Low	1	28
		4.570 - 4.581	Low	2	
		4.581 - 4.593	Moderate	3	
		4.593 - 4.605	High	4	
		4.605 - 4.628	Very High	5	

Continued

Sunshine	h/day	6.300 - 6.307	Very Low	1	21
		6.307 - 6.313	Low	2	
		6.313 - 6.327	Moderate	3	
		6.327 - 6.333	High	4	
		6.333 - 6.340	Very High	5	
Temperature	°C	33.89 - 33.95	Very Low	1	20
		33.95 - 34.01	Low	2	
		34.01 - 34.08	Moderate	3	
		34.08 - 34.20	High	4	
		34.20 - 34.26	Very High	5	
Cloud Coverage	Octas	3.35 - 3.41	Very High	5	5
		3.41 - 3.47	High	4	
		3.47 - 3.59	Moderate	3	
		3.59 - 3.65	Low	2	
		3.65 - 3.71	Very Low	1	
Elevation	m	2 - 12	Very Low	1	5
		12 - 15	Low	2	
		15 - 18	Moderate	3	
		18 - 20	High	4	
		20 - 44	Very High	5	
Slope	m	0 - 0.5	Very High	5	15
		0.5 - 2.12	High	4	
		2.12 - 3.32	Moderate	3	
		3.32 - 5.26	Low	2	
		5.27 - 13.83	Very Low	1	
Land Use Land Cover	Level	Water	Very Low	1	6
		Tree/Crops	Low	2	
		Build Area	Moderate	3	
		Barren Field	High	4	
		Range Land	Very High	5	

Figure 4 shows that the south and southeast of the study area have high solar radiation values, while the north has relatively lower solar radiation values. So, places with more sunlight will be more likely to be able to get a solar power plant. On the other hand, the temperature raster model shows that, as usual, the average temperature is higher in the south and southeast of the study area and lower in the north and west. Solar power generation panel will work best when temperatures are between 33.9 and 34.3 degrees Celsius. In addition, clouds are blocking, on average, 3 to 4 octas, the amount of solar radiation from reaching the solar cell. The southern edge regions have more cloud coverage area than other regions. The average value is approximately 30% to 40%, which is fine for solar panels to

produce energy. As a result, southern Char can be preferable for installing solar-based power plants. On the other hand, elevation and slope results illustrated that the most suitable lands in the study area are slightly sloping. The center area is highly elevated, and the surrounding area is somewhat elevated between 20 m and 22 m. The center and a part of the southern region have slightly high slopes. As a result, the northern and western regions are less suitable for installing solar power plants.

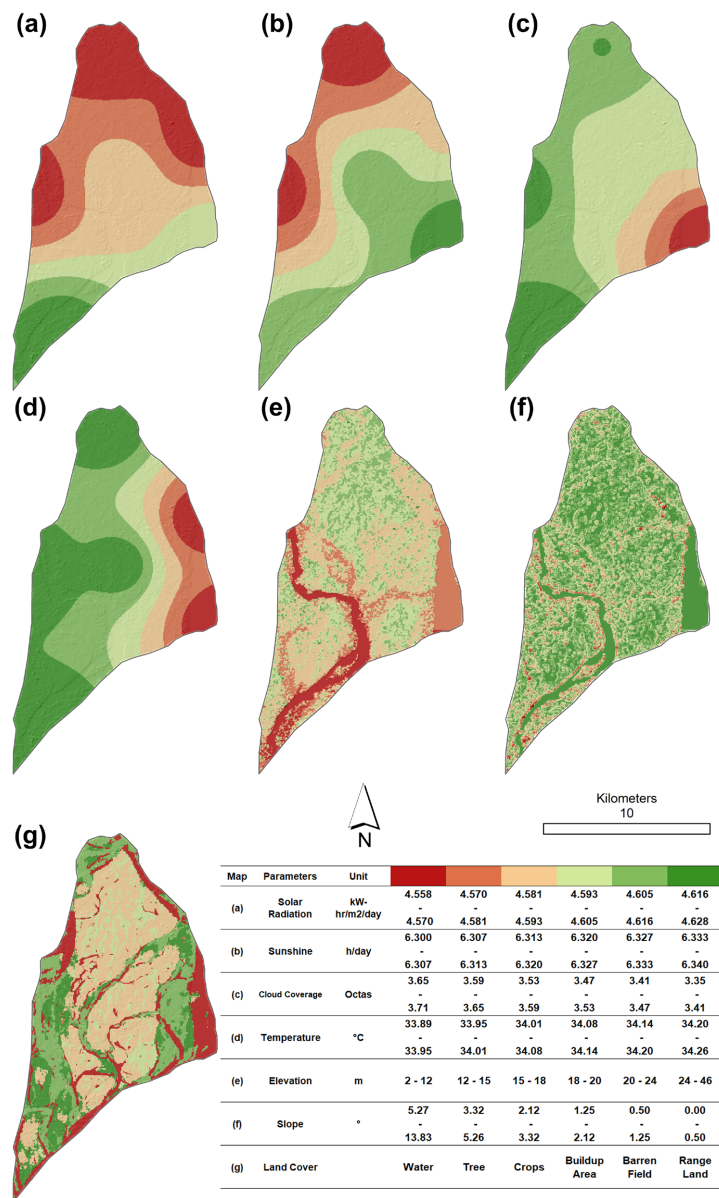


Figure 4. Reclassified raster models for the criteria adopted in the study.

Figure 5 shows suitable areas for installing solar based power plants dividing them into five groups. The first group is the dark red color class, which has a very low level of suitability because it has a house, a market, and other infrastructures.

On the other hand, the last category is the dark green color class with a high level of suitability (76% - 100%). The light green colors are moderate suitable area due to its crop land. However, with some modifications, changes and highly equipped installment for solar plants, this area could also be highly potential area for solar firms. Although the southern area has moderate to high slopes, the study area has high solar radiation and average sunshine values for establishing solar farms in the southern part of the area. Contradiction with slope and other values is due to site selection algorithm (Weighted overlay tool) because the algorithm not only includes slope criterion, but also other criterion like climatic, and geomorphology which had a clear influence on the decision-making. Recent Landsat-8 satellite images showed that the results of the search for suitable areas were correct. Most of the land with a suitability level between 0% and 25% is either built on or has water on it. So, they are not at all good places to put up a solar power plant. Moreover, the images from satellites showed that areas with a high level of suitability are mostly barren. While calculating the bankline change of the island, a typical area was found inside the land, which has never been eroded or added in the past 30 years. If outer parts are excluded from the familiar bankline area from our suitable area, as illustrated in **Figure 5**, the result will be the optimum area for the solar based power plant.

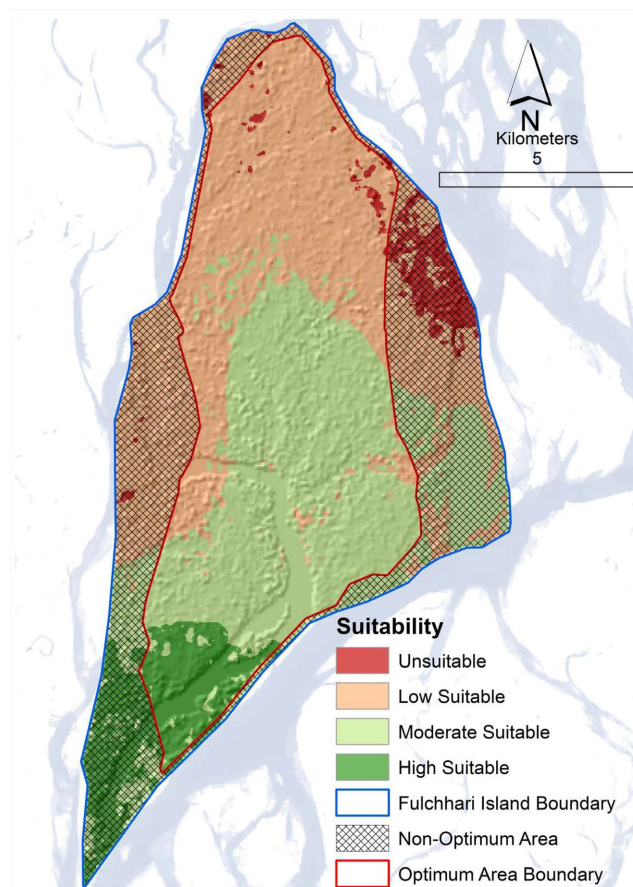


Figure 5. Suitable and optimum areas for installing solar based power plant.

4.3. Optimum Area for Solar Power Plant

The determination of optimal site selection for solar power facilities is critical in order to optimize the capacity for energy production. The delineation of regions exhibiting high and moderate potential by this study offers significant insights that can be utilized in the strategic planning and execution of solar energy initiatives. Concentrating on the final optimal region characterized by high potential, which comprises an estimated 9% - 10% (7.2 sq km) of study area, brings attention to a confined area that is highly suitable for substantial solar infrastructure development. Furthermore, recognizing the moderate potential area comprising approximately 50% of the optimal area (40 sq km) highlights the wider range of opportunities for solar projects, albeit with a marginal reduction in efficiency.

4.4. Solution to Pressing Environmental and Energy Challenges of Bangladesh

The implications of this research are profound, potentially revolutionizing energy issue resolution, promoting environmental sustainability, and stimulating economic growth. Solar energy potential in Bangladesh is high, making it a viable alternative for fossil fuel (Hussain et al., 2024). Utilizing the Fulchhari river island for solar based power plant installations offers a promising solution to minimize the dependency on fossil fuel as a densely populated country. Transitioning to solar power could mitigate greenhouse gas (GHG) emissions and alleviate dependence on declining fossil fuel reserves (Ahiduzzaman & Islam, 2011; Dogan & Seker, 2016). The study's findings align with national energy targets, such as achieving 10% renewable energy by 2021 and 100% by 2050 (PSMP, 2016). These findings have the potential to socially uplift communities by enhancing energy security, creating job opportunities, and reducing reliance on fossil fuels. The adoption of solar energy in designated areas promises cleaner air, improved health outcomes, and greater resistance to climate change impacts.

5. Conclusion

The rapid expansion of solar power infrastructure underscores a strong commitment to sustainable energy strategies. Unlike previous studies, this research stands out for its comprehensive approach to assessing the potential of solar energy. By including areas of both high and moderate potential, this study provides a thorough evaluation of the terrain's suitability for solar power generation. The research also emphasizes the scalability of solar projects, particularly in the Fulchhari union of Gaibandha district, demonstrating how the findings can be pragmatically applied to address local energy shortages. By pinpointing optimal locations for solar power installations, it will equip policymakers, energy developers, and local communities with a strategic blueprint to effectively exploit renewable energy resources. Moreover, the scientific rigor of our methodology lends credibility to our findings and supports evidence-based decision-making in infrastructure investment and energy planning.

Furthermore, localized solar energy initiatives can strengthen regional economies and enhance energy access, particularly in rural and underserved areas. This study not only advances scientific knowledge but also offers practical solutions to pressing environmental and energy challenges. Ultimately, it contributes positively to the sustainability and resilience of Fulchhari union, Gaibandha district, and beyond by efficiently harnessing solar energy resources.

Acknowledgements

We would like to thank the academic experts, NGOs, and Government authority who helped us generate logical criteria and factors for AHP analysis of our research. We would like to express our deep gratitude and gratefully acknowledge the people of Fulchhari island for their kindness, hospitality, and support during AHP data collection period. The authors also thank the anonymous reviewers whose feedback considerably improve the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- Abdullah-Al-Mahbub, M., & Islam, A. R. M. T. (2023). Current Status of Running Renewable Energy in Bangladesh and Future Prospect: A Global Comparison. *Heliyon*, *9*, e14308. <https://doi.org/10.1016/j.heliyon.2023.e14308>
- Ahiduzzaman, M., & Islam, A. K. M. S. (2011). Greenhouse Gas Emission and Renewable Energy Sources for Sustainable Development in Bangladesh. *Renewable and Sustainable Energy Reviews*, *15*, 4659-4666. <https://doi.org/10.1016/j.rser.2011.07.086>
- Al Garni, H. Z., & Awasthi, A. (2017). Solar PV Power Plant Site Selection Using a GIS-AHP Based Approach with Application in Saudi Arabia. *Applied Energy*, *206*, 1225-1240. <https://doi.org/10.1016/j.apenergy.2017.10.024>
- Alam, K. F., & Ahamed, T. (2022). Assessment of Land Use Land Cover Changes for Predicting Vulnerable Agricultural Lands in River Basins of Bangladesh Using Remote Sensing and a Fuzzy Expert System. *Remote Sensing*, *14*, Article No. 5582. <https://doi.org/10.3390/rs14215582>
- Al-Zubieri, A. G., Ghandour, I. M., Bantan, R. A., & Basaham, A. S. (2020). Shoreline Evolution between Al Lith and Ras Mahāsin on the Red Sea Coast, Saudi Arabia Using GIS and DSAS Techniques. *Journal of the Indian Society of Remote Sensing*, *48*, 1455-1470. <https://doi.org/10.1007/s12524-020-01169-6>
- Anders, F. J., & Byrnes, M. R. (1991). Accuracy of Shoreline Change Rates as Determined from Maps and Aerial Photographs. *Shore and Beach*, *59*, 17-26. https://www.researchgate.net/publication/284041608_Accuracy_of_shoreline_change_rates_as_determined_from_maps_and_aerial_photographs
- Apergis, N., Ben Jebli, M., & Ben Youssef, S. (2018). Does Renewable Energy Consumption and Health Expenditures Decrease Carbon Dioxide Emissions? Evidence for Sub-Saharan Africa Countries. *Renewable Energy*, *127*, 1011-1016. <https://doi.org/10.1016/j.renene.2018.05.043>
- Ashworth, P. J., Best, J. L., Roden, J. E., Bristow, C. S., & Klaassen, G. J. (2000). Morphological Evolution and Dynamics of a Large, Sand Braid-bar, Jamuna River, Bangladesh.

- Sedimentology*, 47, 533-555. <https://doi.org/10.1046/j.1365-3091.2000.00305.x>
- Banglapedia (2023). *Fulchhari Upazila*. [https://en.banglapedia.org/index.php/Fulchhari Upazila](https://en.banglapedia.org/index.php/Fulchhari_Upazila)
- Bristow, C. S. (1987). Brahmaputra River: Channel Migration and Deposition. In *Recent Developments in Fluvial Sedimentology* (pp. 63-74). SEPM (Society for Sedimentary Geology). <https://doi.org/10.2110/pec.87.39.0063>
- Colak, H. E., Memisoglu, T., & Gercek, Y. (2019). Optimal Site Selection for Solar Photovoltaic (PV) Power Plants Using GIS and AHP: A Case Study of Malatya Province, Turkey. *Renewable Energy*, 149, 565-576. <https://doi.org/10.1016/j.renene.2019.12.078>
- Dogan, E., & Seker, F. (2016). Determinants of CO₂ Emissions in the European Union: The Role of Renewable and Non-Renewable Energy. *Renewable Energy*, 94, 429-439. <https://doi.org/10.1016/j.renene.2016.03.078>
- Dolan, R., Fenster, M. S., & Holme, S. J. (1991). Temporal Analysis of Shoreline Recession and Accretion. *Journal of Coastal Research*, 7, 723-744. <http://www.jstor.org/stable/4297888>
- Genz, A. S., Fletcher, C. H., Dunn, R. A., Frazer, L. N., & Rooney, J. J. (2007). The Predictive Accuracy of Shoreline Change Rate Methods and Alongshore Beach Variation on Maui, Hawaii. *Journal of Coastal Research*, 231, 87-105. <https://doi.org/10.2112/05-0521.1>
- Gulagi, A., Choudhary, P., Bogdanov, D., & Breyer, C. (2017). Electricity System Based on 100% Renewable Energy for India and SAARC. *PLOS ONE*, 12, e0180611. <https://doi.org/10.1371/journal.pone.0180611>
- Günen, M. A. (2021). Determination of the Suitable Sites for Constructing Solar Photovoltaic (PV) Power Plants in Kayseri, Turkey Using GIS-Based Ranking and AHP Methods. *Environmental Science and Pollution Research*, 28, 57232-57247. <https://doi.org/10.1007/s11356-021-14622-x>
- Habib, M. H. R., Rahman, M., Uddin, M. M., Shimu, N. J., Hasan, M., Alam, M. J. et al. (2024). Application of AHP and Geospatial Technologies to Assess Ecotourism Suitability: A Case Study of Saint Martin's Island in Bangladesh. *Regional Studies in Marine Science*, 70, Article ID: 103357. <https://doi.org/10.1016/j.rsma.2023.103357>
- Habib, S. M., El-Raie Emam Suliman, A., Al Nahry, A. H., & Abd El Rahman, E. N. (2020). Spatial Modeling for the Optimum Site Selection of Solar Photovoltaics Power Plant in the Northwest Coast of Egypt. *Remote Sensing Applications: Society and Environment*, 18, Article ID: 100313. <https://doi.org/10.1016/j.rsase.2020.100313>
- Hasan, M. Z. (2018). *Assessment of Hydro-Morphological Response of Selected Reach of the Jamuna River Due to Structural Intervention Using Delft3D Model*. Master's Thesis, Department of Water Resources Engineering, Bangladesh University of Engineering and Technology (BUET). <http://lib.buet.ac.bd:8080/xmlui/handle/123456789/5455>
- Hussain, M. N., Zaman, M. R., Halim, M. A., Ali, M. S., & Khan, M. Y. A. K. (2024). A Comprehensive Review of Renewable and Sustainable Energy Sources with Solar Photovoltaic Electricity Advancement in Bangladesh. *Control Systems and Optimization Letters*, 2, 1-7. <https://doi.org/10.59247/csol.v2i1.59>
- Islam, M. A., Murshed, S., & Hasan, M. (2020). Selecting Suitable Landfill Site with Multi-Criteria Evaluation and GIS: A Case of Savar Upazila in Bangladesh. *Arabian Journal of Geosciences*, 13, Article No. 952. <https://doi.org/10.1007/s12517-020-05925-3>
- Islam, M. K., Hasan, M., Rahman, M., Fayyaz, R., Chowdhury, M., & Hamid, T. (2022). Shoreline Dynamics Assessment of Moheshkhali Island of Bangladesh Using Integrated GIS-DSAS Techniques. *The Dhaka University Journal of Earth and Environmental Sciences*, 11, 1-14. <https://doi.org/10.3329/dujees.v11i1.63707>

- Khazael, S. M., & Al-Bakri, M. (2021). The Optimum Site Selection for Solar Energy Farms Using AHP in GIS Environment, a Case Study of Iraq. *Iraqi Journal of Science*, *62*, 4571-4587. [https://doi.org/10.24996/ij.s.2021.62.11\(si\).36](https://doi.org/10.24996/ij.s.2021.62.11(si).36)
- Kumar, J. C. R., & Majid, M. A. (2020). Renewable Energy for Sustainable Development in India: Current Status, Future Prospects, Challenges, Employment, and Investment Opportunities. *Energy, Sustainability and Society*, *10*, Article No. 2. <https://doi.org/10.1186/s13705-019-0232-1>
- Meshkova, L. V., & Carling, P. A. (2013). Discrimination of Alluvial and Mixed Bedrock-Alluvial Multichannel River Networks. *Earth Surface Processes and Landforms*, *38*, 1299-1316. <https://doi.org/10.1002/esp.3417>
- Mirdan, M. M., Tolba, E. R., Abdellah, S., & Galal, E. M. (2023). Digital Shoreline Analysis System Techniques for Stability Detection: An Applied Case Study on Port Said, Egypt. *Egyptian Journal of Aquatic Research*, *49*, 460-470. <https://doi.org/10.1016/j.ejar.2023.08.001>
- Nassar, K., Mahmood, W. E., Fath, H., Masria, A., Nadaoka, K., & Negm, A. (2018). Shoreline Change Detection Using DSAS Technique: Case of North Sinai Coast, Egypt. *Marine Georesources & Geotechnology*, *37*, 81-95. <https://doi.org/10.1080/1064119x.2018.1448912>
- Peters, J. J. (1993). Morphological Studies and Data Needs. In *Proceedings of the International Workshop on Morphological Behaviour of Major Rivers* (pp. 333-364). River Survey Project FAP24, Dhaka. https://scholar.google.com/scholar_lookup?&title=Morphological%20studies%20and%20data%20needs&publication_year=1993&author=Peters%2CJ
- PSMP (2016). <https://powerdivision.gov.bd/site/page/f68eb32d-cc0b-483e-b047-13eb81da6820/Power-System-Master-Plan-2016>
- Rousseeuw, P. J., & Leroy, A. M. (1987). *Robust Regression and Outlier Detection*. Wiley. <https://doi.org/10.1002/0471725382>
- Saaty, T. L. (1980). The Analytic Hierarchy Process (AHP). *The Journal of the Operational Research Society*, *41*, 1073-1076. <https://www.iasj.net/iasj/download/9c50d6dda6342d0f>
- Settou, B., Settou, N., Gouareh, A., Negrou, B., Mokhtara, C., & Messaoudi, D. (2020). A High-Resolution Geographic Information System-Analytical Hierarchy Process-Based Method for Solar PV Power Plant Site Selection: A Case Study Algeria. *Clean Technologies and Environmental Policy*, *23*, 219-234. <https://doi.org/10.1007/s10098-020-01971-3>
- Solangi, Y. A., Shah, S. A. A., Zameer, H., Ikram, M., & Saracoglu, B. O. (2019). Assessing the Solar PV Power Project Site Selection in Pakistan: Based on AHP-Fuzzy VIKOR Approach. *Environmental Science and Pollution Research*, *26*, 30286-30302. <https://doi.org/10.1007/s11356-019-06172-0>
- Thorne, P. D., Hardcastle, P. J., & Soulsby, R. L. (1993). Analysis of Acoustic Measurements of Suspended Sediments. *Journal of Geophysical Research: Oceans*, *98*, 899-910. <https://doi.org/10.1029/92jc01855>
- Ul-Haq, A., Jalal, M., Sindi, H. F., & Ahmad, S. (2020). Energy Scenario in South Asia: Analytical Assessment and Policy Implications. *IEEE Access*, *8*, 156190-156207. <https://doi.org/10.1109/access.2020.3019648>
- Yildiz, S. S. (2024). Spatial Multi-Criteria Decision Making Approach for Wind Farm Site Selection: A Case Study in Balıkesir, Turkey. *Renewable and Sustainable Energy Reviews*, *192*, Article ID: 114158. <https://doi.org/10.1016/j.rser.2023.114158>