Soil spatial analysis for Agricultural land use optimization using Geostatistical techniques in Sagar Island, West Bengal

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Abstract

For the agriculture planning and sustainable crop production, understanding the soil fertility status is very necessary. The present study has been conducted in the coastal saline agro-ecological environment of Sagar Island, West Bengal for to evaluate the status of surface soil and soil site suitability region. To delineate the soil suitability region for more crop production using GIS-based Multi-Criteria Decision Approach, eight soil fertility parameters such as soil texture, soil pH, electrical conductivity, soil depth, organic content, Nitrogen (N), Phosphorus (P) and Potassium (K) has been analyzed and categorized as highly, moderately, marginally and not suitable . An Analytical Hierarchical Process (AHP) has been used to rank the various suitability factors and the resulting weights used to generate the suitability map layers using weighted sum overlay techniques in Arc GIS 10.1 platform. The findings revealed that about 20.04% (4673.67 ha) of studied area are classified in highly suitable, 33.94% (7914.41 ha) in moderately suitable, 32.51% (7582.43 ha) in marginally suitable and 13.51% (3150.94 ha) not suitable for sustainable intensive agriculture. Findings from the study can be harness in increasing crop area diversification and intensification with appropriate irrigation and crop management practices in Sagar Island and similar such coastal Islands.

Keywords Soil suitability; Multi-criteria decision analysis; Analytic hierarchy process; weighted overlay analysis; soil quality

Introduction:

To increase food production and supply food security, crops must be grown in the areas where they are best suited. To achieve this, the first and foremost requirement is that of land suitability analysis (Kihoro et al., 2013; Molla et al, 2020). The method of land suitability analysis measures the degree of suitability of land for certain use and identify the main limiting factors of crop production (Halder, 2013; Molla et al., 2020). Land suitability analysis is the capability of a tract of land for more production of crops in a sustainable method. It is a function of crop requirements (Mustafa et al. 2011) and is a measure of how the properties of a land unit match the requirements of a particular form of land use (FAO 1976). Agriculture shares about 40 percent of the gross national product (GNP) and provides livelihood to about 70 percent of the population in India. Rainfed agro-ecosystem holds a high position in Indian agriculture (Lal 2008). About two-thirds (67 percent) of the country's cropped area is under rainfed agriculture. The efficiency of rainfed crop production depends on many factors including suitable climatic conditions, slope of land, suitable soil nutrients, etc. In India, weather plays an important role in crop yield since extreme conditions like flood, drought, etc.

Soil suitability analysis has been used by several researchers for different crops such as rice, barley, wheat, maize, Potato rapeseed, sugarcane, sunflower, pea, and soybean etc. (Bhagat et al., 2009; Kumar et al., 2010) with different methods or approaches either in considering input factors containing soil properties or suitability rating and matching procedures etc. (Sys et al., 1991b ; Sys et al., 1991a , p. 274&Sys et al., 1993, p. 199). Land suitability evaluation refers to the assessment of the capacity of the land for a specific use (FAO, 1976). Despite many limitations, FAO soil bulletins 32 (1976) and 55 (1985) for land assessment are still the most widely used in soil site suitability evaluation due to their straight forward approach with applications to simple models (Bagherzadeh & Danesh var, 2011).

Investigating the suitability of a field for farming requires substantial effort in terms of information collection that presents both opportunities and limitations for decision-makers for sustainable agriculture planning. Any scientific crop planning requires a comprehensive detailed inventory of soils that relate to their physical, chemical, hydrological, and site-specific properties (Dent and Young 1981). Geographic information systems (GIS) have reduced the complex of interpretation of huge multidisciplinary soils, land use, agriculture and socio-economic data (Burrough et al. 1986; Maji et al. 1998). This makes it possible for the processing of spatial and non-spatial data generated by remote sensing databases and traditional methods to prepare action plans for the development of a region (Maji et al. 2005). So far some studies have been done to suggest soil and water conservation measures, alternative uses etc. based on watersheds through GIS (Obi Reddy et al. 2008; Rao et al. 1997; Maji et al. 1998, 2002).

Soil is the most significant natural resource for crop growth and socio economic development of human (Gandhi & Savalia, 2014). Crop farming is not important without knowing the inherent potential of a specific location due to soil health as well as productivity decline and soil health deterioration (Gandhi & Savalia, 2014; Naidu et al., 2006). Crop farming considering soil specific location capacity optimizes the use of soil resources while maximizing marginal returns (Choudhury et al., 2013). In soil site suitability analysis, some fundamental adaptive properties (such as soil texture and nutrient, Bandyopadhyay, Maji, Sen, & Tyagi, 2003 , p. 62, life subsistence and availability, Electrical conductivity, organic carbon, pH, and soil resiliency; balance between restoration and degradation process)are overemphasized because of their high controllability over cropping systems, despite other ecological characteristics (Bhagat et al., 2009; Dharumarajan & Singh, 2014; Kumar et al., 2010; Naidu et al., 2006). Soil site suitability assessment helps in selecting suitable cultivated crops for specific soil units to optimize crop productivity (Naidu et al., 2006).

The present study aimed at performing the soil site suitability assessment by adopting some relevant FAO principles (FAO 1978, 1994, 1996) in addition to using remote sensing and GIS techniques and delineate the suitable zones for sustainable crop production at best suited area (O. sativa) based on selected parameters of production as per FAO guidelines (FAO 1978, 1994, 1996). The current examination will be most useful, especially to encourage farmers to grow the appropriate crops in their fields. MCE is a modern and emerging technique in GIS to handle such limitations for GIS-based decision making (Pereira et al. 1993). The use of MCE and GIS techniques emerges to a large extent in soil suitability analysis. Many researchers used this approach over different parts of the globe including Beni-Moussa irrigated subperimeter (Barakat et al. 2017), Kumaon Himalayas (Surya et al. 2020), black soil region of Central India (Walke et al. 2012), Tadla plain (Morocco) (Ennaji et al. 2018) and northeastern part of the Nile Delta (AbdelRahman and Arafat, 2020) etc.

Materials and methods:

General description of the study area

The selected study area Sagar Island (also known as Ganga Sagar) located on the continental shelf of Bay of Bengal about 150 km (80 nautical miles) south of Kolkata, in West Bengal. Sagar Island is the gargantuan low-lying archipelago setting in the utmost southern end of Sundarbans region extended from 21° 37′ 20″ N to 21° 52′ 28″ N latitude and 88° 2′ 17″ E to 88° 10′ 25″ E longitude, with an elevation range of 2.5–3.5 m above mean sea level (Figure 1). Size of the island is shrinking over the periods due to sea level rise and geomorphic submergence (Lakshmi and Patterson, 2010; Chand et al., 2012). The Island faces many natural calamities such as heavy coastal erosion (Bandyopadhyay, 1997; Gopinath, 2010), the intrusion of saline water (Majumdar and Das, 2011), frequent cyclones and depressions for the past 120 years (Chand et al., 2012). There are 42 villages in the island ecosystem which are distributed among eight gram panchayats (GP). Each village occupies an average of 673 ha area, 4847 population, 820 households and 418 cultivators. At present the total geographical area (GA) of the Island is about 23834 ha and the length of the coastal periphery is about 67.8km. Nearly 61% of GA (14618 ha) is under agricultural production system, majority (11089 ha; 46.5% GA) of which is under rain-fed low land rice cultivation. Only a small proportion of area (3529 ha; 14.5% GA) is under double cropping system. During winter season widely cultivated crops are *boro* rice (irrigated rice) chilli, potato, khesari (grass pea), mustard, sunflower and lentils etc. Lack of irrigation support and proper information on soil properties are the major constrains for the expansion of double cropping system (Mandal and Choudhury, 2014).

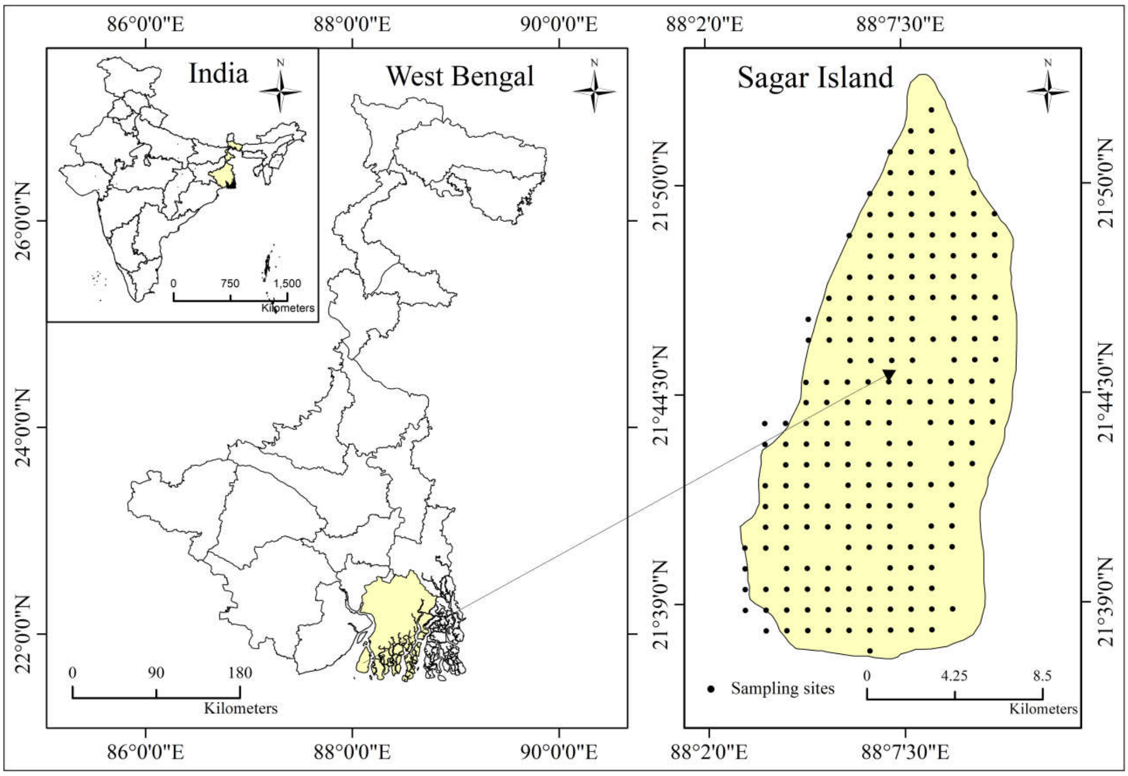

Figure 1 Geographical location of the study area

Data sources

The present study analyzed the soil site suitability for sustainable intensive agriculture in Sagar Island using GIS-based multi-criteria decision making (MCDM) application. The FAO frame work on land evaluation (FAO, 1976& "Guidelines in land evaluation for rain fed agriculture," 1983) customized by Naidu et al., 2006 had been adopted for soil suitability evaluation. Different parameters including soil texture, soil pH, electrical conductivity, soil depth, organic carbon content, Nitrogen (N), Phosphorus (P) and Potassium has been taken for the present study (Table 1). The climatic parameters has been considered as spatially homogeneous in nature because of the smaller spatial extensions of the Island and thereby, excluded from the analysis. Similarly, the soil slope (varied from 0 to 3%) and stoniness (nil) was considered as non-limiting factors of production hence, not considered.

Table 1 Materials and data source of the parameters

Materials	Data source
Toposheets map	79C/1, 79C/2; RF 1:50,000; SOI
Soil texture	Soil Testing Lab, RAKVK, Nimpith (ICAR)
Soil depth	indiawaterportal.org
Soil pH	
Electrical conductivity	

Organic content	National Bureau of Soil Survey and Land Use Planning (NBSS & LUP)
Nitrogen (N)	
Phosphorus (P)	
Potassium (K)	
Experts' opinions	Literature survey &local agronomist knowledge

Methodology

To fulfill the objectives of present study, Remote Sensing and GIS technique has been used to identifying suitable soil sites for sustainable intensive agriculture following six steps: (1) selection of criteria, (2) Generation of thematic maps using interpolation (IDW), (3) standardization of criteria (Reclassify), (4) weight calculation to criteria and each sub-criteria using pairwise comparison matrix (PCM), (5) weighted overlay analysis, and (6) soil site suitability map. The overall methodology is mentioned in **Error! Reference source not found.**.

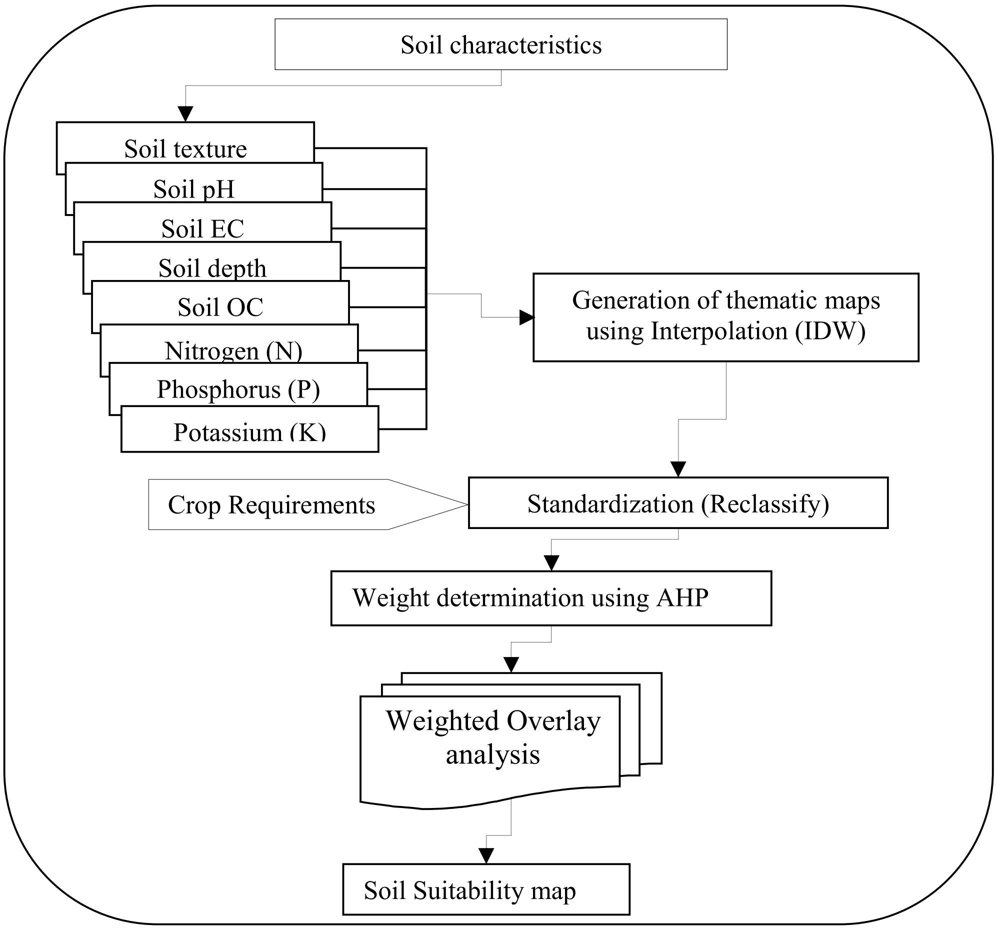

Fig 2 Flowchart of the methodology prepared by authors

Generation of criterion maps using geospatial techniques

In this study, eight variables namely, soil texture, soil pH, soil electric conductivity, organic carbon content, Nitrogen (N), Phosphorus (P), Potassium (K) and soil depth (cm) (Figure 3a, 3b, 3c, 3d, 3e, 3f, 3g and 3h respectively) have been considered as specific crop requirement factors to identify soil site suitability according to the FAO guidelines (1976) (

Table **5**). Criteria maps for Soil texture (Figure 3a) and soil depth (Figure 3h) were geo-referenced and area of interest (AOI) was extracted; subsequently vector layers were produced through on-screen digitization and these vector layers were rasterized through conversion tool in Arc GIS 10.1 software. Thematic layers of soil pH, electrical conductivity of soil, organic carbon content, nitrogen (N), phosphorus (P) and potassium (K) (Figure 3b, 3c, 3d, 3e, 3f, and 3g) is generated using point data that was in the excel sheet which later transformed into shape files and applied inverse distance weightage (IDW) in the GIS environment to calculate the spatial distribution in the study area.

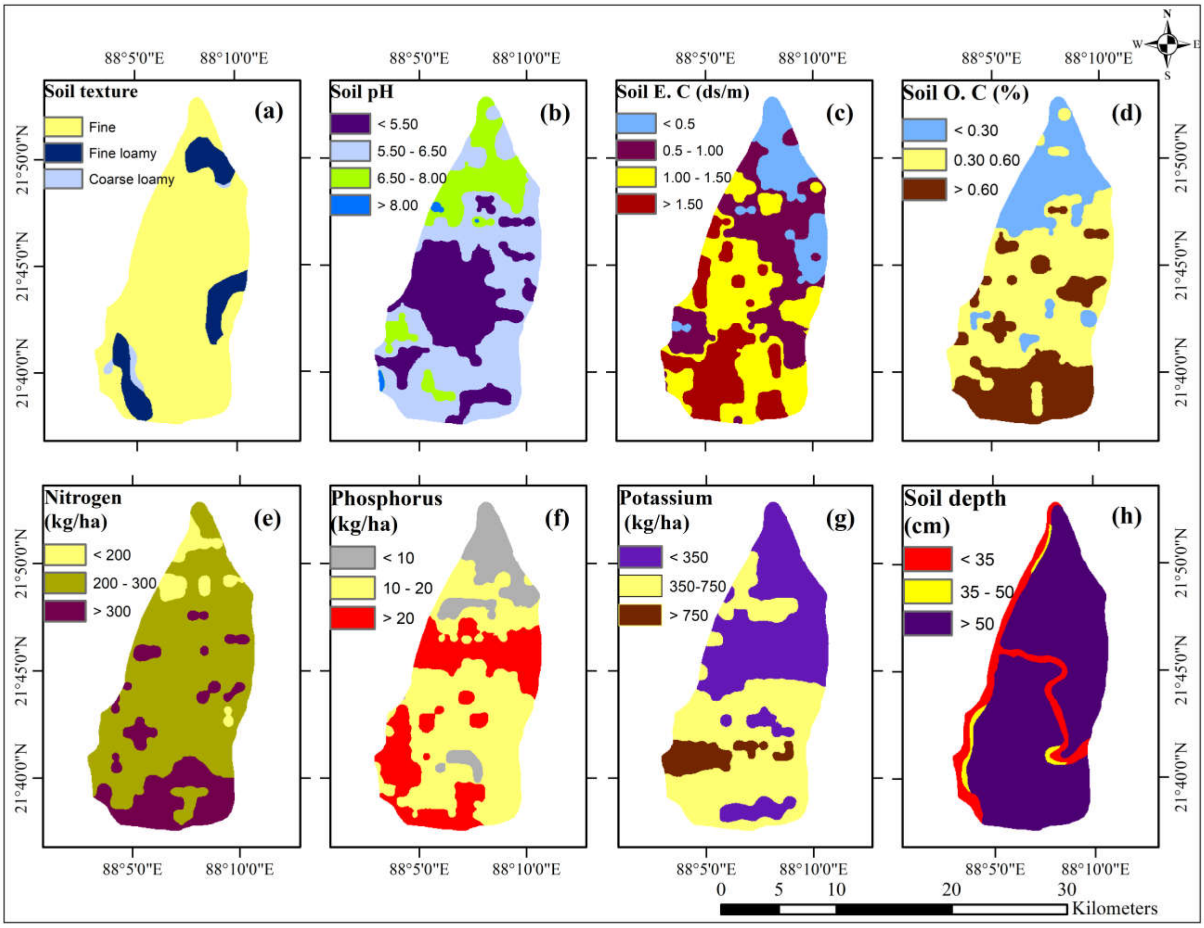

Figure 3 Spatial distribution of soil physic-chemical properties: (a) soil texture (b) soil pH (c) electrical conductivity (ds/m) (d) Organic carbon (%) (e) Nitrogen (kg/ha) (f) Phosphorus (kg/ha) (g) Potassium (kg/ha) (h) soil depth (cm)

Standardization of selected criteria maps

All of the selected criteria are in different units so executing the weighted overlay method requires converting them to the same units and therefore a standardized value. The standardization technique converts measurements into uniform units, and the resulting score is lost along with its dimension as well as the measurement unit of all criteria (Effat and Hassan 2013). The vector layer of all criteria maps has been converted to raster layer which shown in Figure 3. After that, all raster layers were reclassified and used for the input data to the weighted overlay method which finally create the soil suitability map for agriculture. Reclassify method in spatial analyst toolbox of Arc GIS 10.1, standardizes the value of all selected criteria for the analysis of comparative significance based on local agronomist knowledge and extensive literature survey (

Table **5**).

Weight derivation

In multi-criteria decision-making purposes, researchers extensively used the GIS platform with the AHP method (Joerin et al. 2001; Xu 2012). This semi-quantitative method was introduces by Thomas L. Saaty in (1977) to develop a hierarchal model for elaborating complex problems of land management with the most suitable alternatives (Malczewski 2006). AHP allows the inclusion of GIS-based land suitability modeling for site suitability (Alshabeeb 2016). The analytical hierarchy process gives a structural basis for determining the strong comparison of design criteria and elements in a pairwise technique and thereby reduces the complexity of the decision-making process (Miller et al 1998; Saaty 1977).

Table 2 Fundamental scale for pairwise comparison (Saaty 1980)

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one activity over another
5	Strong or essential importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	An activity is strongly favored and its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values	When compromise is needed
Reciprocals	Used for inverse comparisons	

Using the analytic hierarchy process the pairwise comparison matrix (PWCM) was calculated using the scale with values from 9 to 1/9 introduced by Saaty (1980). A rating of 9 indicates that in relation to the column factor, the row factor is more important. On the other hand, a rating of 1/9 indicates that relative to the column factor the row factor is less important. In cases where the column and row factor were equally important, they have a rating value of 1 according to saaty's underlying scale as shown in Table 2. After completing the pair-wise comparison matrix, each cell value i.e. performance score of each cell was divided by the sum of that specific criteria column to normalized the pairwise comparison matrix table (Table 4) (Saaty 1980; Feizizadeh 2014; Malczewski 1999). From the normalized matrix table, the relative priority value of each criterion was calculated using saaty's method. In this study, the eigenvector method was applied to estimate the weight of each criterion from the normalized pair-wise comparison matrices table (Table 4). After calculating the priority decision matrix, the ‘Weighted Sum Vector’ was estimated to find out the inconsistency among the parameters because there may be some inconsistency in the result due to random matrix formation (Saaty 1980, 1990, 1994). Equation 1 was used for estimating this inconsistency (Saaty 1980; Feizizadeh 2014; Garcia et al. 2014).

$$WSV = \sum_{j=1}^{n} wj * xij$$

Equation 1

where WSV = Weighted Sum Vector; wj = Weight of each parameter; xij = Performance Value of each criterion (from the primary pair-wise matrix).

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

Equation 2

Where: Lambda (λ_{max}) is the Maximum Eigen Value
CI: Consistency Index
CR: Consistency Ratio
RI: Random Index, which is the average of the resulting consistency Index depending on the order of the matrix given by Saaty (Saaty 1977) (see Table 3).
n: The numbers of criteria or sub-criteria in each pairwise comparison matrix.

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

Equation 3

A consistency ratio (CR) of 0.10 or less indicates a reasonable level of consistency (Saaty 1977). The symmetry of factors within each group, a smaller number of factors in the group, and a better understanding of the decision problem improves the consistency index (Saaty 1993). The value of the Consistency Index depends on the value of lambda (λ max). The larger value of lambda (λ max) indicates high inconsistency, i.e., with increasing the value of lambda (λ max), the ratio of inconsistency is also be increased and vice-versa. Consistency Index was calculated using Equation 3. The CR result for soil suitability was 0.0094 (

Table **5**), indicating that the comparison of land characteristics was completely consistent and the relative weight was chosen appropriately in this particular study.

All the numerical calculations of the individual parameter (eight parameters) as well as one class from the other within a single criterion are separately calculated and derived their weights using 'AHP' methods in Microsoft excel as shown in

Table **5**.

Table 3 Values of Random Index (R.I)

Order Matrix	1	2	3	4	5	6	7	8	9	10
R.I	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Table 4 Normalized pairwise comparison matrix and computation of criterion weights

Criteria	Texture	pH	Soil E.C	Soil depth	Organic Content	Nitrogen (N)	Phosphorus (P)	Potassium (K)
Texture	0.3349	0.4440	0.3112	0.3015	0.2548	0.2353	0.2424	0.2195
pH	0.1674	0.2220	0.3112	0.3015	0.2548	0.2353	0.2121	0.2195
Soil E.C	0.1674	0.1100	0.1556	0.2010	0.1911	0.1569	0.1515	0.1707
Soil depth (cm)	0.1163	0.0740	0.0778	0.1005	0.1911	0.1569	0.1515	0.1463
Organic Content	0.0837	0.0555	0.0519	0.0335	0.0637	0.1176	0.1515	0.1463
Nitrogen (N)	0.0558	0.0370	0.0389	0.0251	0.0212	0.0392	0.0303	0.0488
Phosphorus (P)	0.0419	0.0317	0.0311	0.0201	0.0127	0.0392	0.0303	0.0244
Potassium (K)	0.0372	0.0247	0.0222	0.0168	0.0106	0.0196	0.0303	0.0244

Maximum eigen value (λmax) = 8.3569
n = 8
Consistency index (CI) = (λmax - n)/(n-1) = 0.0510
Random index (RI) = 1.41
Consistency ratio (CR) = CI/RI
CR = 0.0510/1.41 = **0.0362**

Table 5 Standardization and detailed weights of criterion & sub-criterion obtained from AHP

Soil-site characteristics	Unit	Weight	CR	Sub-criterion (with ranges)	*Weight*	*CR*	References
Soil texture[a]	%	0.2930	0.0362	Fine (sc, sic, c)	0.3202	0.0158	IIASA and FAO, 2012
				Fine loamy (scl, cl, sicl)	0.5571		
				Coarse loamy (sl, l, sil)	0.1250		
Soil pH	in H_2O	0.2405		< 5.50	0.1219	0.0439	Barakat et al. (2017)
				5.50 – 6.50	0.2633		
				6.50 – 8.00	0.5579		
				> 8.00	0.0569		
Electrical conductivity	(ds/m)	0.1630		< 0.50	0.4824	0.0054	Raza et al. (2018)
				0.50 – 1.00	0.2718		

			1.00 – 1.50	0.1575		
			> 1.50	0.0883		
Soil depth	cm	0.1268	< 35	0.1199	0.0639	Dengiz (2013)
			35 – 50	0.2721		
			>50	0.6080		
Organic Content	%	0.0880	< 0.30	0.1285	0.0048	Hossain et al. (2001)
			0.30 – 0.60	0.2766		
			> 0.60	0.5949		
Nitrogen (N)	Kg ha^{-1}	0.0370	< 200	0.2611	0.0463	Manda et al. (2020)
			200 - 300	0.3278		
			> 300	0.4111		
Phosphorus (P)	Kg ha^{-1}	0.0289	< 10	0.1976	0.0462	Manda et al. (2020)
			10 – 20	0.3119		
			> 20	0.4905		
Potassium (K)	Kg ha^{-1}	0.0232	< 350	0.1061	0.0332	Manda et al. (2020)
			350 – 750	0.2605		
			> 750	0.6333		

[a] sc- sandy clay, sic- silty clay, C – clayey; scl- sandy clay loam, cl-clay loam, sicl- silty clay loam; sl- sandy loam, l- loamy,sil- silty loam

Soil site suitability zone for agriculture using weighted overlay analysis

In order to overlay the map layers weighted sum overlay techniques have been applied. A weighted overlay is a technique for applying a common scale of values to diverse and diffuse input data to create a unified analysis (Kuria et al. 2011). In this study, individual map layers as well as each sub-layer within a criterion were separately weighted according to their importance using the AHP process presented earlier (

Table **5**). After assigning weights, all the raster layers and classes were overlaid to obtain the soil suitability map for sustainable intensive agriculture (Equation 4) (Figure 4).

$$S = \sum_{i=1}^{n} Wi\, Xi$$

Equation 4

where S represents suitability index for each map pixel, Wi is the weight of the ith criteria layer, Xi is the sub-criteria weight of the ith criteria layer, and n is the number of suitability layers (Elaalem et al. 2010). The above formula is applied to each thematic layer. The analysis was carried out using weighted sum overlay techniques in ArcGIS 10.1. In the overall outcome, the higher "S" value indicates the higher soil suitability for agriculture.

Results and Discussion

Description of factor maps

The main soil physic-chemical properties used for generation of the thematic map layers which used in MCDM process for generating the soil suitability map are discussed here under (Table 6).

Table 6 Areal and percentile distribution of the selected criteria and sub-criteria in the study area

Soil-site characteristics	Sub-criterion (with ranges)	Area (ha)	Area (%)
Soil texture	Fine (sc, sic, c)	20327.49	87.18
	Fine loamy (scl, cl, sicl)	2054.97	8.81
	Coarse loamy (sl, l, sil)	1371.28	5.58
Soil pH	< 5.50	7950.78	33.47
	5.50 – 6.50	11586.02	48.77
	6.50 – 8.00	4072.95	17.14
	> 8.00	147.41	0.62
Electrical conductivity	< 0.50	3714.39	15.64
	0.50 – 1.00	6854.39	28.85
	1.00 – 1.50	8442.95	35.54
	> 1.50	4744.85	19.97
Soil depth (cm)	< 35	2858.68	12.03
	35 – 50	475.85	2.00
	>50	20420.09	85.96
Organic Content	< 0.30	5324.42	22.41
	0.30 – 0.60	11744.06	49.43
	> 0.60	6692.52	28.17
Nitrogen (N)	< 200	1349.15	5.68
	200 - 300	17200.02	72.40
	> 300	5207.91	21.92
Phosphorus (P)	< 10	3487.22	14.68
	10 – 20	13012.30	54.76
	> 20	7262.13	30.56

Potassium (K)	< 350	10281.64	43.27
	350 – 750	11729.47	49.37
	> 750	1748.81	7.36

Soil texture

Many soil properties (EC, pH, soil composition, nutrients, microbial biomass) depend on soil texture, one of the important parameters of soil (Mustafa et al. 2011; Aderonke and Gbadegesin 2013; Bhagat 2014). Majority of the arable land dominated by fine soil (87.18%), followed by fine loam (8.81%), distributed in the north-eastern and south-western part, and coarse loam (5.58) with small pockets located in the southwestern part of the island (Figure 3a) (Table 6).

Soil pH

Soil pH provides information about solubility for the possible availability of elements for crops which is very useful in soil suitability assessment and management. The wide variation has been seen in soil reaction of selected study area i.e. from extremely acidic (pH: 3.94) to moderately alkaline (pH: 8.45). Though the majority of the area (48.77%) falls under slightly acidic to near neutral in reaction (pH: 5.50 – 6.50) and this zone will be conductive for nutrient availability for crop intensification since most plant nutrients are readily available in this range of soil pH (Figure 3b) (Table 6).

Electrical Conductivity (EC)

Soil salinity refers to the presence of soluble salts within the root zone. The soluble salt content is examined in terms of electrical conductivity (EC). Salt soils negatively affected plant growth in several ways. In addition to specific ion toxicities such as Na, Cl and B; causing direct injury to plants. The spatial variability of EC is given in Figure 3c which showed that 35.54% is marginally suitable for agriculture, 28.85% moderately suitable, 15.64% highly suitable and 19.97% was not suitable in the study area (Table 6).

Soil depth

The depth of soil is important for plant growth because it provides the foothold to the plant to pull the necessary water and nutrients from ground water. Deep soil has more room for roots than shallow depth soil. Crop growth and yield at soil depth are highly reliable. In fact, in the island, most areas (85.96%) are soil depths> 50 cm (Figure 3h), based on soil information (Table 6).

Organic Content (OC)

Soil OC is a key feature of measuring the sustainability of crop management related to a carbon source and its engagement with nutrients. It is positively correlated with crop yield due to its beneficial contribution to soil properties (Bennett et al. 2010). However, the spatial distribution pattern of organic content in the selected study area showed that approximately 22.41% was recorded low (<0.30%), 49.43% medium (0.30 - 0.60%) and 28.17% found high (> 0.60%) (Figure 3d).

Nitrogen (N)

The available Nitrogen (N) in the surface soil varied from 131.98 kg/ha to 445.3 kg/ha, with an average content of 266.17 kg/h across the study area. Majority of the soils over the Island (54.76%) has been reported medium in available N content (200 - 300 kg/h), while only 21.92% found high (>300 kg/h) (Table 6). The spatially explicit nitrogen distribution map showed that the middle range (200–300 kg / hr) of available N is concentrated in parts of the entire central (Bishunpur, Purushottampur and Kirtankali) islands (Figure 3e). The high availability of nitrogen increases the suitability of the soil to grow many crops.

Phosphorus (P)

Island soils were high in available P content with an average content of 18.34 kg / hr, although wide variations have been observed (3.6 - 78.20 kg / hr). A large number of area (54.76%) in the island occupied by 10–20 kg / ha of phosphorus content which is distributed in the south-central part of the island (Figure 3f) (Table 6). Dominance of low land paddy based system keeps soil under near saturation, thus, results in anaerobic geo-chemistry, which occasionally favors the P availability by increasing the mobility of P-fixing cations like iron, aluminum, and others through reduction process (Mandal et al., 2020)

Potassium (K)

Potash (K) available material has been found to be high in the soil of the island. The available K materials (350 - 700 kg / hr) has been reported a lot of soil (49.37%), which is concentrated in the southern and northeastern part of the island and the reason might be due to very high clay contents or may be attributed to the prevalence of potassium-rich minerals like illite and feldspars (Table 6&Figure 3g).

Soil site suitability map

In order to generate the soil suitability map for sustainable intensive agriculture, the weights of each indicator and each of their sub-classes also has been calculated using AHP multi-criteria analysis are listed in Table 7. After assigning weight, the soil quality map of the study area has been generated to superimposition of all thematic raster layers using the weighted sum overlay analysis (Figure 4). The land soil suitability map has been classified into four categories (Figure 4) including highly, moderately, marginally suitable and not suitable which showed that 4673.63 ha (20.04%) is found highly suitable, 7914.41 ha, (33.94%) moderately suitable, 7582.43 ha (32.51%) marginally suitability, and only 3150.94 ha (13.51%) recorded under not suitability (Table 7). Together, the highly suitable and moderately suitable categories make up about 53.98% of the total research area that could be recommended for intensive agriculture in the study area. Furthermore, 13.51% of the agricultural soil is determined as not recommendable for intensive agriculture (Table 7).

Based on consideration these results of physico-chemical properties of soil, it has been noted that the highly suitable areas are characterized by: textural class - Fine loamy (scl, cl, sicl), soil pH level between 6.50 – 8.00, electrical conductivity level < 0.50, organic carbon more than 0.75%, soil depth > 0.50 cm, NPK concentration > 300 kg/h, > 20 kg/h, above 350 kg/ha respectively and this zone is distributed across the northern portion (Kashtala, Sapkhali, Kachuberia, Muriganga, Shikarpur, Ramkrishnapur, Companirchar, Dhaspara, Bamankhali and Gobindapur mouza), middle-eastern (Debimathurapur, Kaylapara, Mrityunjaynagar and Sumatinagar mouza) and south-western portion (Mahismari, Gangasagar and Dhablat mouza) of the Island. Whereas, most of the not suitable areas is concentrated narrowly along the middle-east coast (Krishnanagr, Narharipur, Radhakrishnapur, Beguyakhali, Bankimnagar and Kirankhali mouza) characterized by intensive salt stresses with an upper threshold limit of 3.00 ds/m, pH levels less than 4.5 or more than 8.5, textural classes as course loamy, shallow soil depth, lack of NPK concentration on soil and almost zero resource of ground water for irrigation which undoubtedly reduce the fertility and ability of the soil to sustain crop growth and consequently minimize agricultural production.

It is true that the intensive agriculture contribute to meeting the increased global food demand, but it uses massive inputs (products and materials), and vast land. These methods of intensification are, over time, threat to the global environment through the loss of ecosystem services and global warming, emergence of new parasites, responsible for soil impoverishment, biodiversity degradation and deforestation. Furthermore, intensive farming kills beneficial insects and plants, creates polluted run-off and clogged water system, increase susceptibility to flooding. An alternative to these negative effects seems to be sustainable agricultural land that requires the identification of the best agricultural land according to their potential to sustain soil works and eco-friendly agriculture. Specifically, agricultural activity must be practiced in the suitable lands where they suit best and foremost and only if they are really required permits the use of inputs in a reasonable way.

Table 7 Area under different level of soil site suitability for sustainable intensive agriculture

Suitability degree	Intensity of suitability	Area (ha)	Proportion (%)
S1	Highly suitable	4673.63	20.04
S2	Moderately suitable	7914.41	33.94
S3	Marginally suitable	7582.43	32.51
N	Not suitable	3150.94	13.51

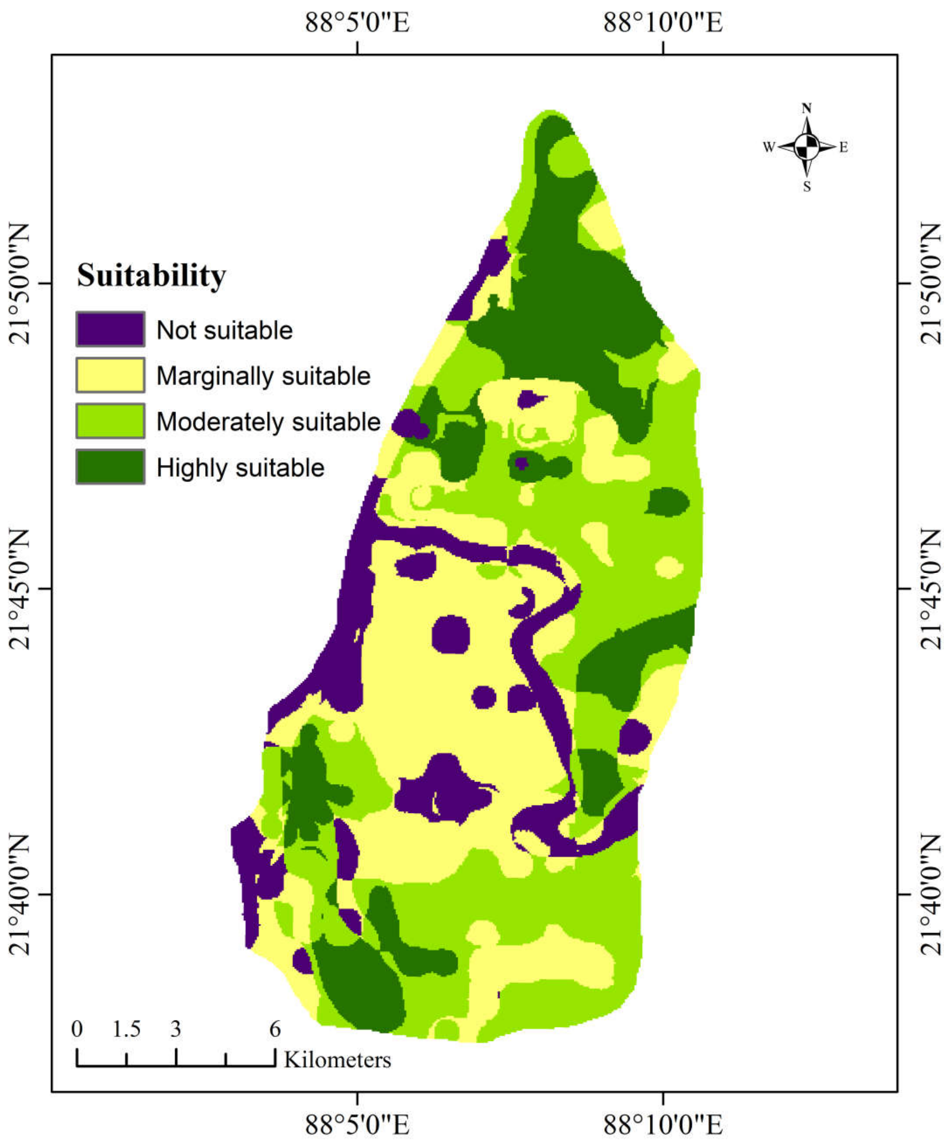

Figure 4 Overall potential soil suitability map

Conclusion

This study investigated the characterization of the soil properties and its spatial variability in the agrarian ecosystem of coastal saline Island using remote sensing GIS environment and AHP approaches. The map of soil suitability for agriculture has been generated based on a set of indicators, namely soil texture, pH, EC, OC, soil depth, and NPK concentration. AHP approach has been applied to derive the weights of indicators and sub-indicators to account their influences in selecting suitable land for intensive agriculture. The results indicate that 20.04% has highly suitability, 33.94% has moderate suitability, 32.51% has marginal suitability, and 13.51% of the study area has not suitability for a sustainable intensive agriculture. The following are some of the driving factors that have contributed to the formation of not suitable land for agriculture in the coastal Sagar Island are lack of irrigation facility, severe soil and water salinity, waterlogging during monsoon season, lack of climatic knowledge and soil site suitability base information to the farmers for precision farming and several climatic adversities like cyclone.

In concluding, the study demonstrated spatial information on site suitability can be used for crop area diversification and intensification plan in improving land productivity of the Island. The methodology can be used for other such similar agrarian small coastal Islands across Indian sub-continent.

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