Soil site suitability for sustainable intensive agriculture in Sagar Island, India: a geospatial approach

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Abstract
The procedure of examining the potential land use for intensive cultivation is known as soil site suitability evaluation. It refers to a method of assessing land that assesses how much of the area is potential for enhanced agriculture output. The objective of this work was to delineate the soil attributes and three-dimensionally changeability of soil in the agrarian environs of the coastal saline area of Eastern India and to develop the site suitability of soil for agricultural output on FAO land suitability criteria based on Geospatial and Multi-Criteria evaluation method. Eight soil quality factors—texture, depth, pH, electrical conductivity (EC), organic carbon, nitrogen (N), phosphorus (P), and potassium (K)—were investigated and categorized into highly suitable (S1), moderately suitable (S2), Marginally suitable (S3) and not soil suitable (N) regions. The relevant suitability parameters were ranked using an Analytical Hierarchical Process (AHP), and the generated weights were employed to develop the suitable map layers in the Arc GIS 10.1 platform through weighted sum overlay algorithms. Soil suitability investigation reveals 20.04% as highly suitable, 33.94% as moderately suitable, 32.51% as marginally suitable, and 13.51% as unsuitable for sustainable intensive agriculture. Additionally, around 53.98 percent of the region is covered by the highly and moderately suitable ranges due to loamy textural class, ideal soil pH and high NPK concentration, which can be suggested for intensive agriculture in the selected study region. Furthermore, the marginal coastal areas have been rendered unsuitable for farming as a result of severe climatic catastrophes like cyclones, elevated saline soils and insufficient soil depth. Results of this research can be applied to advance crop management strategies throughout the study's targeted region and on the surrounding coastline Islands, which are diversifying and intensifying their agricultural production. Hence, an effective and appropriate tool for evaluating site suitability is the GIS-based AHP model. This can be utilized examine similar studies on coastal islands of the Indian Subcontinent.

Keywords Coastal soil quality parameter · AHP · Multi-criteria evaluation · Weighted overlay analysis (WOA) · Soil suitability

Introduction

The biggest hurdle to the improvement of agriculture-based nations like India is the lack of agricultural land, a problem that is getting worse every day due to the population's rapid increase in displacing available resources and land. Consequently, the best way to satisfy the needs of the expanding population is to boosting agriculture production (Halder 2019). Over 70% of Indians rely on agriculture for their livelihood, contributing about 40% of the country's GNP. Since India experiences harsh weather conditions including floods, droughts, etc., the weather conditions have a noteworthy influence on agriculture productivity. Soil is the most significant natural resource for food production and human socioeconomic progress (Dissanayake et al. 2019; Gandhi and Savalia 2014). Due to declining production, deteriorating soil health, and the intrinsic potential of a particular place, crop farming is not relevant without understanding these factors (AbdelRahman et al. 2018; Gandhi and Savalia 2014; Naidu et al. 2006). Soil-specific site capacity is considered in crop farming that optimizes marginal returns while maximizing the use of soil resources (Choudhury

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et al. 2013). Numerous soil and water treatment difficulties related to ecological, agricultural and environmental problems require an understanding of soil hydraulic characteristics (Saha et al. 2021). It is vital to comprehend changes in soil and croplands, hydrological properties of soil, dams, and grasslands using Geographic Information System technology (Khairy 2021). Additionally, soil-specific suitability screening is useful for selecting cultivable plants for certain soil units that would maximize farm output (Naidu et al. 2006). Some basic adaptation features, including soil texture and nutrients (Bandyopadhyay et al. 2003), life subsistence and availability, electrical conductivity, organic carbon, pH, and soil resiliency, as well as the balance between restoration and degradation processes, are overemphasized in soil site suitability analyses due to their high controllability over cropping systems, notwithstanding unalike ecological parameters (Bhagat et al. 2009; Naidu et al. 2006).

A better location and level of appropriateness of an agricultural region can be determined using agricultural land suitability assessment criteria in order to satisfy the rising population's desire for greater crop output and food to support agriculture (Chuma et al. 2022; Yalew et al. 2016). Crops must be cultivated in surroundings that are ideal for them if we are to boost food production and guarantee food sufficiency. The most crucial action to take in order to do this is to conduct a evaluation of land suitability (Kihoro et al. 2013; Molla et al. 2020; Moisa et al. 2022; Mandal et al. 2020).The ability of the soil to maintain agriculture land and its yields has been well-defined as a requirement for land capability and appropriateness. To define a management region with adequate land use for growing crops without long-term deterioration, the land suitability method can be an applicable strategy (FAO 2007; Klingebiel and Montgomery 1961; Field and Odgers 2016; Bandyopadhyay et al. 2009).

The land suitability modeling approach examines the level of a piece of land's appropriateness for a given use and determines the primary crop cultivation impediments (Halder 2013; Orhan 2021; De Feudis et al. 2021). It is based on necessary conditions of specific crop (Mohamed et al. 2016; Mustafa et al. 2011) and determines how efficiently the characteristics of a land unit meet the requirements for a particular agricultural function (FAO 1976; Ostovari et al. 2019). Land quality in agriculture can be determined by strong indicators of soil qualities such as texture, depth, OC, EC, pH, OM, and slope, among others, utilising a geospatial technique to give particular indicator maps and establish land suitability for intensive agriculture. Several studies have employed soil modelling for various crops (Kumar et al. 2010; Bhagat et al. 2009) with multiple alternatives such as examining input components containing soil attributes or compatibility grading or rating and corresponding systems, etc. (Sys et al. 1991a, b, 1993). Land suitability examination involves assessing a plot of land's

suitability for a particular use (FAO 1976). The most widely used manuals for land evaluation are currently FAO soil bulletins 32 (1976) and 55 (1985) for assessing the suitability of soil sites, despite their many shortcomings, because of their uncomplicated approach and use of basic models (Bagherzadeh and Daneshvar 2011). For those responsible for making decisions in the planning of sustainable agriculture, the time and effort required to obtain the data required to establish if a region is ideal for producing presents both opportunities and obstacles. An adequate inventory of soils that considers their physiological, biochemical, hydrodynamic, and geographical features is necessary for any scientific crop planning (Dent and Young 1981). It is now simpler to examine vast amounts of multidisciplinary soil, agriculture use, and socioeconomic data thanks to GISs (Geographic Information Systems) (Maji et al. 1998; Burrough 1986). As a result, it is possible to create a development strategy for remote sensing databases and for processing data obtained using traditional methods, both spatial and non-spatial (Maji et al. 2002, 2005). Numerous research conducted on this method in various regions of the world, notably Kumaon Himalayas (Surya et al. 2020), Beni-Moussa irrigated subperimeter (Barakat et al. 2017), 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. A hardly any investigations have used GIS and remote sensing to recommend potential zone for intensive agriculture in the Costal Island of Sundarban. Coastal zone management, particularly for agricultural purposes, is a very challenging element of a place such as Sagar Island, which is located close to the Ganga's estuary deltaic environment (Jayappa et al. 2006). Identifying optimal soil areas for agricultural productivity is critical in the coastal Island since it is densely populated and 61% of GA (14,618 hectares) is used for agricultural activity. As a result, the key objective of this endeavor was to:

1. the evaluation of soil characteristics and soil variation in the coastal saline agriculture environment Island
2. generate a Coastal soil site suitability map for agricultural production based on FAO land suitability criteria (FAO 1978, 1994, 1996)
3. provide recommendations for appropriate coastal soil for sustaining intensive agriculture production

The latest study will be very helpful, especially in motivating harvesters to plant the right harvests in their areas.

Basic info about the study area and goals

Sagar Island or Ganga Sagar, is the chosen research location which situated on the Bay of Bengal continental shelf, roughly 150 kms (80 nautical miles) south of Kolkata, West Bengal, India. Sagar Island is a massive close to the bottom
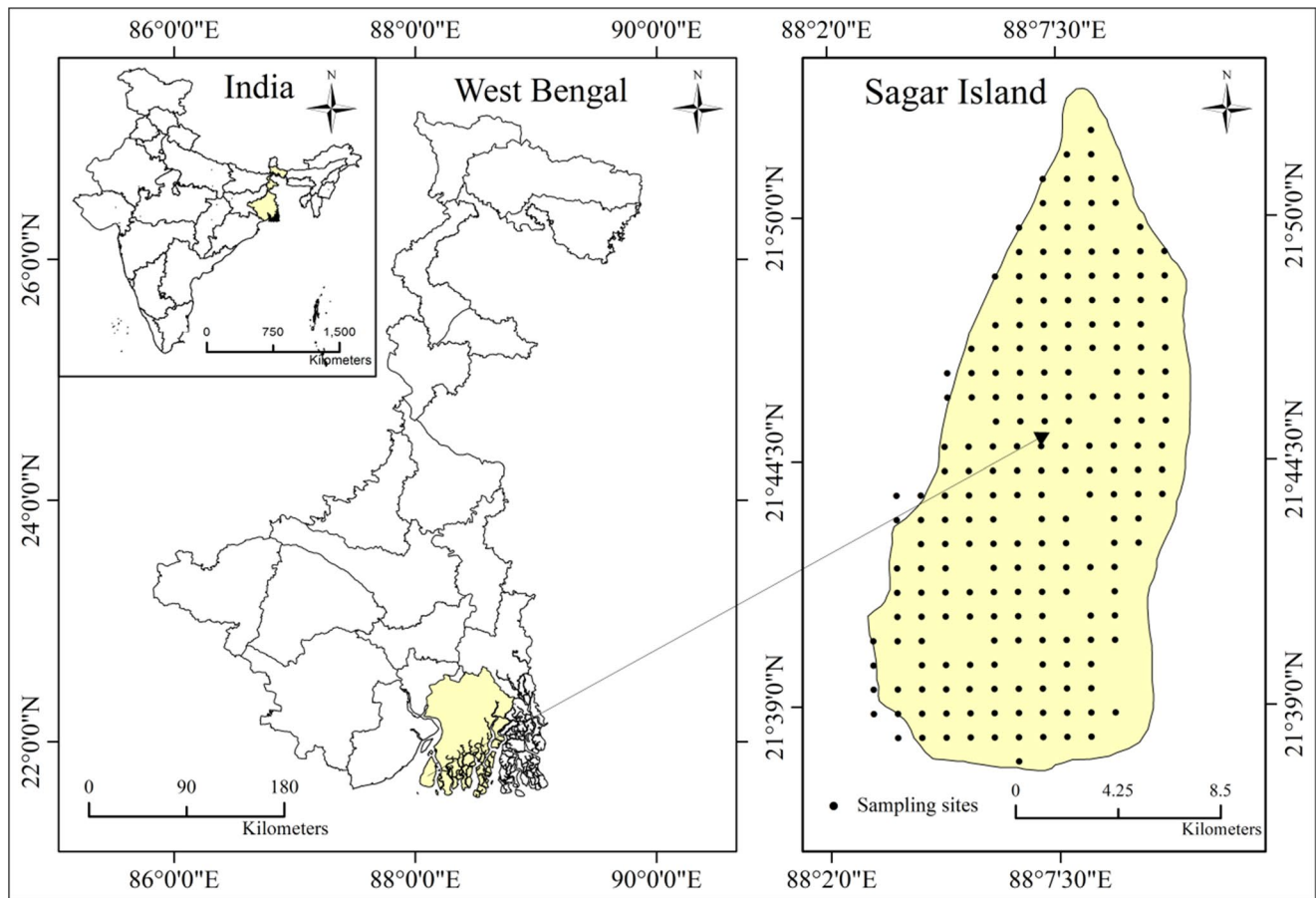
Fig. 1 Geographical position of the experimental site

island located in the far southern extremity of the Sundarbans area, stretching from 21° 36′ 20″ N to 21° 51′ 28″ N latitude and 88° 1′ 17″ E to 88° 9′ 25″ E longitude, having a range of altitudes between 2.5 and 3.5 m atop the mean sea level (Fig. 1). The island's size has shrunk over time owing to rise of te Sea level and geomorphologic engulfment (Chand et al. 2012; Lakshmi and Patterson 2010). For the last 120 years, the island has been subjected to several natural disasters, including extensive coastline erosion (Bandyopadhyay 1997; Gopinath 2010), brackish water infringement (Majumdar and Das 2011), and recurrent storms and bouts of depression (Chand et al. 2012).The Island's entire geographical area (GA) is around 23,834 ha, while the length of the coastline edge is approximately 67.8 km.Agricultural production covers about 61% of GA (14,618 hectares), with rain-fed low-land rice growing accounting for the almost all (11,089 ha; 46.5% GA).Widely grown crops throughout the winter include boro rice (irrigated rice), mustard, sunflower, khesari (grass pea), chilies, potatoes, and lentils, among others. The main obstacles to the spread of the double cropping system are inadequate irrigation support and accurate knowledge of soil conditions (Mandal and Choudhury 2014).

Data sources and methodological approach

For the current study, multiple soil quality parameters including soil texture, pH, depth, organic carbon content, electrical conductivity, Nitrogen (N), Phosphorus (P), and potassium were used (Table 1). Because of the lesser geographical expansions of the Island, the climatic characteristics were deemed spatially uniform and hence removed from

Table 1 Data sources

Materials	Data source
Toposheets	Survey of India, RF 1:50,000
Soil texture	Nimpith RAKVK (ICAR)
Soil depth	indiawaterportal.org
Soil pH	
Electrical conductivity	
Organic content	NBSS & LUP
Nitrogen (N)	
Phosphorus (P)	
Potassium (K)	
Experts' opinions	Literature survey &local agronomist knowledge

the assessment. Likewise, gradient (ranging from 0 to 3%) and stoniness (nil) were deemed non-restricting variables of output and thus ignored.

Making of criterion maps employing geospatial techniques

Criteria maps for soil texture (Fig. 3a) and soil depth (Fig. 3h) were geo-referenced, and after determining an area of interest (AOI), vector layers were produced using on-screen digitization and then rasterized using the conversion tool in the Arc GIS 10.1 software. Thematic layers of soil

pH, electrical conductivity of soil, organic carbon content, nitrogen (N), phosphorus (P), and potassium (K) (Fig. 3, c, d, 3e, f, and g) are generated using point data in an excel spreadsheet in.csv format, which is then converted on shape-file and implemented inverse distance weightage (IDW) in a GIS platform to quantify the spatial dispersal. The overall methodology is mentioned in Fig. 2.

Standardization of chosen parameter layouts

Because the parameters are all in dissimilar units, executing the weighted overlay operation necessitates converting them to the same units and thus a standardized value.
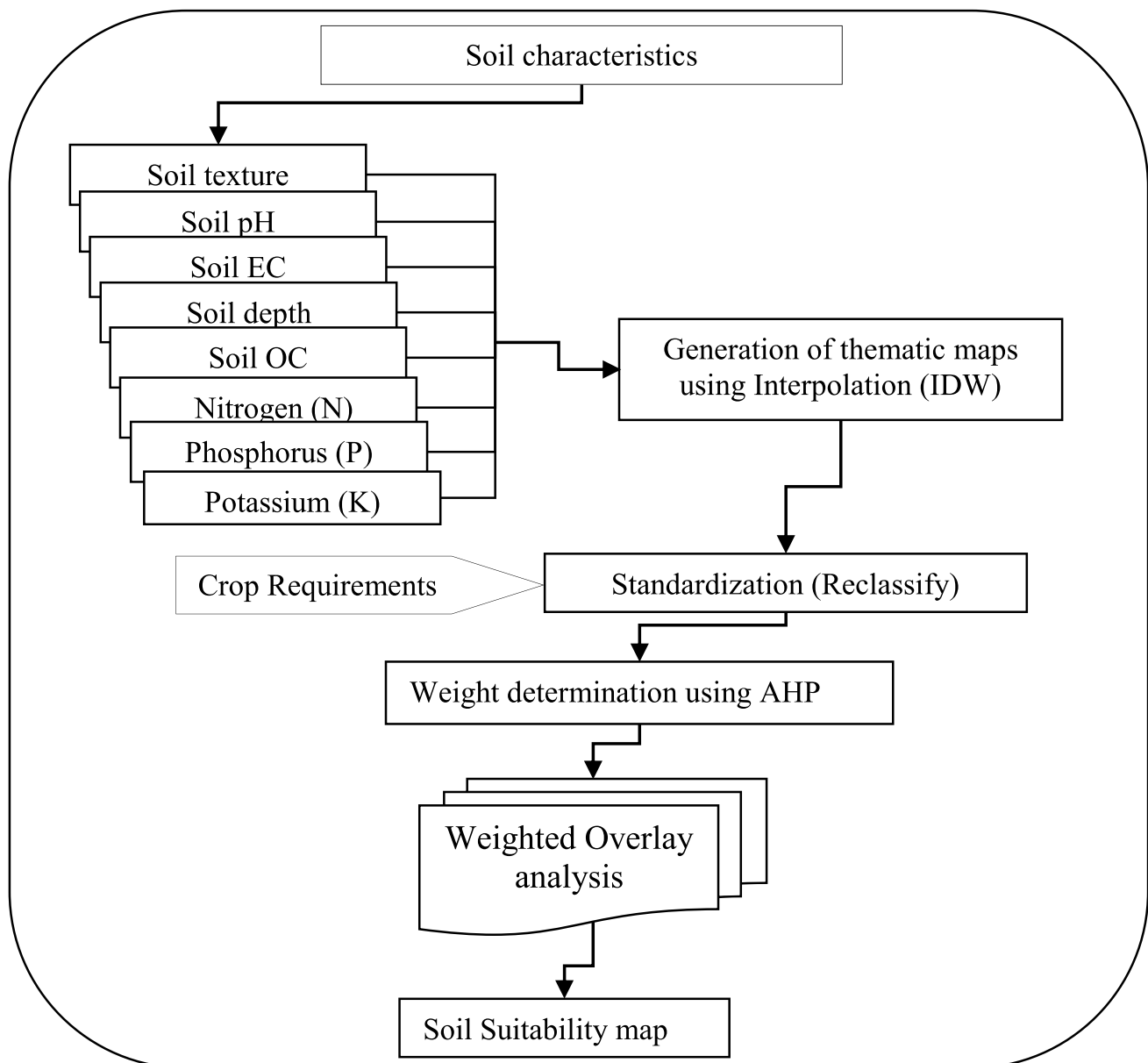

**Fig. 2** Flowchart of the methodology prepared by authors

The standardization technique converts measurements into uniform units, and the resulting score is lost along with its dimension as well as the subsequent measurement unit of each parameter (Effat and Hassan 2013). All criterion maps' vector layers have been transformed to raster layers, as shown in Fig. 3. The weighted overlay approach was then applied to construct the agricultural soil suitable site after categorizing all raster layers and using them as input data. The reclassify approach in Arc GIS 10.1's spatial analyst toolkit provides a standard the value of all specified criteria for relative importance analysis based on local agronomic expertise and a comprehensive literature review (Table 5).

Weight derivation

Researchers actively employed the GIS platform in conjunction with the AHP technique for MCDM (Xu et al. 2012; Joerin et al. 2001; AbdelRahman et al. 2018).

Thomas L. Saaty introduced this semi-quantitative technique in (1977) to design a hierarchal model with the most appropriate options for developing challenging land management issues (Malczewski 2006; AbdelRahman et al. 2018). For site suitability, AHP permits the use of GIS-based land suitability models (Pramanik 2016; Alshabeeb 2016). The analytical hierarchy process provides a fundamental foundation for defining the robust correlation of blueprint parameters and components in a pairwise strategy, limiting the judgement process's ambiguity (Saaty 1977; Miller et al 1998).

The pairwise comparison matrix (PWCM), which has been constructed by using analytical hierarchy technique, was established by Saaty (1980) using a scale having ranges from 9 to 1/9. The row element is believed to be more significant than with the column element, according to a grade of 9. A grade of 1/9, on the other hand, shows that the row element is less relevant in comparison to the
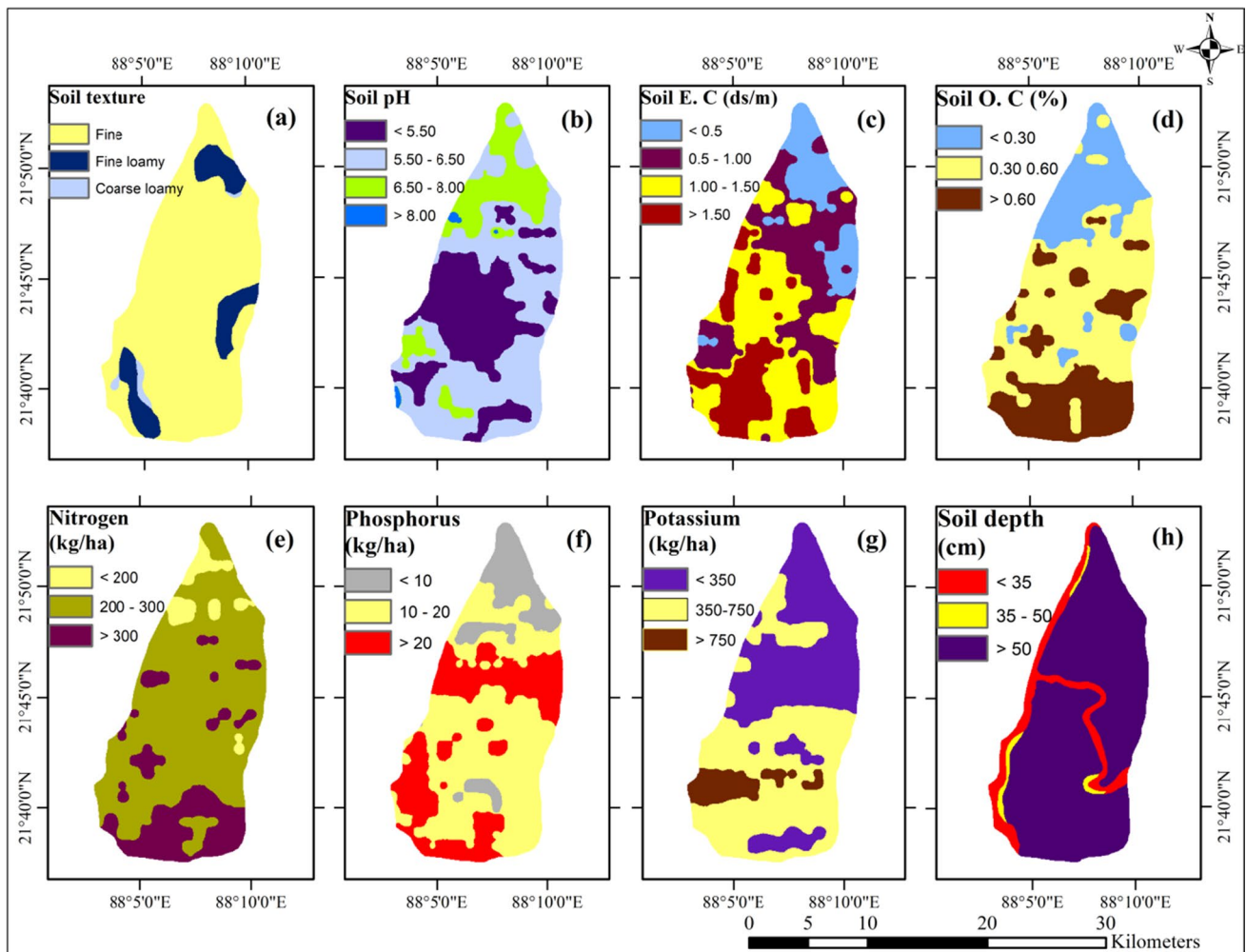
Fig. 3 Spatial variability of soil's physic-chemical factors: (**a**) soil texture (**b**) soil pH (**c**) electrical conductivity (ds/m) (**d**) Organic carbon (%) (**e**) Nitrogen (kg/ha) (**f**) Phosphorus (kg/ha) (**g**) Potassium (kg/ha) (**h**) soil depth (cm)

column element. In situations in which both column and row components appeared equal significant, they received a score of 1 on saaty's foundational scale, (Table 2). Each cell value, or the performance score of each cell, was divided by the sum of that specific criterion column to normalise the table following the completion of the pairwise comparison matrix (Table 3) (Malczewski 1999; Saaty 1980). Using Saaty's procedure, the comparable priority value of apiece criterion was measured from the normalised matrix table. The eigenvector technique was included in this study to determine the criteria weights from the normalised pair-wise comparison matrix table (Table 3). The 'Weighted Sum Vector' was calculated after computing the priority decision rule to discover inconsistencies among the parameters since there may have been some discrepancy in the outcome owing to non deterministic

construction (Saaty 1980, 1990, 1994).This inconsistency was detected utilizing Eq. 1 (Feizizadeh et al. 2014; Saaty 1980; Garcia et al. 2014).

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

where WSV denotes the weighted Sum Vector, wj denotes the rating classes of each layer, and xij denotes the weight for each factor.

$$CR = \frac{CI}{RI} \tag{2}$$

$$CI = \frac{\lambda max - n}{n - 1} \tag{3}$$

Table 2 The basic dimension for pairwise comparisons (Saaty 1980)

Degree of significance	Outlining	Explication
1	Uniform	The goal is equally benefited by the two activities
3	Reasonable	By experience and judgement, one activity is slightly preferred above others
5	Robust or requisite	Experience and judgement highly preferred one activity to other
7	Demonstrated	Strong support is given to one activity, and it is shown to be dominant in actual use
9	excessive	The strongest potential order of affirmation may be found in the data supporting one action over another
2, 4, 6, 8	Intermediaries values	When to make a compromise
Reciprocals	Used for inverse comparisons	

Table 3 Normalized matrices and criterion weight computation

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	0.0558	0.0370	0.0389	0.0251	0.0212	0.0392	0.0303	0.0488
Phosphorus	0.0419	0.0317	0.0311	0.0201	0.0127	0.0392	0.0303	0.0244
Potassium	0.0372	0.0247	0.0222	0.0168	0.0106	0.0196	0.0303	0.0244

Highest eigen value (λmax) = 8.3569

$n = 8$

CI = (λmax—n)/(n-1) = 0.0510

RI = 1.41

CR = CI/RI

CR = 0.0510/1.41 = 0.0362

where Lambda (λ_{max}) is the highest Eigen value

CI stands for Consistency Index.
CR stands for Consistency Ratio.
RI stands for Random Index (Table 4),

The number of criteria or sub-criteria in each pairwise comparison matrix is denoted by the letter 'n'.

A satisfactory amount of consistency is stated by a consistency ratio (CR) of 0.10 or less (Saaty 1977). The consistency index is enhanced by the symmetry of the elements within each group, the reduction in group size, and a deeper comprehension of the choice issue (Saaty and Vargas 1993). The value of lambda (max) determines the Consistency Index's value. High inconsistency is indicated by a bigger value of lambda (λ max), meaning that as lambda (λ max) increases, so does the ratio of inconsistency and vice versa. Equation 3 was used to determine the consistency index. The CR value for soil suitability was 0.0094 (Table 5), demonstrating that the relative weight in this investigation was properly determined and that the comparison of land attributes was entirely consistent.

As indicated in Table 5, all of the numerical computations of each individual parameter (eight parameters), as well as the distinction of one class from another based on a specific set of criteria, were performed individually and their weights were obtained using "AHP" methods in Microsoft Excel.

Table 4 Random Index (R.I)

Order matrices	1	2	3	4	5	6	7	8	9	10
R.I	0.00	0.00	0.525	0.882	1.115	1.252	1.341	1.404	1.452	1.484

Table 5 The weights of each criteria and sub-criterion were standardized and derived from the AHP

| Soil-site characteristics	Unit	Weight	CR	Sub-criterion and 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 (cl, scl, sicl)	0.5571		
				Coarse loamy (l, sl, 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 and Lin (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

Agricultural soil suitability zone determined through weighted overlay technique

Weighted sum overlay techniques were utilised to overlay the map layers. A weighted overlay is a method of generating a cohesive evaluation by employing a single scale of values to different and diffuse input data (Kuria et al. 2011; Yalew et al. 2016). Individual map layers and sub-layers within a criterion were independently weighted in this study based on their value using the AHP technique described before (Table 5). After weighting the raster layers and classes, the map of soil suitability for sustainable intensive agriculture was developed. (Eq. 4) (Fig. 4).

$$S = \sum_{i=1}^{n} WiXi \qquad (4)$$

where S denotes the suitability score for every map pixels, Wi denotes the weight of the ith criterion layer, Xi denotes the weight of the ith criteria layer's sub-criteria, and n is the quantity of suitability layers (Elaalem et al. 2010). Each thematic layer receives the aforementioned formula. The investigation was done out in ArcGIS 10.1 utilising weighted sum overlay methods. The higher the "S" score in the total result, the better the soil for agriculture.
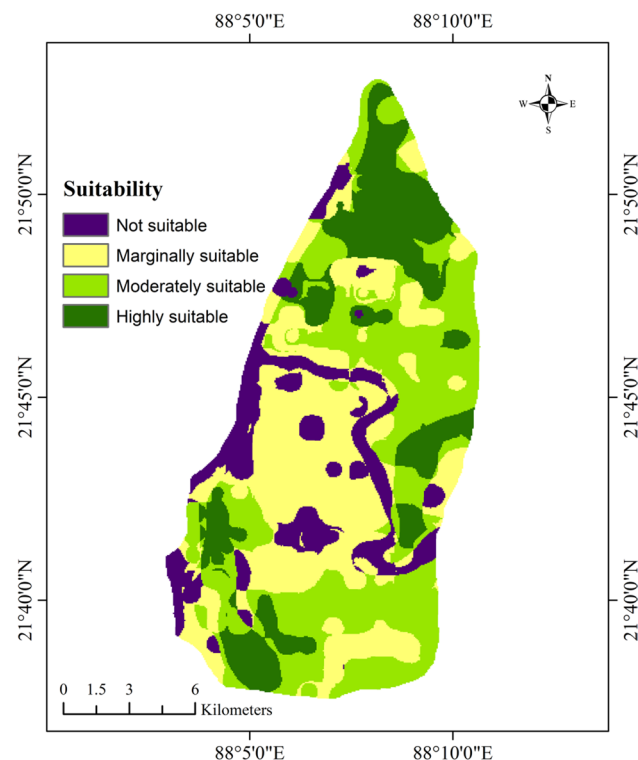
Fig. 4 Map of overall potential soil suitability

Results and discussion

The geological structure and soil development

Sagar Island is a portion of the Bengal delta that formed from a dormant continental coast in the pre-Oligocene to a remnant ocean basin in the early Miocene. The basin is made up of three geo-tectonic prefectures: the Stable shelf, the Central deep basin, and the Chittagong-Tripura fold belt (Alam et al. 2003; Agarwal et al. 1991; Das et al. 2013). The Island was formed by three different types of estuary deposits, as per the Geological Survey of India's (GSI) geological map of the region (Mandal et al. 2020). In the northwest, southwest, and southeast lie the active estuarine formations (Q_2mae) of the upper Holocene era. On the concave side of the channel bar, the creek section is intermingled with clay deposits, and the easternmost section of the Island is made up of inter-distributary supratidal flats beneath a thick layer of greyish black clay (Mandal et al. 2020). Bandyopadhyay et al. (2003) identified two unique mechanisms of soil development, stating that alluvium was directly conveyed and deposited by the river Hugli while silt–clay loads were indirectly deposited in the deltaic zone by backwater. The clay fractions underwent partial alteration in the highly salinized seawater that was returned through the rivers and dumped on the island (Bandyopadhyay et al. 2003).

Description of factor maps

The most important element of an ecosystem that supplies nutrients to plants is soil. It is a crucial component of the raw materials needed to grow all agricultural crops (Rukhsana and Molla 2021). The primary soil physicochemical parameters involved for production of thematic map layers employed in the MCDM method for developing the soil suitability map are explained below (Table 6).

Soil texture Soil texture is regarded as a crucial basic soil property because of its impact on soil structure, water holding capacity, infiltration, aeration, and other factors (Abdel-Rahman et al. 2017; Elsheikh et al. 2013). Soil texture also affects a number of soil variables, including EC, pH, soil composition, minerals, and microbial biomass (Mustafa et al. 2011; Bhunia 2016). 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 sited in the southwest of the island (Fig. 3a) (Table 6).

Soil pH Assessing the potential availability of nutrients and toxic elements to plants requires taking into account the pH of the soil (Kilic et al. 2022). The importance of taking into

Table 6 The research area's areal and percentile distribution of the specified criterion and sub-criteria

Soil-site characteristics	Sub-criterion (with ranges)	Area (ha)	Area (%)
Soil texture	Fine (sc, sic, c)	20,327.49	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	11,586.02	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	20,420.09	85.96
Organic Content	< 0.30	5324.42	22.41
	0.30 – 0.60	11,744.06	49.43
	> 0.60	6692.52	28.17
Nitrogen (N)	< 200	1349.15	5.68
	200—300	17,200.02	72.40
	> 300	5207.91	21.92
Phosphorus (P)	< 10	3487.22	14.68
	10 – 20	13,012.30	54.76
	> 20	7262.13	30.56
Potassium (K)	< 350	10,281.64	43.27
	350 – 750	11,729.47	49.37
	> 750	1748.81	7.36

account soil pH characteristics in this study is to examine the crucial soil processes affected by crop production, crop suitability, soil microbial activity, and availability of plant nutrients (USDA-Natural Resources Conservation Service 2021). The most ideal soil pH for plant growth is typically thought to be between 6 and 7 (Goulding 2016). The soil reaction of the chosen research region has shown a considerable variance, ranging from severely acidic (pH:3.94) to mildly alkaline (pH: 8.45). Despite the fact that the bulk of the land (48.77%) is slightly acidic to nearly neutral in reaction (pH: 5.50–6.50), this zone will facilitate nutrient readiness for crop intensification since the majority of plant nutrients are easily accessible in this range of soil pH (Fig. 3b) (Table 6).

Electrical Conductivity (EC) The term "soil salinity" describes the amount of soluble salts present in the root zone. Electrical conductivity (EC) is used to analyse the soluble salt concentration. Particularly in arid, semi-arid, and coastal regions, soil salinity is a limiting factor for plant growth. As a result, the EC is regarded as an essential indicator of soil quality and was used in the analysis of the suitability of the land. Figure 3c shows the spatial variability of EC 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 research area (Table 6).

Soil depth According to Hirzel and Matus (2013), one of the most fundamental factors affecting the hydrological dynamics of soil types and plant growth is soil depth. The depth of topsoil is vital for plant growth since it gives the plant a footing to draw water and nutrients from the earth. Deep soil has greater root space than shallow 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 (Fig. 3h), based on soil information (Table 6).

Organic Content (OC) Infiltration rates and water holding capacity are controlled by soil OC (%), which improves soil aggregate formation. In addition to acting as a nutrient reservoir for plants, soil organic matter provides nutrients and energy to microorganisms (Zdruli et al. 2004). In order to determine whether a piece of land is best suited, organic matter content of the soil was considered (Richards 1954). However, overall geographical proportion of organic content in the chosen research region revealed that roughly 22.41% was recorded low (< 0.30%), 49.43% medium (0.30—0.60%) and 28.17% found high (> 0.60%) (Fig. 3d).

Nitrogen (N) Nitrogen (N) availability in surface soil ranged from 131.98 kg/ha to 445.3 kg/ha, including an average value of 266.17 kg/h over the research region. The majority of the soils on the island (54.76%) had medium available nitrogen concentration (200–300 kg/h), whereas only 21.92% had high (> 300 kg/h) (Table 6). The centre (Bishunpur, Purushottampur, and Kirtankali) islands are all concentrated in the intermediate range (200–300 kg / ha) of accessible nitrogen, according to the spatially explicit nitrogen distribution map (Fig. 3e). The high availability of nitrogen increases the suitability of the soil to grow many crops.

Phosphorus (P) The available Phosphorus level of island soils was high, with an average amount of 18.34 kg/ha, 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 found in the island's south-central region (Fig. 3f) (Table 6). The prevalence of low land rice systems maintains the topsoil at wet and causes anaerobic geo-chemistry, which can periodically enhance the mobility of P-fixing cations like iron,

aluminium, and others through the lessening process, therefore boosting the P availability (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 north-eastern part of the island and the cause may be linked to extremely high clay concentrations or to the predominance of minerals rich in potassium, such as illite and feldspar (Table 6 and Fig. 3g).

Soil site suitability map

Soil quality parameters such as soil texture, soil depth, pH, CEC, EC, OC, OM, and slope, among others, may be used to determine the suitability of a piece of land for intensive farming using a geospatial method. The weights of each indicator and each of their subclasses have also been evaluated using AHP multi-criteria analysis, and are reported in Table 7 with a view to produce the suitable soil map for sustainable crop cultivation. Using the weighted sum overlay methodology, the soil quality map of the research region has been created by superimposing all of the thematic raster layers (Fig. 4). Figure 4 displays the four categories of the agricultural soil suitability map, with 4673.63 ha (20.04%) being found to be highly suitable, 7914.41 ha(33.94%) being found to be moderately suitable, 7582.43 ha(32.51%) being found to be marginally suitable, and only 3150.94 ha(13.51%) being recorded as being not suitable (Table 7). The complete research area that may be suggested for intensive agriculture in the study region falls into the highly suitable and moderately suitable categories together, making up around 53.98% of the total research area. Additionally, it has been discovered that 13.51 percent of agricultural soil is unsuitable for intensive farming (Table 7).

These findings on the physico-chemical characteristics of soil have led researchers to conclude that the following characteristics are present in highly appropriate areas: 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 (Mahis-mari, Gangasagar and Dhablat mouza) of the Island. While the majority of the unsuitable places are mainly centred near the coast of the Middle East (Krishnanagr, Narharipur, Radhakrishnapur, Beguyakhali, Bankimnagar and Kirankhali mouza) accompanied by intense saline stresses including an upper tolerance level of 3.00 ds/m, pH levels < 4.5 or > 8.5, textural categories as course loamy, shallow soil depth, lack of NPK concentration on soil, and virtually no groundwater resource for irrigation, all of which unquestionably lessen the soil health and capabilities of the soil to support agricultural production and, as an outcome, decrease farm productivity. While it is undeniable that intensive farming enables to address the rising demand for food throughout the world, it also consumes a lot of resources and land. These intensification techniques provide a long-term hazard to the environment because to the decline of ecological systems, climate change, the appearance of new parasites, soil pollution, extinction of species, and deforestation. Additionally, intense cultivation destroys valuable plants and insects, culminates in polluted runoff and obstructed waterways, and increases floods susceptibility. Sustainable agricultural land appears to be a countermeasure to these adverse consequences, however finding the best agricultural land depends on its capacity to support soil development and environmentally friendly agriculture. In particular, agricultural activity must be carried out in suitable places where it is most appropriate and only if it is truly necessary allows for the use of inputs in a fair manner.

Conclusion and recommendations

This study applied remote sensing, a GIS environment, and AHP techniques to evaluate the identification of soil qualities and their spatial variability in the agricultural ecosystem of a coastal saline island. The map of agricultural soil suitability was constructed using a set of quality indicators such as soil texture, pH, EC, OC, soil depth, and NPK content. The AHP algorithm was used to compute factor weights and sub-parameters in identifying appropriate land for intensive farming. The results indicate that 20.04% as highly suitability, 33.94% moderate suitability, 32.51% marginal suitability, and 13.51% not suitability. The following

Table 7 Areas with varying degrees of soil suitability for sustainable intensive agriculture

Degree of suitability	Area (ha)	Proportion (%)
Highly suitable (S1)	4673.63	20.04
Moderately suitable(S1)	7914.41	33.94
Marginally suitable(S1)	7582.43	32.51
Not suitable (N)	3150.94	13.51

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 various climatic calamities, such as cyclones. Finally, the study indicated that modelling on site suitable may be utilized for agricultural field diversifying and intensity initiatives in boosting the Island's agricultural yields. As a consequence, the acquired results are not only utilised to improve crop production in the soil suitable areas in the selected research region, but also provide an adequate conceptual approach and quality factors with their features for consideration in similar areas. This study can be useful for agricultural planners who guide small farmers to cultivate their crops for higher production in highly soil suitable area which can increase their agricultural productivity in a more sustainable way. The current land-use pattern should be adjusted in accordance with its suitability classes and land management strategies should be planned accordingly.

- Effective soil and water conservation strategies are required for the management of soil resources and to boost this region's output.
- Investments are needed in the form of bettering and regulating the fertilizing system and constructing a specialized irrigation system in order to transform the marginal and unsuitable land to a greater degree of suitability.
- The agriculture department is needed to supply seeds, fertilizer, and pesticides as well as more importantly to build embankments that make farming possible.

Declarations

Declaration of interests The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests.

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