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ORIGINAL ARTICLE

Modelling of alternative crops suitability to tobacco based on Analytical hierarchy process in Dinhata subdivision of Koch Bihar district, West Bengal

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Abstract Land suitability evaluation is a systematic way for alternative crops cultivation and sustainable agricultural development in a region. Global anti-tobacco movement against health hazards and harmful impact of tobacco cultivation on environment, food production and human health, it is necessary to evaluate alternative cropping potentiality to tobacco in Dinhata subdivision. In the present study and research work land suitability evaluation has been determined for five alternative rabi crops such as potato, maize, boro paddy, mustard and wheat in Dinhata subdivision of Koch Bihar district, West Bengal by using parametric method for climate suitability and Analytical Hierarchy Process for soil-site suitability. Analytical Hierarchy Process is a powerful tool for evaluating land suitability for these crops followed by FAO (A framework for land evaluation, FAO Soils Bulletin 52. FAO, Rome; FAO, A framework for land evaluation, FAO Soils Bulletin 52, FAO, Rome, 1976) method. The parametric method examined climatic suitability for five major rabi crops, alternative to tobacco under irrigated condition, result showed that potato and wheat had high suitability (S1), with suitability rating 94.45 and 85.05% respectively. Boro paddy, maize and mustard were moderately suitable (S2) with suitability rating 67.63, 77.92 and 62.59% respectively. The selected theme layers includes slope, soil texture, soil reaction, organic carbon, nitrogen, phosphorous, potassium, boron, sulphur, manganese, zinc and soil erosion, which are most influence crop suitability have been combined by the adopted methodology. Overlay operations have been done on these layers according to weighted significance of each of the factor. Results of the land suitability evaluation for potato, maize, boro paddy mustard and wheat indicated that highly suitable class (S1) accounts 15.88, 15.29, 14.52, 13.46 and 16.90% while moderately suitable (S2) constitutes 29.01, 30.99, 29.06, 29.62 and 25.01% and the marginally suitable (S3) are 33.38, 32.14, 34.69, 34.62 and 35.43% respectively. Whereas not suitable (N) areas for potato, maize, boro paddy mustard and wheat accounts 21.73, 21.58, 21.73, 22.31 and 22.66% respectively. It was found that better alternative crops of tobacco of the study area is exists for replacement of tobacco cultivation.

Introduction

Tobacco is a leading commercial crop in Dinhata subdivision occupying about 7.2 thousand hectares of area (14.25% of the total arable land in the subdivision) and producing around 9.38 thousand tonnes of leaf annually (Sub-divisional Agricultural Office, Dinhata, 2011). Dinhata occupies unique place in non-FCV (non-flue-cured Virginia) tobacco cultivation producing with the capability of good quality and strong flavor. Among non-FCV

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tobacco, cigar wrapper, cigar filler (cigar tobacco), Jati (chewing tobacco) and Motihari tobacco (hookah and chewing tobacco) are well grown in this subdivision during the Rabi season on alluvial sandy loam to silty loam soils under irrigated conditions. Thousands of people are engaged in the production, manufacture and distribution of tobacco and its production. But recently cultivation of tobacco is facing challenging problems in view of the growing anti-tobacco campaigns world over against health hazard. Tobacco consumption, cultivation and processing have assumed proportion of an epidemic (Panchamukhi 2000). Tobacco control cannot succeed until completely banned its cultivation. In this perspective, World Health Organization Framework Convention on Tobacco Control (WHO-FCTC) was adopted a treaty on 21 May 2003. The Government of India signed the WHO Framework Convention on Tobacco Control (FCTC) on 10th September 2003 and ratified the treaty on 5th February 2004 (Schwartz 2011). It is imperative that the area under tobacco cultivation ought to be reduced to 50% by 2020 in India. These issues are posing a serious challenge to tobacco farmers in the study area. So, farmers who depend on tobacco production for their livelihood will therefore be left with no option but to seek other alternative crops to produce. In these circumstances, it is therefore necessary to develop a systematic approach to facilitate the production of land suitability information for alternative crops of tobacco. Hence, the present study aims to assess the suitability of the land in Dinhata subdivision for substitute crops to replace tobacco cultivation.

Food and agriculture organization (FAO) guideline on the land evaluation system is widely acceptance. According to FAO (1976) land evaluation is "the process of assessment of land performance when used for specific purpose. It involves the execution and interpretation of surveys and the studies on landforms, soils, vegetation, climate and other related aspects of land for a compromising between the promising land use and specific land use". Land suitability studies gives information on the choice of crops to be grown to replace tobacco cultivation on a specific site for maximizing crop production per unit land. Suitability is measured by the land qualities with the specific crop requirements. In order to assess suitability of an area for a particular crop, several criteria need to be evaluated (Belka 2005). In this study, analytical hierarchy process (AHP) integrated with GIS platform was applied to establish a spatial model of the suitability of agricultural land of the study area for five alternative rabi crops such as potato, maize, boro paddy, mustard and wheat.

Method and materials

General description of the study area

The studied area is located between 25°57′24″N to 26°14′06″N latitudes and 89°15′17″E to 89°37′36″E longitudes and covers an area of 765 km (Fig. 1). Physio-graphically the area is a level plain with gentle slope northwest to southeast and belongs to the sub-Himalayan margin. Geologically the area cover alluvium of recent deposition and the basement of igneous and metamorphic rock under this area lie at depth between 1000 and 1500 m. The agro-climatic condition of this subdivision is characterized as humid subtropical climate having mean annual rainfall of 2929.88 mm and average monthly maximum and minimum temperatures of this study area as 29.7 and 19.3 °C respectively. The soil taxonomy is Ustifluvents and the soil temperature regime is Hyperthermic. The thickness of the solum varies from 100 to 130 cm (NBSS and LUP 2001).

Trend of tobacco production

Tobacco is planted during rabi season in the region. Production of tobacco in the region had been fluctuated due to anti-tobacco campaign, health hazard and market fluctuation. To computing compound annual growth rate of tobacco production, area and yield rate Exponential curve have been used (Gupta 2008). Total area of tobacco cultivation has been increasing at an average annual rate of 3.5% in Dinhata sub-division. Similar to the trend in the volume of production, the area planted/harvested in the three blocks of Dinhata subdivision had been incline, except Jati tobacco area. Among Motihari tobacco area, Dinhata-I having the highest incline (6.99%), while Sitai had the least incline at 1.69% annually. But in Jati tobacco had experienced a decline in the total area cultivated in this subdivision at an average annual rate of − 2.19% (Table 1).

Total production of tobacco in Dinhata Subdivision had been increasing by an average of 3.0% annually from 2006 to 2012. Among the 3 administrative blocks, Dinhata-I exhibited the highest incline of Motihari tobacco averaging 6.80% annually from 1920 metric tons in 2006 to 3125 metric tons in 2012, while Sitai block had the least incline at 1.45% annually from 5900 metric tons in 2006 to 6525 metric tons in 2012. But in case of Jati tobacco it was only Dinhata-I that exhibited negative growth. However, this was very minimal decline an average of 1.83% annually. This decline was due to the reduction in the area planted/harvested during this time period.

Production of tobacco per hectare has been little increasing at an average annual rate of 0.44% in Dinhata subdivision. But in Motihari tobacco, there was a decreasing trend at an average rate of 0.85% annually in the study area in spite
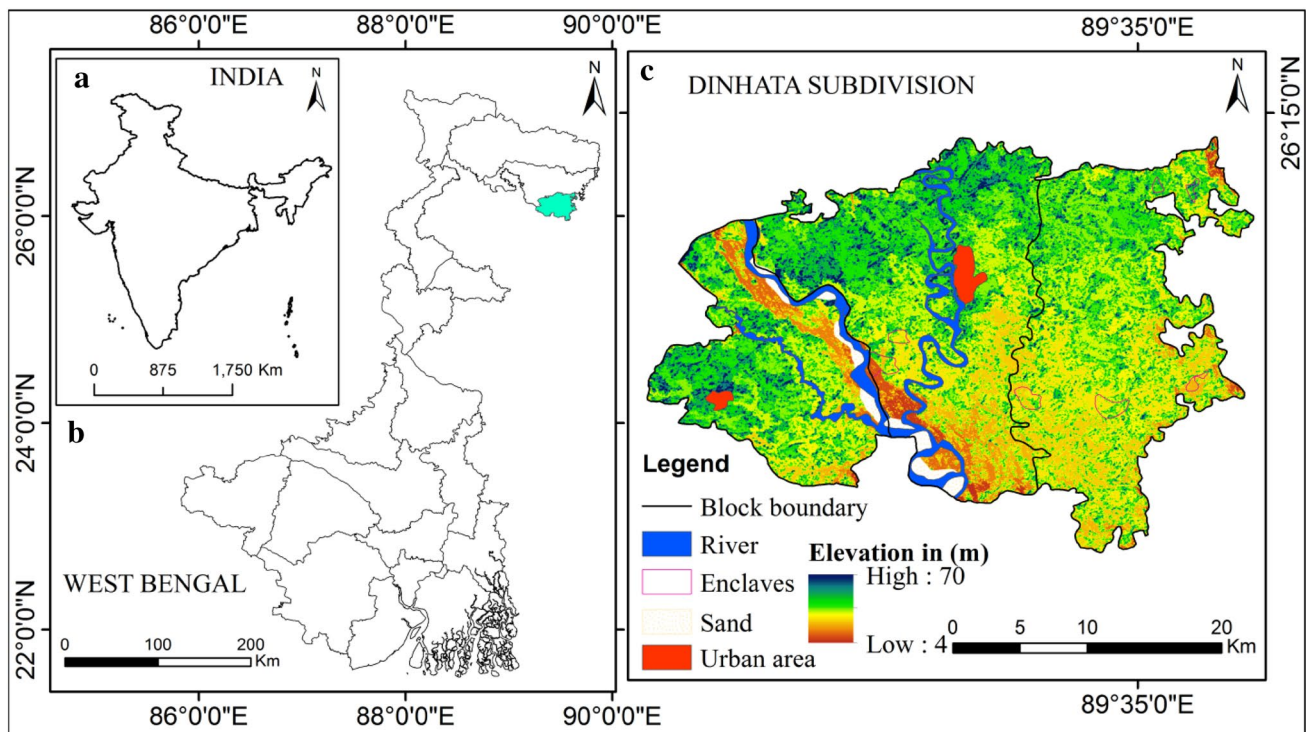
Fig. 1 **a** India. **b** Dinhata subdivision in north-east part of West Bengal. **c** Dinhata subdivision with altitude

Table 1 Annual growth rate (%) of area, production and yield rate of tobacco in the study area (2006–2012)

Tobacco types	Block	Annual growth rate (%)		
		Harvested area	Production	Yield rate
Motihari tobacco	Dinhata-I	6.99	6.8	− 0.17
	Dinhata-II	6.89	4.67	− 2.07
	Sitai	1.69	1.45	− 0.25
	Total	3.61	3.1	− 0.85
Jati Tobacco	Dinhata-I	− 2.09	− 1.83	0.3
	Dinhata-II	–	–	–
	Sitai	− 1.85	2.17	4.06
	Total	− 2.19	0.02	2.09
Total tobacco production		3.35	3	0.44

of aggressive extension activities of the various government agencies particularly CTRI and private tobacco companies. This decline yield rate was due to continue tobacco cultivation at same land year after year.

Result indicate that despite the treaty with WHO-FCTC tobacco production is still increasing. This is perhaps due to restrictions in other countries on tobacco cultivation. Tobacco cultivation in the study area is not under the contract farming, but farmer take Credit advance from local tobacco companies or tobacco bussinessmen, which is not available for other crops. Unstable market price of all other crops is another hindrance for alternative crops. In case of FCV tobacco, no person shall grow Virginia tobacco

seedlings for commercial purposes; grow FCV tobacco with obtaining registration from the Tobacco Board, but there have not such regulation in non-FCV tobacco. Obviously, this is not good news for replacement of tobacco cultivation in the study area.

Structure of land suitability classification

Food and agriculture organization (FAO) guideline on the land evaluation system is widely acceptance. There are four categories or level of classification: land suitability orders, classes, sub-classes and units. The present study has not used

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the units, whereas land units are the basis for classification by grouping specific areas (Table 2).

Parametric method

In the parametric method a numeral rating is attributed to each characteristic (Sys et al. 1991b). The process of evaluation is based on the FAO qualitative land evaluation system (FAO 1976, 1984, 1985), which compares climatic conditions including insolation, temperature, rainfall and relative air humidity with each specific crop requirements developed by Sys et al. (1991a, b, 1993). The climatic indices are calculated from the individual rating. If the observed value is x and it falls into the interval $[a, b]$ it needs to get a score y that falls into the interval $[c, d]$. The formula (Bagherzadeh and Gholizadeh 2016) to calculate y is:

$$y = a + \frac{(b - a)(x - c)}{(d - c)}. \tag{1}$$

Then, climate index has been calculated based on Khiddir's square root method. The formula to calculate Climate Index (CI) is based on Square root method (Khiddir 1986):

$$CI = R_{min} \times \sqrt{\frac{A}{100} \times \frac{B}{100} \times \ldots,} \tag{2}$$

where R_{min} = minimum rating. A, B … = other rating besides the minimum rating.

The climatic rating to be used in the total evaluation has to be calculated by (Sys et al. 1991b). If index between 25 and 92.5, climatic rating = 16.67 + 0.9 index. If index less than 25, Climatic rating = 1.6× index.

The suitability classes are defined according to the value of the index (Table 3) as suggested by Sys et al.

Table 3 Climate suitability classes according to climate index and climate rating based on Sys et al. (1991b)

Climatic classes	Limitation level	Climate Index	Corresponding rating
S1	No to slight	100–75	100–85
S2	Moderate	75–50	85–60
S3	Severe	50–25	60–40
N	Very severe	25–12.5	40–20
		12.5–0	20–0

The average day (t_d) and night (t_n) temperature are calculated by following formula (Gommes 1983; Sys et al. 1991a)

$$t_d = \frac{(t_{max} + t_{min})}{2} + \frac{(t_{max} - t_{min})}{4\pi} \frac{(46 - N)}{N} \tag{3}$$

$$t_n = \frac{(t_{max} + t_{min})}{2} - \frac{(t_{max} - t_{min})}{4\pi} \frac{(46 - N)}{(24 - N)}, \tag{4}$$

where, t_d = average daytime temperature °C, t_n = average night time temperature °C, t_{max} = daily maximum temperature °C, t_{min} = daily minimum temperature °C, π = 3.1416.

It is noted that, in the study area, rabi crops are grown under irrigation supply, hence rainfall parameter has not to be considered for climate index.

Thematic data layer

Land suitability evaluation requires criteria mostly from the land and soil attributes. Several soil parameters used for generation of the thematic map layers which used in AHP for

Table 2 Structure of the suitability classification () Source: FAO 1976; Juniarti et al. 2013

Order	Class	Suitability	Rating scale (%)	Limitations
S	S1	Highly suitable	85–100	Land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level
	S2	Moderately suitable	60–85	Land having limitations which an aggregate are moderately severe for sustained application of a given use; the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on Class S1 land
	S3	Marginally suitable	40–60	Land having limitations which in aggregate are severe for sustained application of a given use and will so reduce productivity or benefits, or increase required inputs, that this expenditure will be only marginally justified
N	N1	Currently not suitable	25–40	Land having limitations which may be surmountable in time but which cannot corrected with existing knowledge at currently acceptable cost, the limitations are so severe as to preclude successful sustained use of the land in the given manner
	N2	Permanently not suitable	0–25	Land having limitations which appear as severe as to preclude any possibilities of successful sustained use of the land in the given manner

generating the final suitability map for each crop. Following important soil parameters are discussed.

Soil texture

Texture is one of the important parameter of soil. Most of the physical and chemical characteristics of the soil depend upon texture class (Mustafa et al. 2011). Soil texture affects the retention and infiltration of water, aeration, absorption of nutrients, tillage, microbial activities and irrigation system (Foth 1990; Gupta 2004). It is an inherent physical properties of soil which less affected by management. The rate of increase in gluiness or ability to mould as the moisture content increases be determined by the content of silt and clay, the degree to which the clay particles are bound together into stable pellets and the organic matter content of the soil (White 1997). Over a long time, various pedogenic processes such as erosion, deposition, eluviation, illuviation and weathering can change the textures of various soil horizons (Forth 1990; Brady and Weil 2002).

The soils of the subdivision belonged to sandy, loamy and clayey textural groups. Sandy soils occupies as area of 2.0492 km^2 constituting only 0.27% area of the study area. Coarse loamy soil textural classes covered 20.53% area, while fine-loamy soils textural classes occupied 58.07% area. Clayey soils classified as fine soils constituted 11.42% area in the study area (Fig. 2a).

Soil pH

Soil reaction is the degree of soil acidity or alkalinity, which is caused by particular chemical, mineralogical and biological environment (Tilahun 2007). The supply of plant nutrients and thus the fertility of the soil are affected by pH. A number of natural and human activities such as leaching of exchangeable bases, acid rains, decomposition of organic materials, application of chemical fertilizers and different farming practices effect soil pH (Rowell 1994; Tisdale et al. 1995; Brady and Weil 2002). The solubility of most nutrients varies in response to pH. As acidity increases, the loss of these nutrients by leaching increases and their availability to plants decreases. The quantity of some nutrients may rise so greatly under acidic and alkaline conditions that they become toxic to plants (Briggs 1977). Therefore, it is very essential to control soil pH between 6.5 and 7.5 regard most of the nutrients are available to plants for maintaining soil fertility (Daji 1996).

Data on soil pH indicated that majority of the soils in the studied area were acidic. Strongly and moderately acidic soils together were mapped in 71.61% area. Another 14.04% area was occupied by slightly acidic soils. Neutral and slightly alkaline soils occupied 3.77 and 0.87% area respectively (Fig. 2b). Due to high rainfall in the study area, most

of the alkaline materials go through the lower horizon and most of the soil became acidic also due to agro-forestry and agricultural practice.

Organic carbon

According to Dudal and Decaers (1993) soil organic matter is defined as any living or dead plant and animal materials in the soil and it comprises a widespread of organic species includes humic substances, proteins, carbohydrates, and plant residues. The organic matter is a vital store of available nutrients. Sources of nutrients such as N, P, and S are most micronutrients and growth promoting substances, that is, hormones or growth-promoting and regulating substances valuable to plants may be produced by organisms that decompose soil organic matter (Cook and Ellis 1987; Tisdale et al. 1995). It helps to sustain soil fertility by improving soil structure, retention of mineral nutrients, increasing water holding capacity, water infiltration, drainage, aeration and root penetration. It also helps to increase the amount of soils flora (Havlin et al. 2010). It comes in a soil from remains of plants and animals. However, in addition to this, it also includes grasses, trees, bacteria, fungi, protozoa, earthworm and animal manure.

The soils from the study area are classified on the basis of their organic carbon content into different categories such as low, medium and high. The results on organic carbon content status indicated that soils in 39.08% area of the subdivision contained low organic carbon status. Medium and high organic carbon status soils were mapped on 31.11 and 20.10% area respectively (Fig. 2c). In general, majority of the soils in the area have low to medium carbon content. That is to say that these soils require adequate nitrogen fertilization through organic manure, farmyard manure, green manure etc.

Nitrogen

Deficiency of nitrogen is almost universal in Indian soils. Therefore, nitrogen application is a must for canopy development and high yields. Nitrogen is the fourth plant nutrient taken up by plants in greatest quantity next to carbon, oxygen and hydrogen (Sanchez 1976; Mengel and Kirkby 1987), it should be present in the soil in appropriate proportion for the growth of plants. The plants absorb nitrogen either as ammonium or as nitrate ion. The occurrence of the nitrogen compounds in the soils involves the processes such as fixations of atmospheric nitrogen by free living and nodule forming bacteria, conversion of nitrogen containing compounds into humid acids, ammonification, nitrification, and then leaching loss of different nitrogen compounds by intra-soil and surface flows (Orlov 1992).

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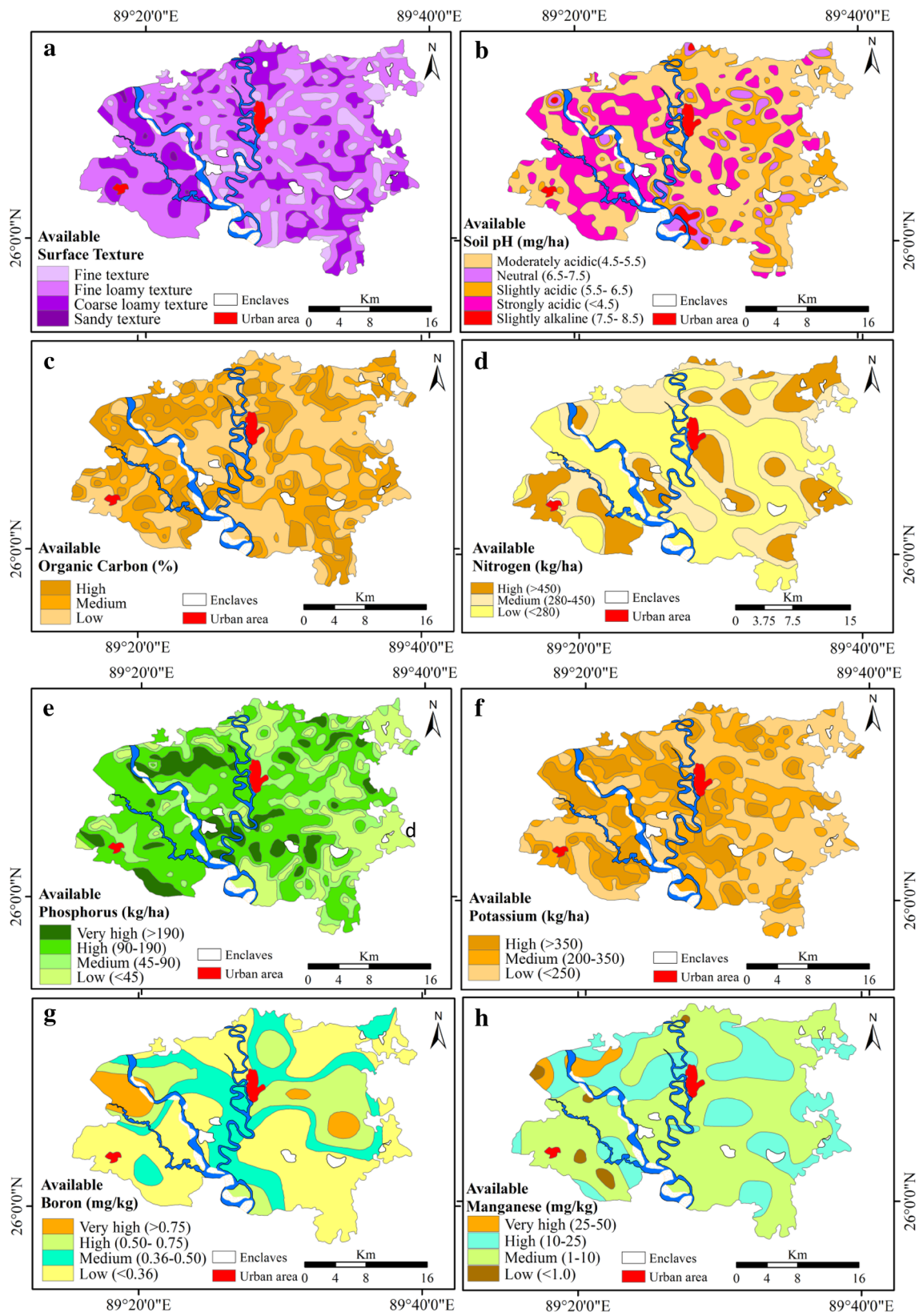Model. Earth Syst. Environ. (2017) 3:1571–1587

Fig. 2 Crop suitability conditioning factors: **a** surface texture, **b** soil pH, **c** organic carbon, **d** nitrogen, **e** phosphorus, **f** potassium, **g** boron, **h** manganese, **i** sulphur, **j** zinc, **k** soil erosion, **l** slope
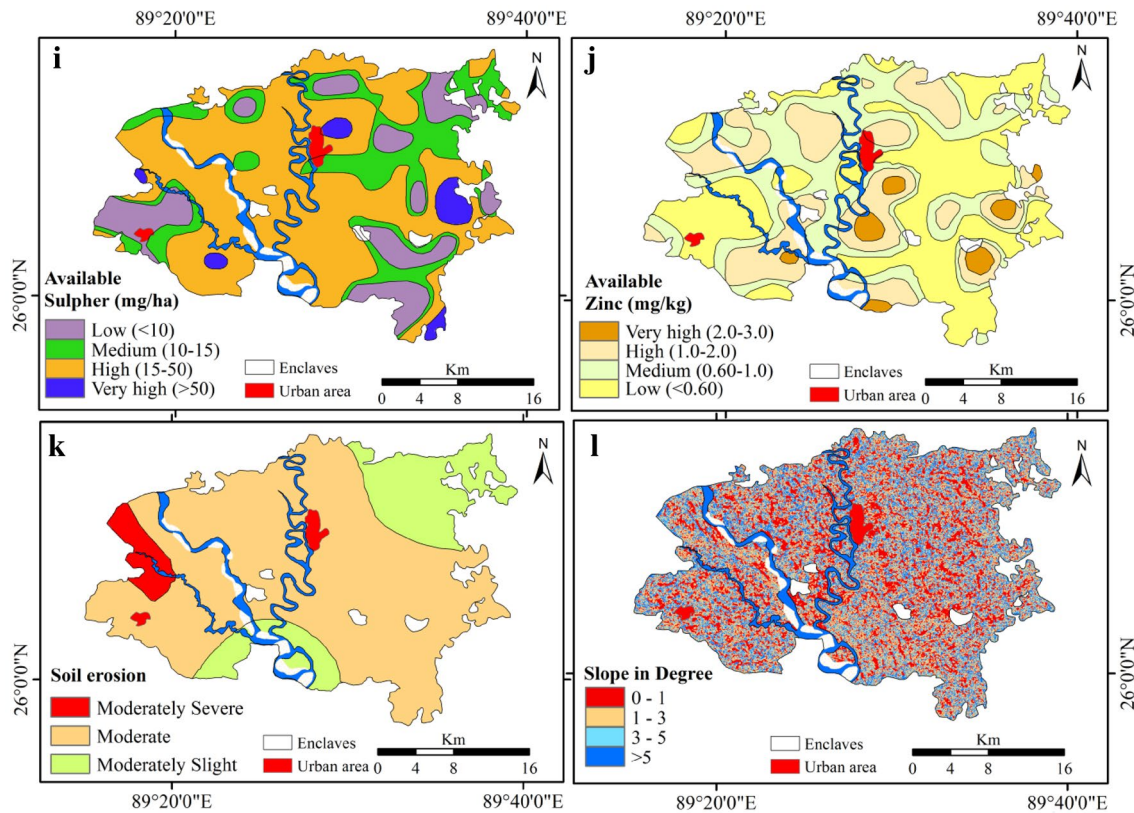
Fig. 2 (continued)

The soils from the study area are classified on the basis of their nitrogen content into different categories such as low, medium and high. Available nitrogen content in first 0–25 cm soils indicated that its availability was Low in the soils 42.89% area of the subdivision. Medium and High status soils with respect to available nitrogen were mapped in 27.35 and 20.05% area of the subdivision respectively (Fig. 2d).

Phosphorus

Phosphorus has been called the "Master key to agriculture" (Foth and Ellis 1997). Because low crop production more often due to lack of phosphorus than the deficiency of other elements except nitrogen. The importance of phosphorus in plant nutrient is many folds. It is essential for growth, cell division, root growth, fruit development and early ripening. It is also required for energy storage and transfer. It is a constituent of several organic compounds including oils and amino acids (Tandon 1997). Phosphate ion enters the soil solution either as a result of mineralization of organo-phosphates or the application of fertilizers. The plants take available P mostly in the form of H_2PO_4 from soil solution. Chemisorption of P occurs due to interaction of phosphate

ions with the atoms like Al, Fe or Ca depending upon soil pH (Orlov 1992).

In the present study the availability of phosphorous plant growth was low in 17.89%. Another 20.38% area was ranked medium, while larger part of the Dinhata subdivision covering 52.02% area was mapped with the high availability phosphorous (Fig. 2e).

Potassium

Potassium is a master nutrient for the production of superior quality crop and it is the third most important essential element next to N and P that limit plant productivity (Brady and Weil 2002). Soil parent materials contain potassium (K) mostly in feldspars and micas. Potassium exists in K ion form and it is released become either exchangeable or exist as adsorbed or as soluble in the solution (Foth and Ellis 1997) and its function appears to be catalytic in nature. The potassium is important for plant because it participates in the activation of large number of enzymes which are involved in physiological process of plants. It controls the water economy and provides the resistance against a number of pests, diseases and environmental stresses (Orlov 1992).

Availability of potassium for plant growth was found low (below 200 kg/ha) in the larger part of the subdivision

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covering 41.46% area, while medium and high availability of potassium were observed in another 30.11 and 9.71% area respectively (Fig. 2f).

Boron

Boron is typical and important trace element. Orthoboric acid (H_3BO_3) and its salts are the main forms of boron present in the soil. Several factors including soil pH, calcium, soil texture, organic matter, light and moisture are known to influence the availability level of boron in soil (Orlov 1992). However, boron greatly influences the metabolism and transport of carbohydrates in plants. It is also involved in membrane integrity and cell wall development, which affect permeability, cell division and cell extension. Boron deficiency like calcium affects the growing points of roots, shoots and young leaves. Boron deficiencies retard the uptake of calcium. The excess lime might reduce the uptake of calcium because of boron deficiency (Tandon 1997).

In the present study the available boron status in the first 0–25 cm soils ranged from 0.36 to 0.75 mg/kg. The data reveals that soils on 68.47% area in the Dinhata subdivision are deficient, while 21.82% areas were sufficient in respect of Boron (Fig. 2g).

Manganese

The concentration of manganese content in soil is a particularly wide range; the lower values are distinctive of severely leached acid soils, whereas excess or toxicities often occur in unleached acid soils and waterlogged conditions. Soil pH is the main controlling factor for manganese availability in soils. A pH value below 6.0 favours reduction of manganese and the formation of the more available bivalent form (Mn^{2+}); higher pH values favour oxidation to the Mn^{4+} ion, forming the insoluble oxides (MnO_2, Mn_2O_3 and Mn_3O_4) (Harmsen and Vlek 1985). Manganese deficiency is characterized by "gray speck" in oats wherein gray lesions developed in the leaves but the tips remains green. Chlorotic patches developed between the veins in the younger leaves of dicots. Deficiency symptoms usually observed in the older leaves (FAO 2006).

Manganese status in the first 0–25 cm of the soils of the study area reveals that about 680.4885 km^2 area (88.97% area) in the subdivision sufficient (> 1 mg/kg) in manganese status (Fig. 2h). Only 1.32% area in the study area deficient in Mn status needs special care for manganese nutrition.

Sulphur

Sulphur (s) is absorbed by plants as sulphate iron (SO_4). Concentration S in plants ranges from 0.1 to 0.4%. Sulphur requirement is high for the crops of families of Gramineae,

Leguminosae and Cruciferae. Sulphur is involved as a ligand in a number of enzymes metallo-proteins, most conspicuously in the iron-sulphur proteins and copper proteins (Adinarayana 1992). It is an integral part of some of the essential amino acid viz, cysteine, cystine and methionine. It is also constituent of glutathione, a compound that plays a part in the plant respiration and synthesis of essential oils. The biologically active sulphate-3 phosphoadenosine-5 phosphosulphate is an important sulphate donor involved in carbohydrate metabolism of the crop plants. The characteristic taste and smell of plant in the mustard and onion families is due volatile compound containing (De Kok et al. 1993). The deficiency of S results in increase in nitrate, soluble organic nitrogenous compounds, amides and ammonia and a decrease in insoluble (protein) nitrogen. Sulphur deficiency symptoms mostly resemble that of N deficiency. Leaves become pale yellow or light green and the symptoms will persist even after N application. Plants become small and spindly with short and slender stalks and crop growth is retarded. In sulphur deficient plants, the stem becomes hard and woody. Available sulphur status in the study area was observed high on 438.4127 km^2 area (57.32% area), medium 139.7528 km^2 (18.27% area) and low in 112.395 km^2 area (Fig. 2i).

Zinc

Plants absorb zinc as Zn^{2+} and it is a constituent of several dehydrogenase, proteinase and peptidase enzymes. Zinc is believed to promote RNA synthesis which, in turn, is needed for protein synthesis (FAO 2006). It plays an important role in the formation of some growth hormones and starch formulation. It also promotes seed maturation and production. Crops such as rice, soya bean, maize and linseed are classified as very sensitive to Zn deficiency. Zn deficiency causes decrease in the level of photosynthesis. Flower and fruit setting are considerably reduced and delayed. Plant growth is stunted and tillering is poor. Characteristic brown rusty spots occur on rice leaves. In maize and sorghum the deficiency is known as 'white bud' and in cotton it is called 'little leaf' (Harmsen and Vlek 1985).

The available Zinc status in first 0–25 cm soils indicated that about 489.326 km^2 (63.98% area of the subdivision) is deficient in Zinc (Fig. 2j). The area having sufficient status of Zinc was marked on 201.2345 km^2 area that constitutes another 26.31% area of Dinhata subdivision.

Soil erosion

Soil erosion is the dominant limiting factor for crop production. It also significantly threatens agriculture, natural resource and environment (Gayen and Saha 2017). The Fig. 2k showed that largest part of the subdivision (70.29%) faced moderate

(10–15 t/ha/year) soil erosion due to water and wind action. Remaining area 16.62 and 3.5% falls under moderately slight (5–10 t/ha/year) and moderately severe (15–20 t/ha/year) soil erosion class respectively.

Slope

Slope is very important factor for land suitability analysis. Places with high slope are not suitable for cultivation due to being impenetrable. On the other hand the very sharp slopes as result of low soil depth and lack of evolved soils have not appropriate condition for growth plants. Meanwhile the elevation criteria because of effect on soil are considered as important factor in land suitability analysis.

Modelling of alternative crops suitability based on analytical hierarchy process:

The analytical hierarchy process is firstly introduced by Saaty in 1980. It is a multi-objective, multi-criteria decision making approach, which enables the user to arrive at a scale of preference drown from a set of alternatives (Saaty 1980). This method is very important for suitability analysis, regional planning, decision making. In the construction of a pair wise comparison matrix, each factor is rated against every other factor by assigning a relative dominant value between 1 and 9 to the intersecting cell (Table 4).

For the AHP model, the final result includes the weights of the derived factors, class weights and a calculated consistency ratio (CR), as seen in Tables 5 and 6. In the AHP method, an index of consistence, known as the consistency ratio (CR), is used to indicate the probability that the matrix judgments were randomly generated (Saaty 1980, 2000).

$$CR = CI/RI, \tag{5}$$

where RI is the average of the resulting consistency index depending on the order of the matrix given by Saaty in 1980 and CI is the consistency index and can be expressed as:

$$CI = (\lambda_{max} - n)/(n - 1), \tag{6}$$

where λ_{max} is the largest or principle eigenvalue of the matrix and can be easily computed from the matrix and 'n' is the order of the matrix. The consistency ratio is a ratio between the matrix consistency index and random index, and in general ranges from 0 to 1. A CR of 0.1 or less is a reasonable level of consistency (Malczewski 1999). A CR above 0.1 requires revision of the judgment in the matrix due to an inconsistent treatment for particular factor ratings.

In this study, the consistency ratio is less than 0.06; the ratio indicates a logical level of consistency in the pairwise comparison that is good enough for recognize factor weights. For all cases of the gained class weights, the CRs are less than 0.1, the ratio indicates a reasonable level of consistency in the pair-wise comparison that is good enough to recognize the class weights. Regard alternative crop suitability mapping (ACSM) by AHP, is used based on following equation:

$$\sum_{i=1}^{n} (R_i \times W_i), \tag{7}$$

where R_i is the rating classes each layer and W_i is the weights for each of the crops conditioning factors. For the estimation of alternative crops suitability value (ACSV) the each crops conditioning factors values is summed by weighted linear sum model on a GIS environment (Lee and Talib 2005). Finally ACSV is classified into four classes (S1, S2, S3 and N) based on natural break to determine the class interval in the ACSM (Fig. 3).

Result and discussion

Climate evaluation

Long term climate data related to different stages of crops growth for 40 years (1972–2011) have been collected from meteorological station of Central Tobacco research Institute, regional research station, Dinhata, which is located at 26°20′N latitude and 89°27′E longitude and 41 m above the

Table 4 Fundamental scale of absolute number between two parameters in AHP (Saaty 2000)

Intensity of importance	Degree of preference	Explanation
1	Equally	Two activities contribute equally to the objective
3	Moderately	Experience and judgment slightly to moderately favour one activity over another
5	Strongly	Experience and judgement strongly or essentially favour one activity over another
7	Very strongly	An activity is strongly favoured over another and its dominance is showed in practice
9	Extremely	The evidence of favouring one activity over another is of the highest degree possible of an affirmation
2, 4, 6, 8	Intermediate values	Used to represent compromises between the preferences in weights 1, 3, 5, 7 and 9
Reciprocals	Opposites	Used for inverse comparison

Table 5 Pair-wise priority rating of different data layers based on AHP

Factor	Class	Rating (Ri) for all crops				
		Boro paddy	Mustard	Maize	Wheat	Potato
Surface texture	Fine soil	0.473	0.138	0.168	0.272	0.189
	Fine loamy soil	0.284	0.478	0.383	0.157	0.109
	Coarse loamy soil	0.170	0.256	0.342	0.483	0.351
	Sandy soil	0.073	0.128	0.107	0.088	0.351
Soil pH	<4.5	0.039	0.039	0.050	0.039	0.064
	4.5–5.5	0.192	0.107	0.151	0.107	0.207
	5.5–6.5	0.368	0.243	0.354	0.243	0.388
	6.5–7.5	0.296	0.383	0.295	0.383	0.219
	7.5–8.5	0.105	0.227	0.151	0.227	0.122
Organic carbon	High	0.540	0.540	0.540	0.540	0.540
	Medium	0.297	0.297	0.297	0.297	0.297
	Low	0.163	0.163	0.163	0.163	0.163
Nitrogen	High	0.570	0.550	0.550	0.550	0.558
	Medium	0.333	0.240	0.240	0.240	0.320
	Low	0.097	0.210	0.210	0.210	0.122
Phosphorus	Very high	0.469	0.487	0.402	0.402	0.469
	High	0.297	0.273	0.337	0.337	0.297
	Medium	0.166	0.134	0.164	0.164	0.166
	Low	0.068	0.106	0.097	0.097	0.068
Potassium	High	0.540	0.540	0.540	0.400	0.540
	Medium	0.297	0.297	0.297	0.400	0.297
	Low	0.163	0.163	0.163	0.200	0.163
Boron	Very high	0.473	0.473	0.473	0.473	0.473
	High	0.284	0.284	0.284	0.284	0.284
	Medium	0.170	0.170	0.170	0.170	0.170
	Low	0.073	0.073	0.073	0.073	0.073
Manganese	Very high	0.473	0.473	0.473	0.473	0.473
	High	0.284	0.284	0.284	0.284	0.284
	Medium	0.170	0.170	0.170	0.170	0.170
	Low	0.073	0.073	0.073	0.073	0.073
Sulphur	Very high	0.326	0.449	0.449	0.449	0.351
	High	0.363	0.288	0.288	0.288	0.351
	Medium	0.163	0.138	0.138	0.138	0.189
	Low	0.148	0.126	0.126	0.126	0.109
Zinc	Very high	0.476	0.476	0.476	0.476	0.476
	High	0.289	0.289	0.289	0.289	0.289
	Medium	0.176	0.176	0.176	0.176	0.176
	Low	0.059	0.059	0.059	0.059	0.059
Soil erosion	Moderately slight	0.582	0.582	0.582	0.582	0.582
	Moderate	0.309	0.309	0.309	0.309	0.309
	Moderately severe	0.109	0.109	0.109	0.109	0.109
Slope	0–1	0.483	0.168	0.168	0.168	0.168
	1–3	0.272	0.461	0.461	0.461	0.461
	3–5	0.157	0.236	0.236	0.236	0.236
	>5	0.088	0.135	0.135	0.135	0.135

Table 6 The priority weights of each cops conditioning factor by analytical hierarchical process (AHP)

Factor	Weights of each factors (Wi)					
	Boro paddy	Mustard	Maize	Wheat		Potato
Surface texture	0.200	0.188	0.188	0.196		0.066
Soil pH	0.053	0.075	0.045	0.177	0.060	
Organic carbon	0.067	0.033	0.060	0.037	0.024	
Nitrogen	0.171	0.145	0.165	0.113	0.165	
Phosphorus	0.154	0.173	0.140	0.143	0.140	
Potassium	0.137	0.124	0.125	0.043	0.125	
Boron	0.020	0.018	0.021	0.017		0.021
Manganese	0.017	0.022	0.018	0.078		0.020
Sulphur	0.034	0.028	0.076	0.094		0.030
Zinc	0.041	0.094	0.098	0.049		0.128
Soil erosion	0.026	0.044	0.035	0.022		0.045
Slope	0.080	0.057	0.028	0.031		0.038
Consistency ratio (CR)	0.039	0.054	0.052	0.040		0.036

Table 7 The values of climate characteristics and the degree of limitation for potato production in the study area based on Sys et al. (1993)

Climate characteristics	Value	Class	Degree of limitation
Rainfall of first month (mm)	15.4	N2	19.25
Rainfall of second month (mm)	8.42	N2	4.21
Rainfall of third month (mm)	10.46	N2	5.23
Rainfall of fourth month (mm)	14.07	S2	77.58
Mean temperature of growing cycle (°C)	17.84	S1	99.6
Average absolute minimum temperature of first month (°C)	9.34	S1	100
Average absolute minimum temperature of other 3 month (°C)	10.44	S1	100
Average temperature difference between day and night (°C)	7.89	S1	90.78
Average day length of growing cycle (h)	7.8	S1	91
Climate Index	86.43		
Climate rate	94.45		
Climate class	S1		

Table 8 The values of climate characteristics and the degree of limitation for maize production in the study area based on Sys et al. (1993)

Climate characteristics	Value	Class	Degree of limitation
Rainfall of growing cycle (mm)	549.94	S1	92.5
Rainfall of first month (mm)	14.07	N2	5.86
Rainfall of second month (mm)	40.01	N2	14.28
Rainfall of third month (mm)	152.05	S1	85.41
Rainfall of fourth month (mm)	343.81	S2	72.56
Mean temperature of growing cycle (°C)	22.47	S1	96.18
Mean minimum temperature of growing cycle (°C)	15.48	S1	94.29
Relative humidity of development stage (%)	67.8	S1	95.6
Relative humidity of maturation stage (%)	78.19	S2	79.68
n/N of development stage	0.63	S1	99
n/N of maturation stage	0.5	S1	85
Climate Index	68.05		
Climate rate	77.92		
Climate class	S2		

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Table 9 The values of climate characteristics and the degree of limitation for Boro paddy production in the study area based on Sys et al. (1993)

Climate characteristics	Value	Class	Degree of limitation
Rainfall of first month (mm)	14.07	N2	7.03
Rainfall of second month (mm)	40.01	N2	20.01
Rainfall of third month (mm)	152.05	S1	96.5
Rainfall of fourth month (mm)	343.81	S1	92.81
Mean temperature of growing cycle (°C)	22.47	S2	78.64
Mean maximum temperature of warmest month of growing cycle (°C)	31.55	S1	92.41
Mean temperature of crop development stage (°C)	21.8	S2	75.83
Mean minimum temperature of ripen stage (°C)	20.49	S1	98.77
Relative humidity of tillage and vegetative stage (%)	69.61	S1	97.69
Relative humidity of harvest stage (%)	75.07	S1	94.98
n/N of growing cycle	0.64	S2	83.75
Climate Index	56.63		
Climate rate	67.63		
Climate class	S2		

Table 10 The values of climate characteristics and the degree of limitation for mustard production in the study area based on Sys et al. (1993)

Climate characteristics	Value	Class	Degree of limitation
Rainfall of growing cycle (mm)	48.35	N2	8.06
Monthly rainfall of vegetative stage (mm)	18.2	S2	65.33
Monthly rainfall of flowering stage (mm)	9.1	N2	22.75
Mean temperature of growing cycle (°C)	17.84	S1	94.47
Mean temperature of vegetative stage (°C)	19.2	S1	91
Mean temperature of flowering stage (°C)	16.3	S1	95.38
n/N of vegetative stage	0.76	S3	59.73
n/N of flowering stage	0..69	S1	89
Climate Index	51.03		
Climate class	62.59		
Suitability class	S2		

mean sea level and the climatic requirements of the crop were extracted from the table developed by Sys et al. (1993). Based on crop climatic requirements, the climate index (CI), climatic rate (CR) was determined as implemented factors in estimating land index (Tables 7, 8, 9, 10, 11).

Potato

Potato is an important rabi crop in the study area. The temperature ranges for the optimal growth of potatoes between 16 and 20 °C. The growth of tuber virtually stops at temperature below 10 °C above 30 °C. A rainfall of 300–700 mm in growing cycle is required. Potato grows well under long day conditions. Sunshine along with cooler nights is essential for reducing the spread of diseases. The climatic ratings under irrigation

conditions for potato cultivation were determined by taking into account the inherent climatic condition and requirements of crop. The result (Table 7) indicates that climate suitability class is S1 to indicate that climatic condition had to be satisfied. But irrigation is necessary during crop cycle.

Maize

Maize is mainly cultivated in Kharif season in all part of India, but in the study area maize is sown in rabi season. According to Singh (1983), the most favourable temperature for germination is 21 °C and for growth 32 °C. Extremely low and high temperature and low humidity during flowering damage the foliage exsiccate the pollen and delay with pollination, causing in poor grain formation. Maize grows in regions that have a total annual rainfall between 500 and 5000 mm (Sys et al. 1993). Maize is very sensitive to stagnant water, particularly during its early stages of growth. The degree of limitation of each climatic parameter and overall index and ratings for maize are illustrated in Table 8. The climate suitability rating is 77.92% and suitability class is S2, which indicate moderate suitability. The relative humidity and insulation are the main hindrances for maize cultivation in the study area.

Boro paddy

Boro paddy is the cultivation of winter rice under fully controlled irrigation; hence rainfall has not to be considered, so availability of water supply is needed trough out the growing cycle. Moderate to high relative humidity (50–90%) during the vegetative stage can result in reduced tillering. The average temperature required throughout the life period of

Table 11 The values of climate characteristics and the degree of limitation for wheat production in the study area based on Sys et al. (1993)

Climate characteristics	Value	Class	Degree of limitation
Rainfall of growing cycle (mm)	232.71	S3	53.08
Monthly rainfall of vegetative stage(mm)	15.73	S2	71.66
Monthly rainfall of flowering stage(mm)	8.17	N2	20.43
Monthly rainfall of ripening stage(mm)	48.02	S1	94.01
Mean temperature of growing cycle (°C)	18.63	S1	98.42
Mean temperature of vegetative stage (°C)	16.3	S1	91.42
Mean temperature of flowering stage (°C)	17.53	S1	99.41
Mean temperature of ripen stage (°C)	23.3	S1	95.88
Average daily minimum temperature of coldest month (°C)	7.49	S1	99.68
Average daily maximum temperature of coldest month (°C)	23.37	S2	82.18
Climate Index	75.98		
Climate rate	85.05		
Climate class	S1		

the crop ranges from 10 to 36 °C. The climate is considered unsuitable when the average temperature of this crop development stage is less than 10 °C and more than 45 °C (Sys et al. 1991b). There was a favourable climate condition with moderate limitation for irrigated boro paddy production in the study area. The climate index is 56.63 and overall rating is 67.63, which fall in S2 climate suitability class (Table 9). The mean temperature of growing cycle and crop development stage and insulation of growing cycle is main obstacle for winter rice cultivation in the study area.

Mustard

Mustard is one of the important oilseed crop in the study area. It is sown in rabi season under irrigated conditions. The optimum average temperature during mustard growing season ranges 15–26 °C but minimum goes down to 8 °C. Mustard grows well under long day conditions. The climatic characteristics of mustard growing season in the study area was favourable for crop growth with an average climate rate of 62.59 which made the region moderately suitable (S2 class) for irrigated wheat crop (Table 10). Main hindrance is fog cover in vegetative stage.

Wheat

Wheat is the second most important staple food crop after rice in India. It is cultivated as rabi crops in the study area, belonging to family Gramineae and genus *Triticum aestivum*. The temperature range for the optimal growth of wheat is 12–23 °C. Wheat growing areas need to receive a rainfall that exceeds 200 mm in growing cycle (Sys et al. 1993). In irrigated rabi crop amble water supply is needed in vegetative stage. The value of climatic characteristics and the degree of limitation for wheat production in the study area is presented in Table 11. The parametric model reveals that this region experience optimum climate suitability for wheat production with climate index is 75.98 and climate rate is 85.05.

Soil site suitability for different crops:

Potato

Suitability analysis revealed that about 78.27% of agricultural area is suitable for potato cultivation and out of which 15.88, 29.01 and 33.38% are highly (S1), moderately (S2) and marginally suitable (S3). The rest of area (21.73%) is having severe limitations that impede the cultivating of potato. High pH and low NPK rating, organic carbon is the major limitations of this area which can be improved by specific management (Fig. 3).

Maize

The key limitations faced by maize cultivation in some parts in the study area due to low potassium, low organic carbon and subsequently low available nitrogen. Based on the data Table 12 and Fig. 3c are clearly showed that about 15.29, 30.99 and 32.14% of area are falls under S1, S2 and S3 classes respectively, whereas 21.58% area falls under N class.

Boro paddy

The Fig. 3a indicated that only 14.52% of the area is highly suitable (S1) for boro paddy cultivation and about 29.06 and 34.69% of the area are fall under S2 and S3 suitability classes. High pH and low nitrogen, phosphorous, zinc are the major restrictions which may be discouraged farmers from growing boro paddy in about 21.73% that belongs to N suitability order.
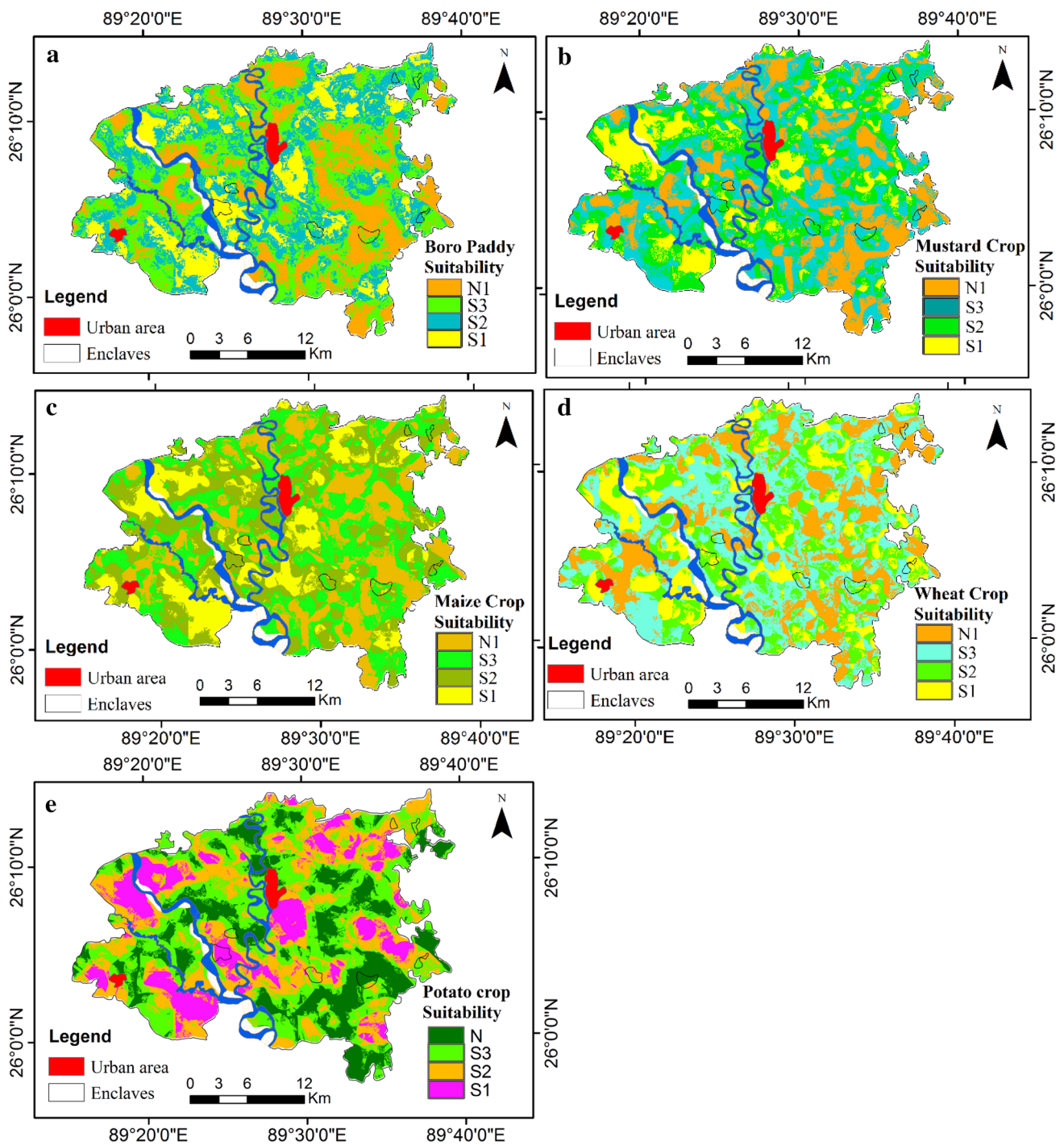
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Fig. 3 Land suitability evaluation: **a** boro paddy suitability, **b** mustard crop suitability, **c** maize crop suitability, **d** wheat crop suitability, **e** potato crop suitability

Mustard

Mustard is extensively cultivated in poor fertile soils, yet about 22.31% of area is not suitable (Fig. 3b). This may be due to the fine and sandy texture that occur in area in addition to the strongly acidic in nature. Suitability analysis showed that about 77.70% of agricultural area is suitable and out of which 13.46, 29.62 and 34.62% are highly (S1), moderately (S2) and marginally suitable (S3).

Table 12 Area (in km²) under different categories of suitability and their percentage distribution

| Crops	Suitability classes				
	Highly suitable	Moderately suitable	Marginally suitable	Currently not suitable	Total
	S1	S2	S3	N	
Maize	108.45 (15.29)	219.78 (30.99)	228 (32.14)	153.06 (21.58)	709.29 (100)
Potato	112.66 (15.88)	205.73 (29.01)	236.74 (33.38)	154.16 (21.73)	709.29 (100)
Boro Paddy	102.99 (14.52)	206.13 (29.06)	246.03 (34.69)	154.14 (21.73)	709.29 (100)
Mustard	95.45 (13.46)	210.07 (29.62)	245.56 (34.62)	158.21 (22.31)	709.29 (100)
Wheat	119.89 (16.90)	177.39 (25.01)	251.27 (35.43)	160.74 (22.66)	709.29 (100)
Mean	107.89 (15.21)	203.82 (28.74)	241.52 (34.05)	156.06 (22.00)	709.29 (100)
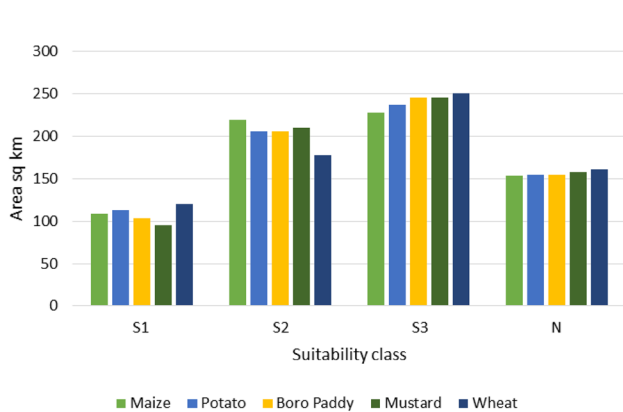
Fig. 4 Comparison of land suitability of alternative crops of tobacco

Fig. 5 Multi crops suitability map

Wheat

Result indicated that about 77.34% of agricultural area is suitable for wheat cultivation and out of which 16.90, 25.01 and 35.43% are highly (S1), moderately (S2) and marginally suitable (S3). Strongly acidic soil, sandy texture, low zinc, manganese are the major curbs which exclude about 22.66% of area from cultivation (Fig. 3d). Finally based on this Table 12 the compression of land suitability is representing in Fig. 4.

Multi crops suitability for alternative crops of tobacco

The results in Table 13 revealed that about 55.04% of total area is suitable for growing the five alternative crops of tobacco with the order of potato + maize + boro paddy + mustard + wheat whereas 4.2% is not suitable for these crops (Fig. 5) due to lack of soil quality in this regions. Also the over al 15.35% area is suitable for growing four alternative crops with the order of Maize + wheat + potato + mustard.
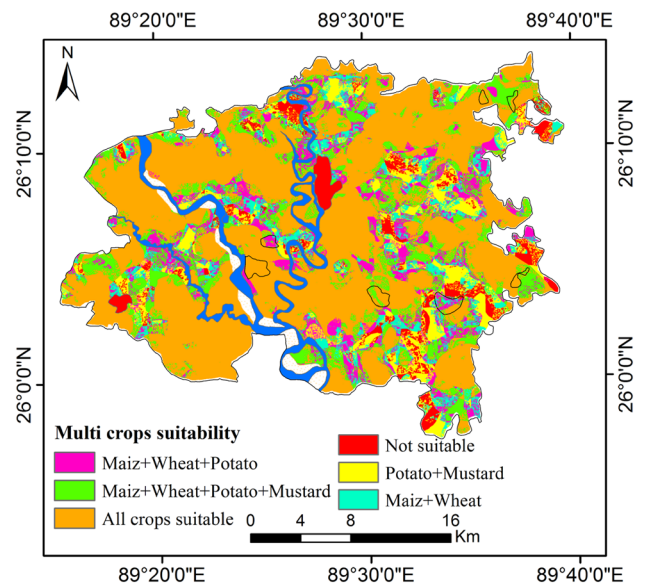
Table 13 Percent of suitable area for alternative crops growing

Crop	Area in sq. km	Area in %
Maize + wheat + potato + mustard + Boro paddy	390.39	55.04
Maize + wheat + potato + mustard	108.87	15.35
Maize + wheat + potato	74.51	10.51
Potato + mustard	56.39	7.95
Maize + wheat	49.37	6.96
Not suitable	29.76	4.2

Conclusion

Soil-site suitability analysis suggests that, potato, maize, boro paddy; mustard and wheat were found more or less similar suitability for major portion of the study area. So the choice of crops from the list can be made according

to socio economic requirements of the farmer and economic profitability. Since farming expansion programs for encouraging shifting rely on upon many components, for example, financial matters, appropriateness of substitute crops to soil conditions, changing the outlook of farmers, the arrangement of marketing offices for substitute crops and mindfulness programs, there is a requirement for the contribution of different associations, with one among the gathering going about as the facilitator. NGOs are required to have an imperative influence in the shift to interchange crops, incorporating parts in the scattering of data, refinement to and attention to the perils of developing tobacco and the potential outcomes of crop shifting, helping the farmers access institutional and specialized bolster and encouraging the formation of SHGs and cooperatives. To motivate the farmers, incentives/assistance in terms of machinery/equipment or other appropriate inputs may be planned as per the guidelines of existing centrally sponsored schemes like National Food Security Mission (NFSM), National Mission on Oilseeds and Oil Palm (NMOOP), Rashtriya Krishi Vikas Yojana (RKVY), National Mission for sustainable Agriculture (NMSA), Mission of Integrated Development of Horticulture (MIDH), etc. and may be needed. The focus should be on farmers who are cultivating tobacco crop for at least last 4–5 years and agree to shift to other crops. For motivating the farmers study tour/exposure visits and campaigns, if needed, may also be organized highlighting harmful effects of tobacco and long term benefits of alternative crops. An established crop diversification programme based on soil site suitability to give greater emphasis on production of crops other than tobacco and is encouraging agro-processing, horticultural and floricultural sections to generate more value added production in the agriculture and allied sections and also generate employment in the rural areas. It is need to introduce a change in the prevailing tobacco based cropping pattern in this agro-ecological situation of the study area to ensure crop diversification with enhanced overall production of food grain to maintain food security. To encourage formation of farmers self-help group simultaneously with formation of farmers' service co-operatives. There would in like manner be a need to make an effective observing and evaluation instrument at the grass-roots level.

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