



Delineation of site suitability mapping units for fishing zones using geo-spatial technology in kakkdwip Sub-division, south west part of Sundarban, India

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Abstract

Geomorphologically, Sundarban is the active portion of the Gangetic delta in which the processes of land formation and erosion, ebb wave activeness are pronounced. The important productive and profit oriented sector in Sundarban after agriculture is aquaculture. The main aim of the study is to assess the suitable site selection of fishing zones for Kakkdwip sub-division mainly consisting of Kakkdwip, Sagar Island, Patharpratima and Namkhana blocks. The Land Use & Land Cover Map (LULC) shows an increasing trend of settlement and increasing nature of aquaculture pond in this region. The study of the fishing zones can be done with the use of a technology based Site Suitability Mapping of Kakkdwip sub-division with the help of Weighted Overlay Analysis. The site suitability mappings have been done on the basis of the weightages given to Land Use & Land Cover (40%), Euclidean Distance (40%) and Slope (20%). The Euclidean Distance is prepared on the basis of suitable fishing zones near the settlements with the point data extraction. The LULC, Euclidean Distance & Slope have been reclassified for the final preparation of the Site suitability mapping for identification of different zones. The Arc GIS 10.1 software helped in marking the suitable sites for fishing zones. Finally the zones are divided into eight classes where the suitable sites are observed along the shoreline part of the area and the marine zone along the creeks, whereas some parts of inner core land is not suitable for fishing that has been depicted in the present study.

Keywords: land use and land cover (LULC), euclidean distance, slope map, tidal creeks weighted overlay analysis and aquaculture pond

Introduction

Coast and estuaries are typical environments in which human impacts have led to a whole range of changes with considerable variation in the degree of impact. Ocean beaches and their surf zones dominate the world's coastlines, comprising 70% of the global interface between land and sea (Bascom, 1964; Woodroffe, 2002) [2, 25]. These shore habitats are of immense economic and social value as prime sites for coastal development, tourism and recreation (Dugan *et al.*, 2010) [4]. Marine reserves are a common, and effective, tool for conserving biodiversity and ecosystem functioning (Lester *et al.*, 2009; Olds *et al.*, 2016) [7, 12]. The coast is typically a highly populated area which states that almost 50 % of the world's population lives within 1 km of the coastal zone. This pressure has the potential to cost change and environmental degradation without careful management. Historically, human interference within the coastal zone has the intention of protecting financial interests, increasing earning potential or providing places to relax and spend leisure time (Paul *et al.* 2002; Sahana M *et al.*, 2019) [13, 23]. Beach morphology, exposure and coastal hydrodynamics can also affect fish assemblages in the surf (Borland *et al.*, 2017; Patrick & Strydom, 2014) [3, 15]. The abundance, diversity and size of macro fauna on beaches are shaped, globally, by tidal range, sediment grain size and both the width and slope of beaches (Defeo & McLachlan, 2013; Schlacher & Thompson, 2013) [5, 22].

Estuarine geomorphology describes the morphology of the river with the changing environment and dynamic characteristics. The fluvial morphology helps us to study the fluvial features around the river environment (Paul *et al.* 2012) [14]. In more sheltered

areas, often where the intertidal and sub tidal profiles are sufficiently shallow wave action is largely removed, either by a process of shoaling or by the direct shelter of a river mouth by a spit. In such cases, waves cease to be the dominant influence, and tides take over as the main formative process. As a result, the depositional landforms reflect the change in dominance, and associated decrease in energy levels, by producing a series of different intertidal habitats. Because of the lower energy levels, sediments tend to be dominated by silts and mud. The deposition of these sediments governed by the tide height, and the position of the depositional environment relative to the tidal frame (Paul *et al.* 2012) [14].

In some cases, a time series of fishery-independent surveys exists for other species, and the data-poor species may be caught occasionally. Fishing zones demarcation with site suitability mapping is one of the most useful applications of GIS for aquaculture planning and management. The analysis mainly aims at i. Preparing classify and reclassify maps for multi criteria evaluation for Land Use Land Cover (LULC), Euclidean Distance & Slope, ii. To assign weightage with pairwise comparison method and iii. Site suitability mapping of fishing zones with the weighted overlay analysis (Mitra *et al.*, 2018) [11]. The site suitability mapping involves the assessment and classification of the areal units according to their suitability for a particular activity. This multi criteria evaluation is GIS based and very useful application of Remote Sensing & GIS (Ali, S, *et al.*, 2019; Falahat *et al.*, 2019; Vaidya, O. *et al.*, 2006; Parry *et al.*, 2018) [1, 6, 24, 16].

Study Area

Sundarban mangroves ecosystem is the World's Heritage Site and largest tidal wetland of the world. It represents a highly valued ecosystem in term of economy, ecology and environment. The study area has been selected with the main focus to study the relationship between human and estuarine morphology. The study area mainly comprises Kakdwip sub-division with special reference to Kakdwip, Sagar Island, Namkhana and Patharpratima of south-west part of Sundarban (Fig.1).

The Sagar Island is located at the downstream section of Hooghly River facing Bay of Bengal towards south and surrounded by

Hooghly and Muriganga River systems. The Kakdwip and Namkhana Administrative blocks are lying on the eastern bank of Muriganga River. The upper part of Namkhana Block is separated by Hatania- Doania channel and the Mousuni Island is separated by Edward creek from Namkhana mainland. The Patharpratima block on the other hand, is located on the eastern bank of Saptamukhi River and extended upto the bank of Thakuran River as another administrative block considered for the study.

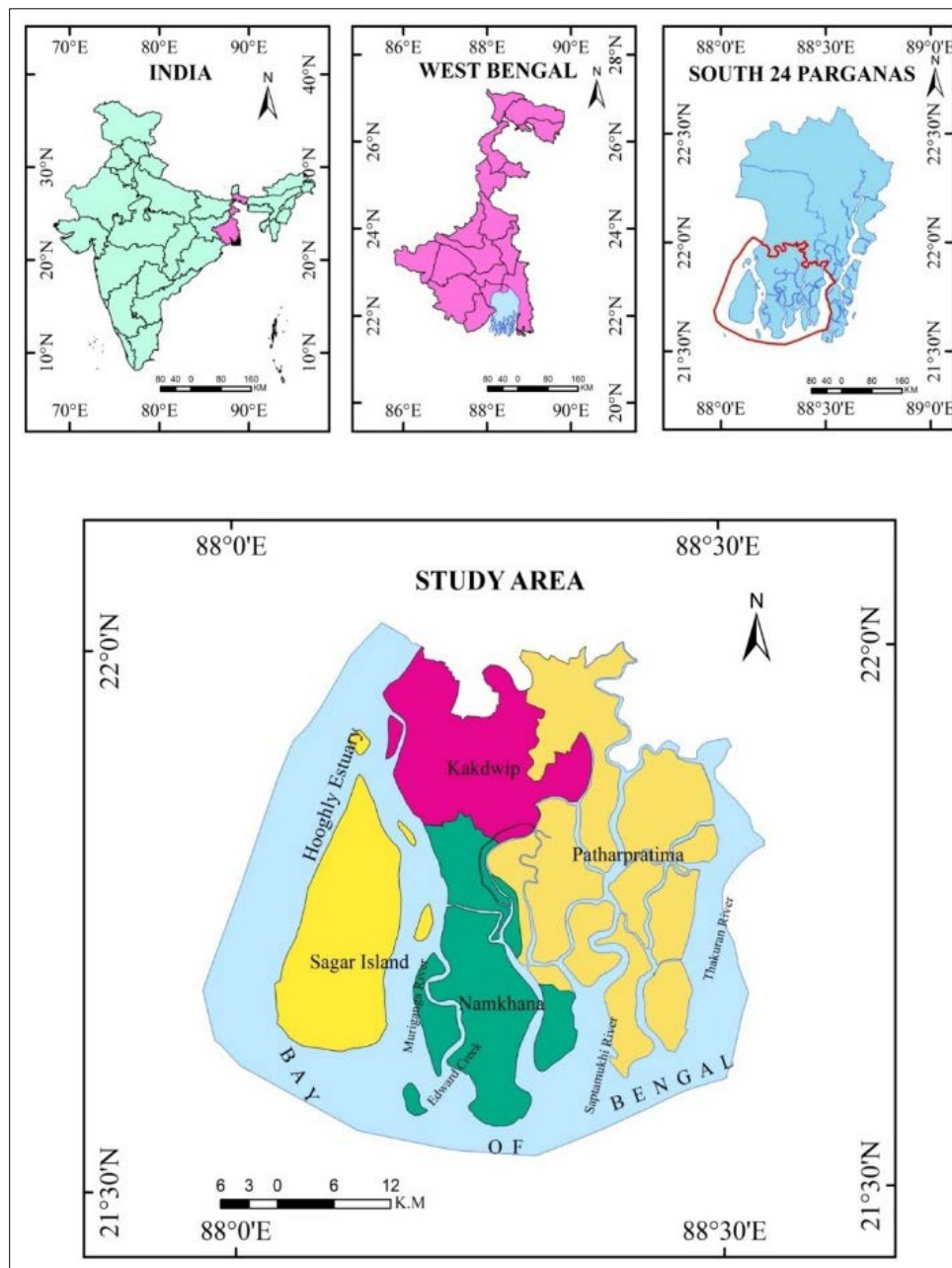


Fig 1: Location map of the study area

Materials and Methods

Data Processing

The GIS is a potential and powerful tool that assists decision-makers for selecting suitable sites analysis with the help of

weighted overlay analysis for aquaculture development. This geospatial technology (GIS and Remote Sensing) has helped decision makers in the formulation of policies regarding site selection, location, areal extent, topography, land use type, soil

types, and market proximities of selected aquacultural area. It can also be added that inherent spatial components of biophysical and socio-economic characteristics which vary from location to location aided aquaculture planning (Mishra, A. K. et.al., 2015)^[9]. The weighted overlay analysis is a useful technique for assigning weightages with accordance needed for the demarcation of suitable sites for fishing zones. The weighted overlay analysis has been prepared with the assigned weightages

of LULC, Euclidean Distance and Slope. The Landsat 8 OLI image, SOI toposheet and Google Earth data's are processed for the Land use and Land cover map (Table.1). The point data extraction of settlements from Google Earth & Satellite image merge have been assigned for Euclidean distance map and the Slope map has been generated on the ASTER global DEM for the final overlay.

Table 1: Details and sources of the data's for the assessment of site suitability analysis

Sl. No.	Data	Date of data acquired	Source	No of Bands	Resolution
1	Land Sat 8 OLI/TIRS	24 th November 2017	http://glovis.usgs.gov/	11	30
2	ASTER Global DEM	20 th November 2011	http://glovis.usgs.gov/		30
3	Toposheet	1972	Survey Of India	Scale	1:50000
4	Google Earth	2018	Developed by keyhole, in c a mountain view based company founded in 2001		

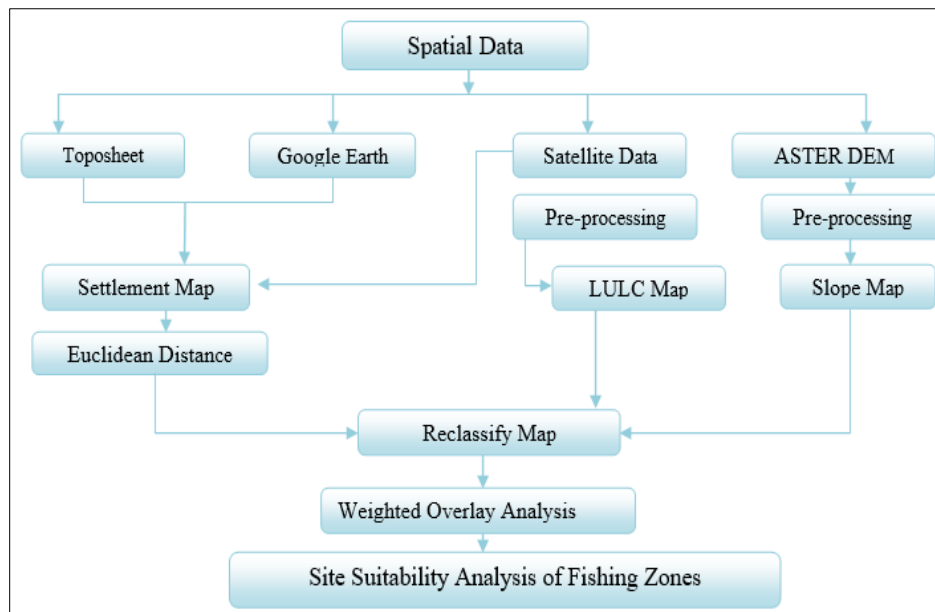


Fig 2: Methodological framework of the study area

The site suitability mapping of fishing zone has been done depending on three criterions; Land Use & Land Cover (LULC); Euclidean Distance & Slope. The LULC map is prepared with the overlaying of Landsat 8 OLI images, SOI toposheet, & Google Earth. The Euclidean distance maps have been prepared with the point data extraction of settlements, whereas the slope map has been generated on ASTER DEM (Fig.2). Finally these maps are reclassified and after Pairwise Comparison, these maps are assigned weightages for the weighted overlay analysis for the final site suitability mapping of fishing zones (Samanta, S et.al, 2011)^[20].

Results & Discussion

Analytic Hierarchy Process

In this study, Analytic Hierarchy Process (AHP) was used as a multi-criteria decision approach to make final decision towards developing site suitable analysis of fishing susceptibility zonation of Kaddwip sub-division.

The AHP method was first developed by Thomas L. Saaty. The AHP was designed to solve multifaceted problems relating multiple criteria. In this method, the importance of criteria is

compared pairwise with respect to the desired goal to develop their weights and then consistency of judgments is checked in order to confirm a reasonable level of consistency in criteria based decision making. Thus, the first of all a hierarchy for the decision have to build which is also called as decision Modeling (Mu, E., & Pereyra-Rojas, M., 2017)^[10].

As the all selected criteria will not have the same significance for a particular instance, hence, the relative priorities or weights for the criteria is to derive in next step. It is called relative because priorities are measured with respect to each other based on their importance in an incidence. Then the pair-wise comparisons have to perform to prepare comparison matrix of the criteria to measure the weightage.

PCM is a relative ranking based matrix table used to calculate the weight value of all alternatives under a selected criterion in decision making process. Ci and j of the matrix, is the measure of importance of the item in row i when compared to the item in column j. AHP finds the significance ranking of Cj,i by calculating the reciprocal of Ci,j.

$$\left(\begin{array}{cccc} C_{j1} & 1/C_{ij1} & 1/C_{ij1} \dots 1/C_{ij1} & w_1 \\ C_{j2} & 1/C_{ij2} & 1/C_{ij2} \dots 1/C_{ij2} & w_2 \\ C_{j3} & 1/C_{ij3} & 1/C_{ij3} \dots 1/C_{ij3} & w_3 \\ \vdots & \vdots & \vdots & \vdots \\ C_{jn} & 1/C_{ijn} & 1/C_{ijn} \dots 1/C_{ijn} & w_n \\ \text{NCS} & \Sigma C_{ij} & \Sigma C_{ij} \dots \Sigma C_{ij} & \end{array} \right)$$

Where, C is the selected criteria, j is the rank of that criteria, i is The reciprocal rank of Cj, NSC is normalized column sum, w is the weight of that criteria and 1, 2, 3 and n indicating the No. of alternatives. The significance rank of all alternatives is compliments and divides of the same alternatives in the matrix (Saaty, T. L. 1990; Vargas, L. G.et.al, 2012) [17, 18, 21]. The AHP employs an underlying scale with values from 1 to 9 to rank the relative importance for two items (Table.2). PCM gives the weights of each criterion with comparison to all others. Once the comparison rank is fitted, the weightage have to be calculated for each respective alternative to judge the consistency for considering into decision. Therefore, the Eigenvector was calculated by the considering the following equation:

Calculated through,
 $Ax = \lambda_{max}x$

$$(w_1 * C_{ij1}) + (w_2 * C_{ij2}) + (w_3 * C_{ij3}) + (w_n * C_{ijn})$$

$$\lambda_{max}x = A_{x1}, A_{x2} \dots A_{xn} / w_{x1}, w_{x2} \dots w_{xn}$$

Table 2: Scale of importance in reciprocal rank to study of AHP method

AHP scale of importance for PCM	Numeric Rank	Reciprocal Rank (decimal)
Extremely importance	9	1/9(0.11)
Very Strong to Extremely importance	8	1/8(0.12)
Very Strongly importance	7	1/7(0.14)
Strongly to very strongly Importance	6	1/6(0.17)
Strongly importance	5	1/5(0.20)
Moderate to Strongly importance	4	1/4(0.25)
Moderate importance	3	1/3(0.33)
Equal to Moderate importance	2	1/2(0.50)
Equal importance	1	1(1.00)

Where, A is the comparison matrix of size n 9 n, for ‘n’ number of criteria, also considered as priority matrix, x is the Eigenvector of size n 9 1 which also called as priority vector, w1...wn are the weight of alternatives, Cij1..... Cijn are the rank of alternatives and λmax is the Eigenvalue. Now, it is required to check that result is either consistent or not. As the numeric ranks are derived from the subjective preferences of individuals, it is highly possible to have some personal bias in making the final matrix of judgments. The question is how much inconsistency is acceptable. For this purpose, AHP always offers a measure of the

consistency of PCM by computing a consistency ratio (CR) comparing the consistency index (CI) of the matrix. Saaty (Saaty, T. L. 2008) [19] provides the calculated RI value for matrices of different sizes of alternatives as given here (Table.3). The ratio is designed in such a way that if the value of the ratio exceeding 0.10 is considered inconsistent for judgments and value 0 is considered as perfectly consistent (Saaty, T. L. 2008, Le AH et al,2009) [19, 8]. The value 0 or close to 0 (i.e. 0.02 or 0.05) are highly acceptable. Consistency ratio (CR) was calculated through the help of CI and RI, whereas, CI was calculated using following equation;

$$CR = CI/RI$$

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

Where, RI = Random index, CI = consistency index, kmax = Average of Rw1...wn. RI depends on the number of elements being compared (i.e. number of alternatives in PCM) and if the value ranges from 0 to 0.09, the matrix will be considered as reasonably consistent and hence, may continue the process of decision-making using AHP.

Table 3: Reciprocal Index values of Random Index (RI) to study of AHP method

N	2	3	4	5	6	7	8	9	10	11	12
RI	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.53

Land Use and Land Cover (LULC)

The Land Use and Land Cover map is an appraisal of spatial information of the physical and social cover types both natural and cultural or anthropogenic on the existing scenario (Fig.3). Land Use could be defined as anthropogenic or human activities (Agricultural land, homestead plantation or garden etc.). On the present day landscape is the vegetational (both natural and cultural forests, plantation) and whereas land cover is artificial construction (Settlement, Transport and Network, embankments etc.).

The Land Use & Land Cover map has been extracted from Landsat 8 OLI image using supervised classification in Erdas Imagine software. Supervised classification has been used for the identification of specific feature through signature trained. The land use & land cover types have been identified as 11 classes i.e. Mangrove Swamp, Agriculture land, River, Tidal Creek, Aquaculture land, Settlement, Sand, Fallow land, Road, Railway & Embankment.

Euclidean Distance

Euclidean distance model is mainly applied for the suitability analysis of selecting optimum site. The settlement data of the study area were used to perform Euclidean distance analysis from the spatial analyst tools in Arc GIS 10.1. The model of the settlement data is calculated on the basis of the straight lines drawn from the distance varying from every cell to a source cell. The model was performed after giving the input of the source data i.e. the settlement point data with the specification for the output file (Fig.4).

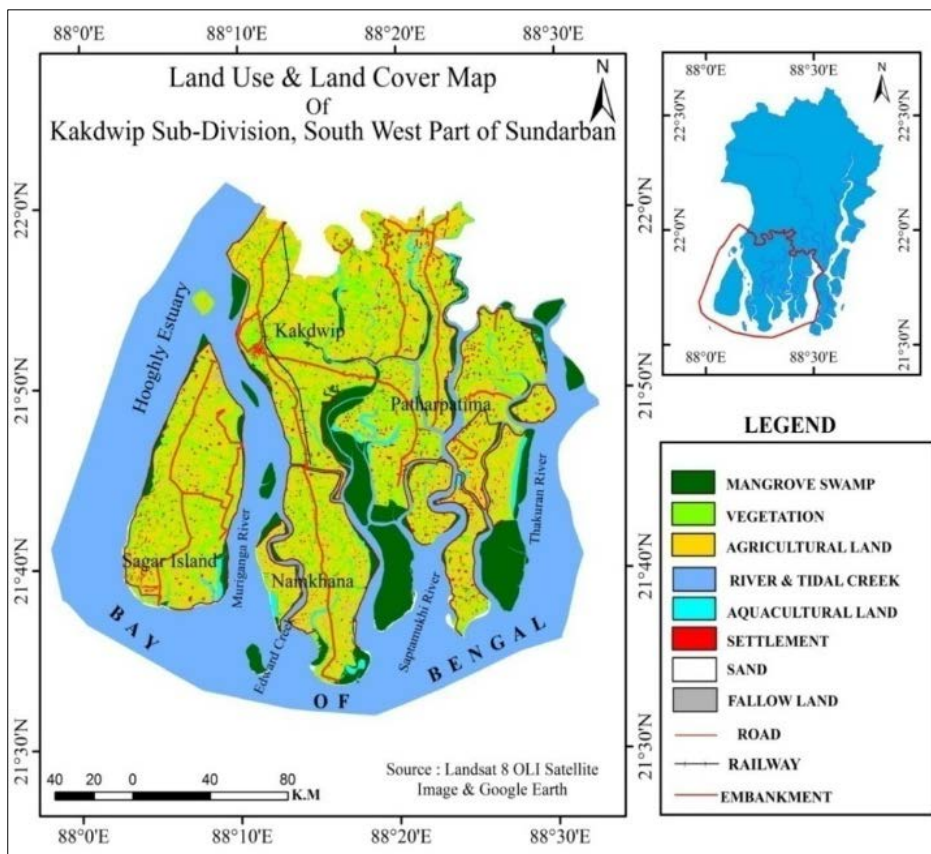


Fig 3: Land Use and Land Cover (LULC) criteria of the study area

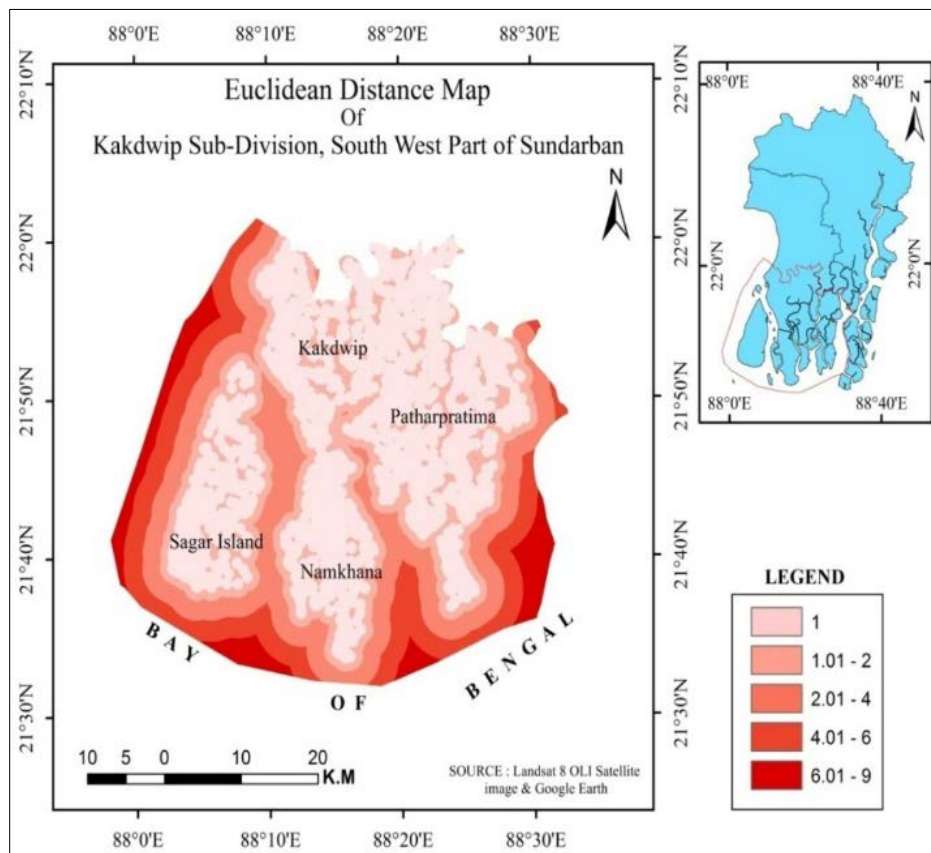


Fig 4: Euclidean distance criteria of the study area Slope

The slope map is done with the help of the DEM generated from Google earth image with import into Arc GIS as point data in degree decimal for (latitude and longitude) , z in meters coordinates have been added with the help of TCX converter. It

was used to produce Triangulated Irregular Network (TIN) model and finally this TIN has been converted to raster model in 3D analyst tools. The TIN to raster model was used to produce a slope map in degree (Fig.5).

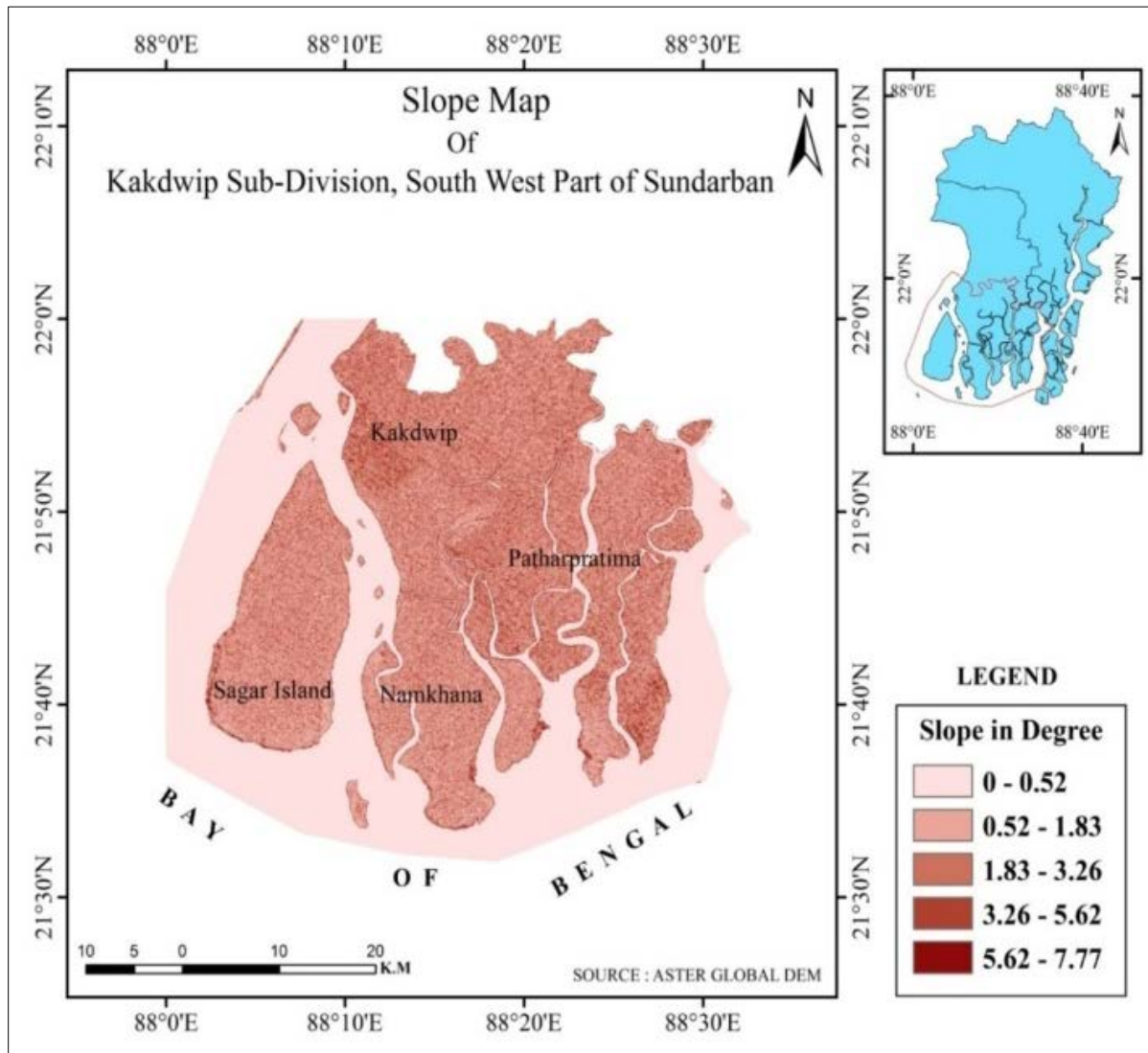


Fig 5: Slope map criteria of the study area

Reclassified Classes

All reclassification methods are applied to each cell within a zone, i.e. when applying an alternative value to an existing value; all the reclassification methods should be applied to each cell of the original zone. No reclassification method applies alternative values to only a portion of an input zone (Sinha-2006). For the effective utilization of this data in weighted overlay analysis it was reclassified from eleven (11) classes of equal interval to eight (08) classes of equal interval for reclassification. The eight classes were ranked with ranking highest as aquaculture land and the lowest rank is considered as sand.

In case of Euclidean Distance, the effective utilization of this data in weighted overlay analysis was reclassified from the reclassify tool into nine (09) classes of equal interval. The classes were ranked with areas closer to settlement as least suitable with rank

1 while farthest distance from settlement as most suitable with rank 9. This condition applied because we want suitable site for aquaculture that will be away from settlements.

The reclassify tool was used to reclassify the model of Slope into equal classes of equal interval as the slope angle (0-0.52 degree) assigning rank 1 as least being not suitable areas and of slope (5.62-7.77 degree) with rank 8 as most suitable areas. The lowest angles of slope occur in the river and as such it was rank 8 its suitable aquaculture sites to be located in the river. After accumulating these three criteria i.e. Reclassified LULC, Reclassified Euclidean distance & Reclassified Slope, the final site suitability mapping has been done for the identification of the suitable sites for fishing (Fig.6). In this study, Remote Sensing and GIS technology was utilized to determine suitable site for aquaculture in South West part of Sundarban.

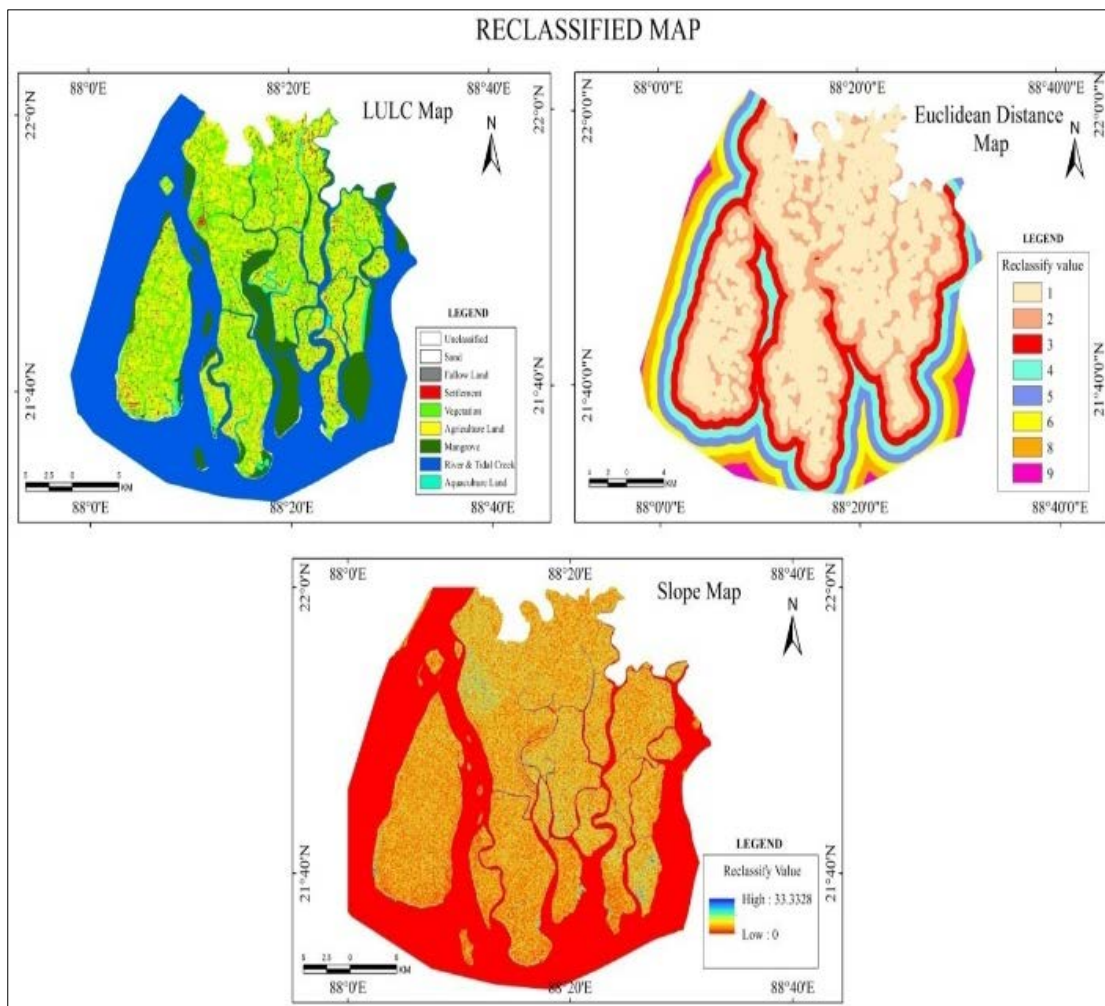


Fig 6: Reclassified Rasterization criteria maps of LULC, Euclidean Distance & Slope

Pairwise Comparison Method

In the context of the Analytic Hierarchy Process (AHP), the pairwise comparison method was developed by Saaty (1990)^[17, 18] which involves the pairwise comparison for creation of a ratio matrix. It acts as an input for the pairwise comparisons and produces the relative weights as output, which are determined by the normalizing Eigen vector associated with the maximum eigen vector of the ratio matrix consisting of three major steps by Jacek Malczewski i.e. i. Generation of the pairwise comparison matrix ii. The criteria weight computation & iii. The consistency ratio estimation. The Lambda (λ) value for the generation of pairwise

comparison matrix can be selected on the basis of number of criterions depending on the choosing of the number of evaluation criteria. However, for the present study only three criterions are considered for generating the Lambda (λ) value which is 3.051215 (Table.4). The formula for the generation of Consistency Ratio (CR) is,

$$CI = \frac{\lambda - n}{n - 1}$$

$$CR = \frac{CI}{RI}$$

(where, $\lambda = 3.051215$ $CI = 0.025608$ $CR = 0.044151104$)

Table 4: Generation of the Pairwise Comparison matrix analysis for multi criteria evaluation criteria map

Pairwise Comparison of the Evaluation Criteria				
Criteria	LULC	Euclidean Distance	Slope	
LULC	1	6	4	
Euclidean Distance	0.16666667	1	5	
Slope	0.25	0.2	1	
Total	1.41666667	7.2	10	
Deterministic of the Relative Criteria Weight				
Criteria	LULC	Euclidean Distance	Slope	Weight Estimation
LULC	0.705882353	0.833333333	0.4	0.646405229
Euclidean Distance	0.117647059	0.138888889	0.5	0.252178649
Slope	0.176470588	0.027777778	0.1	0.101416122
Deterministic of the Consistency Vector				

Criteria	LULC	Euclidean Distance	Slope	Consistency Vector
LULC	0.646405229	1.513071895	0.4056645	3.968318166
Euclidean Distance	0.107734205	0.252178649	0.5070806	3.438012959
Slope	0.025354031	0.05043537	0.1014161	1.747314715
Estimation of the Consistency Ratio				
Estimation of Lambda(λ)			3.051215	
Consistency Index (CI)			0.025608	
Consistency Ratio (CR)			0.044151104	

Weighted Overlay Analysis

After the generation of pairwise comparison matrix, finally the weighted overlay analysis has been generated for the identification and demarcation of the suitable sites for fishing zones. The three factors mainly used in this weighted overlay analysis are Land Use & Land Cover (40%), Euclidean distance (40%) from settlements, and Slope map (20%) which has been

given weightages on the basis of the most suitable location for fishing zones (Fig.7, Table.5). Weighted overlay analysis method enables factor to combined and weighted to solve multi Criteria decision (with special reference to SDSS) problems for the case of selection of Site Suitability analysis for aquaculture in fishing zones.

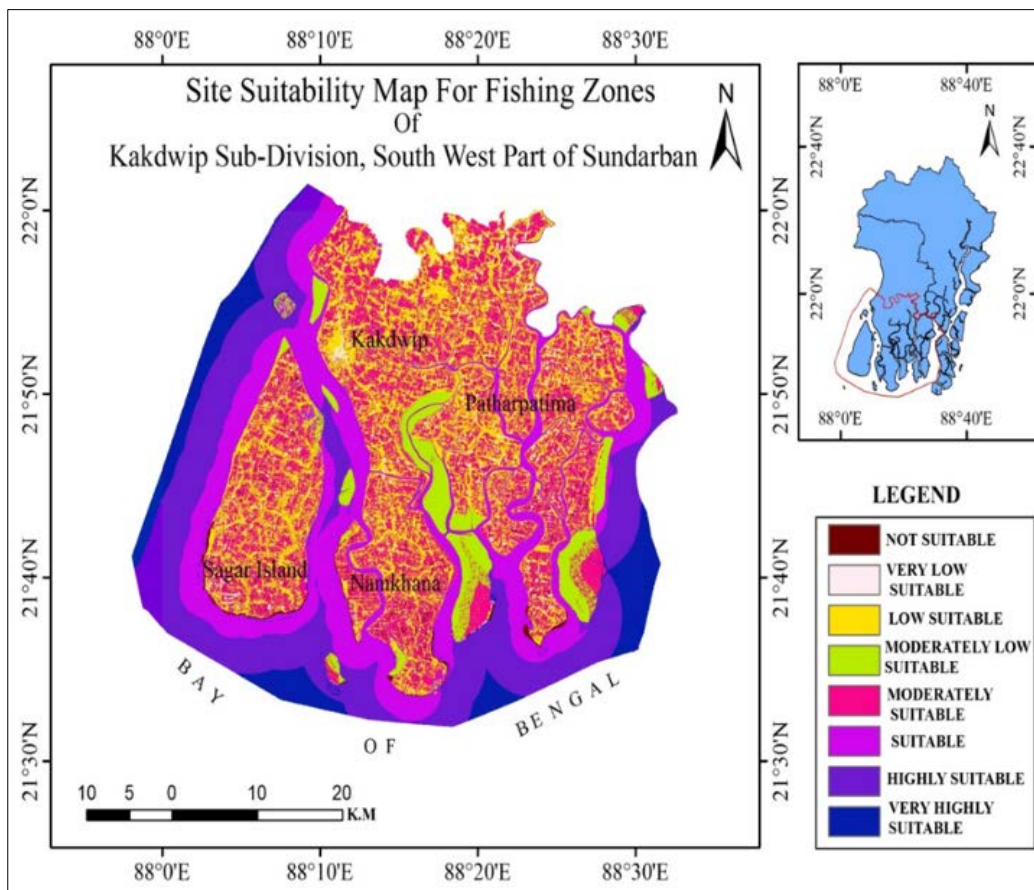


Fig 7: Site Suitability Analysis for fishing zones

Table 5: Calculation of Area and Percentage of Suitable areas of fishing zones

Sl. No.	Class Name	Total Area (Sq. Km)	% of Area
1	Not Suitable	22.17	0.99
2	Very Low Suitable	56.46	2.53
3	Low Suitable	120.76	5.38
4	Moderate Low Suitable	182.06	12.57
5	Moderate Suitable	269.29	11.99
6	Suitable	421.88	18.79
7	Highly Suitable	431.21	19.21
8	Very Highly Suitable	641.59	28.58



Fig 8: (a) Inland fish aquaculture in the coastal fringe sore face areas of G-plot Island; (b) Seasonal fish culture productivity of inland fishing; (c) Field experiment to the study the soil physiochemical parameters in the aquaculture; (d) Available commercial fish productivity in the local market of Fraser ganj fishing harbor

Conclusion

The present study draws following conclusions regarding the potential site suitability classes for fishing and fisheries in the part of the Sundarban. The Site Suitable Map for fishing is classified into eight different classes representing the degree of suitability for fish farming. The suitability map is ranked from the not suitable of 22.17 sq.km with class value 1 and very highly suitable of 641.59 sq.km with class values 8. Following the result of the output map, it is concluded that the most suitable sites are located around the seashores and mangrove forest fringes of the Sundarban. However, the areas adjacent of tidal creeks and remaining wetlands near reclaimed Sundarban, indicated as moderate suitable land for fisheries (Fig.8). The low suitable zones are lying within the inner parts of reclaimed Sundarban with village ponds and abandoned river valleys. Finally the attempt should be taken by the administrators to protect and preserve the potential zones of fisheries for the coastal society by zoning their restrictive uses.

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