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GIS based evaluation of crop suitability for agricultural sustainability around Kolaghat thermal power plant, India

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Abstract

Fly ash exhaust from Kolaghat thermal power plant, West Bengal, India, affects the areas within the radius of 3 - 4 km. Land information system indicated that surface texture within 4 km was silty loam and clay content increased with increase of distance. Soil pH was alkaline (7.58-8.01) in affected circles, whereas soil was acidic (5.95-6.41) in rest of block. Organic carbon (OC) is roving from 0.36 to 0.64% in the nearer circles which is lesser from others. The present Crop suitability analysis revealed that 96.98 % area was suitable (S1) for maize, sesame, jute, whereas these were cultivated in less than 1% of land. Flowers are the best suitable (S1) in 88.9 % but it was grown in 6.02 % area. The present rice area within 4 km of KTPP is showing moderately suitable (S2) and S1 for the rest. Wheat is moderately suitable (S2) in the almost all the circles. Cultivation of vegetable crops is limited in the affected circles while the highly suitable (S1) comprises 67.49 % for the remaining areas though it covered only 6.01 % of the block. This evaluation precisely improves more than 300% from the earlier cropping intensity of 177.95 %. Suitability based land use allocation serves as stepping stone to promote agricultural sustainability. Geographic information system (GIS) model has been developed to assess site specific crop suitability for sustainable agricultural planning.

Key words

Agricultural sustainability, Crop suitability, Fly ash, GIS model, Soil properties

Introduction

Many recent researchers have attempted to identify and specify the suitability criteria for different annual crops through land evaluation approach of FAO and using multivariate regression model with the assistance of soil parameters and yield data (Dai *et al*., 2001; Zolfaghari and Heath, 2008). Land use planning evaluates land and alternative land use patterns for the objectives of selecting the best choices (Roetter *et al*., 2005; Baja *et al*., 2007). Land resource evaluation analysis determines whether the requirements of land use are adequately met by the properties of land (Bandyopadhyay *et al*., 2009). A Geographical Information System (GIS) can suggest the description of land utilization types needed for land evaluation (Van de Putte, 1989; Bronsveld *et al*., 1994; Rossiter, 1995). Dengiz *et al.* (2009) used GIS for evaluation of soil erosion in Ankara-Guvenc Basin of Turkey. GIS also permits combination of maps with data generated by models (Bronsveld *et al*., 1994). Using GIS, Reis and Yomralıoglu (2006) evaluated existing potential hazelnut areas in the province of Trabzon, which is one of the most important hazelnut production areas in Turkey. GIS technology has also been used to detect the changes in forest cover in Kalrayan hills, Tamil Nadu (Sakthivel *et al*., 2010). In short, the basic goal of GIS is to take raw data and transform it *via* overlay and other analytical

operations into new information which can support decision-making processes.

The adverse effect of fly ash on soil properties was observed by Adriano *et al*. (2002). Impact of coal burned thermal power station, especially on agriculture had been studied by Arun and Mauya (2008). Mishra and Mohanty (2010) conducted research on site specific conservation plan for thermal power plant in Naraj of Cuttack, Orissa. They showed impact of coal based thermal power plant and suggested conserving measures. Patil and Katpatal (2008) studied the Chandrapur region in the concern of coal mines and its impacts on the surrounding region. Dwivedi and Tripathi (2007) showed that sensitive plants are abolished due to effect of coal fired industries in Varanasi district of state Uttar Pradesh in India. Information about land use change is necessary to update land cover maps and for effective management and planning of the natural resources for sustainable development (Alphan, 2003). The soil of Kolaghat block where coal-burned thermal power plant of 1260 MW is situated are stained by fly ash and consequently, wrong practices of crop selection and poor yield are being observed that leads to poor socio- economic condition of the people (Dasgupta and Paul, 2011).

The focused research was an attempt to develop land information system and GIS based approach to identify and classify land in relation to crop suitability depending on the present and persistent situation of Kolaghat block affected by coal burned thermal power plant, and to suggest proper utilization of land resources through GIS model to exercise sustainable agriculture.

Materials and Methods

The Kolaghat Thermal Power Plant is situated at 22°28'16"N and 87°52'12" E in Kolaghat block on the bank of Rupnarayan river in Purba Medinipur district, West Bengal, India. This power plant has a total installed capacity of 1260 MW generating about 7500-8000 ton of fly ash every day by consuming a total of 18000 ton of coal (Dasgupta and Paul, 2011). Kolaghat Block is covering 15480.51 ha of land. Total cultivated area is 10948.687 ha and cropping intensity is 177.95%. (District Statistical Handbook, 2004). The Kolaghat block is divided into thirteen circles mentioned by gram panchayats (Fig. 1, 2). The distance of all the circles from Kolaghat thermal power plant has been given in Table 1. Soil samples (130 nos.) were collected from all the circles on the basis of 1: 100000 map scale and their characteristics

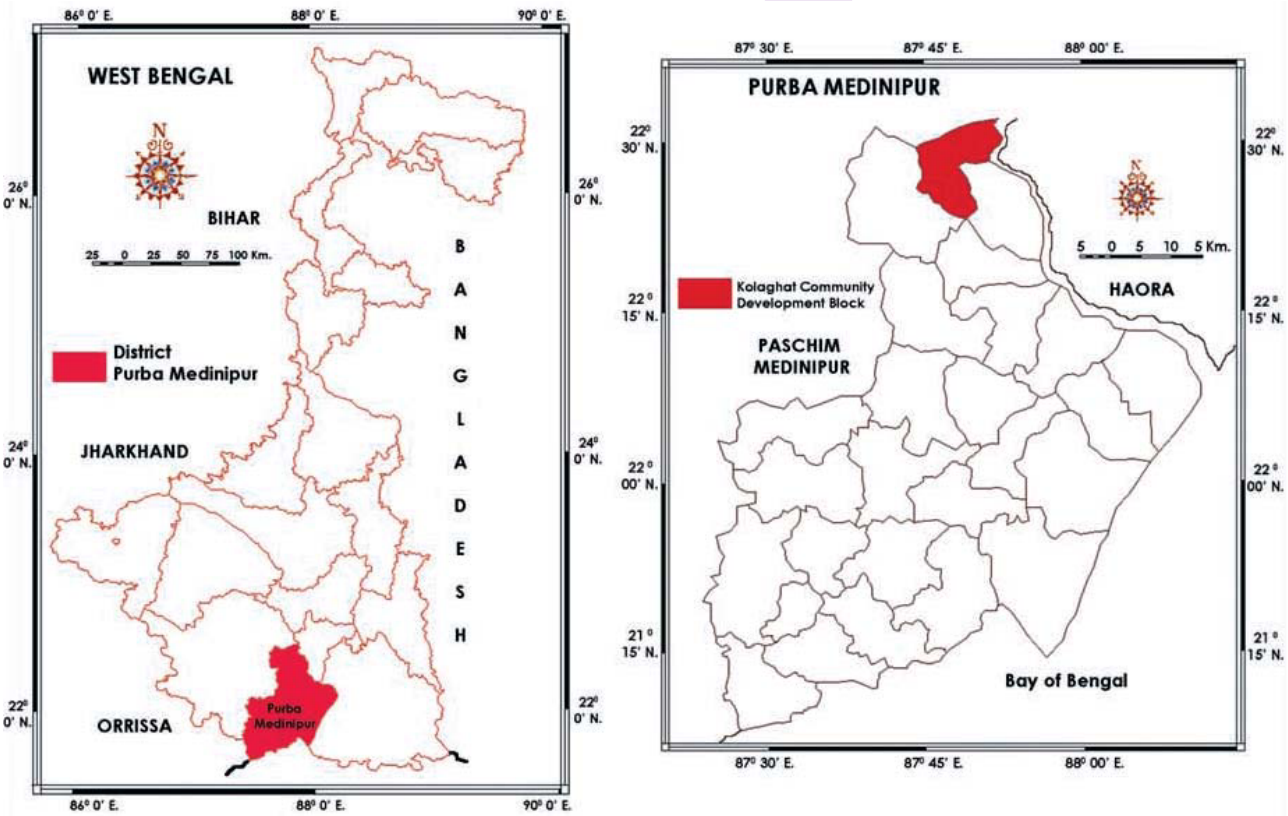

Fig. 1 : Location map of Kolaghat block in the district Purba Medinipur of West Bengal

were evaluated. Climate data, especially rainfall, humidity and temperature were recorded for the year of 2014, 2013 and 2012. The particles size distribution (sand, silt, clay) was determined by hydrometer method (Buoycos, 1962). pH of soil samples were estimated in the ratio of 1: 2.5:: soil: water (Jackson, 1973). Organic carbon (OC) and cation exchange capacity (CEC) were estimated by Walkley and Black method and mixed indicator method, respectively (Jackson, 1967). Available Ca and Mg were estimated by EDTA method (Black, 1965). Available potassium was estimated by flame photometer (Hesse, 1971). Crop suitability was assessed on the basis of concept of land utilization types (FAO, 1996; Sys *et al.*, 1993). With the help of GIS, various crops suitability were produced (Burrough, 1986).

Results and Discussion

The present study was carried out to generate land information systems regarding crop suitability of Kolaghat block and prepare a GIS Model for determination of potential crops to be grown economically and sustainably. The results and subsequent discussion are presented in the following sections:

Every crop prefers suitable climate for their proper vegetative and reproductive growth. Crops grow in different seasons due to impact of several climatic factors mainly rainfall, temperature and humidity. Suitability of potential crops is supported by these factors. The climate of Kolaghat Block is sub-humid, sub-tropical with mean annual temperature of 25.8°C. To evaluate the present land potentiality for selective crops in 2014, it was observed that the area received about 1450-1550 mm of mean rainfall. 1150 mm rainfall was received during June to September. The minimum and maximum air temperatures were 11.5 and 36.1 °C. The mean monthly relative humidity ranged from 40.5-98.3 % (Table 2) .The monthly average rainfall, temperature and humidity were more or less within the range for last three years.

The general slope of the area was 1-2 %. Topography was sub-normal with slow to moderate run-off. Most of the lands had raised mud wall. External drainage was through the small canals which were connected with medium canals. In general, the soils were moderately well to imperfectly drainable. Soils that represented thirteen circles had depth of more than 100 cm which was conducive for agricultural cultivation and was found to be deep soil. Soil texture acted as a guide to many soil characteristics directly or indirectly related to plant growth. The textural class helped in understanding crop suitability. Three broad textural groups identified were as follows silty loam, silty clay loam and silty clay. Fly ash changed texture of soil by increasing the silt content (Basu *et al.,* 2009). The nearer circles had silty loam

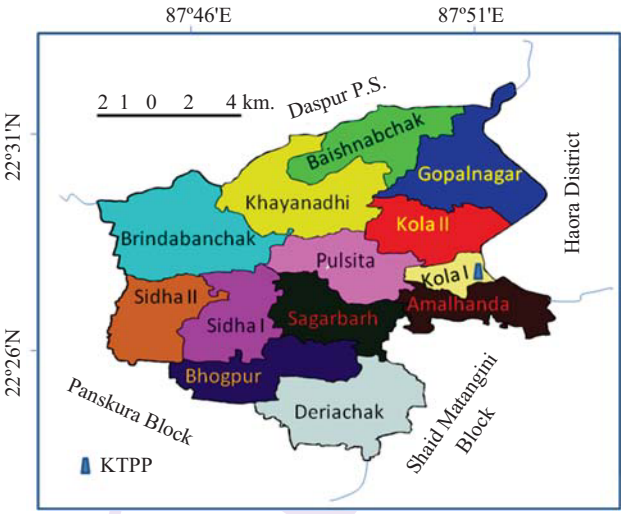

Fig. 2 : Area map of Kolaghat block with 13 circles

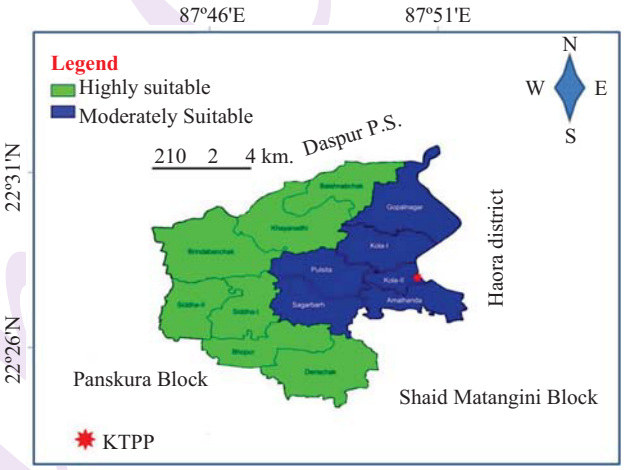

Fig. 3 : Levels of rice suitability with the limiting factor of soil fertility in Kolaghat block

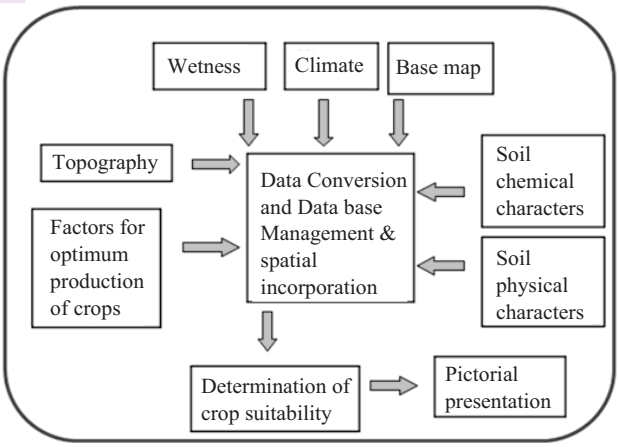

Fig. 4 : GIS Model approach for determination of crop suitability

Table 1 : Names of 13 circles of Kolaghat Block with distance from KTPP

Radius from KTPP	Names of circles or gram panchayats
<4 km	Kola-I, Kola-II, Amulhanda, Pulsita, Sagarbarh
4-8km	Gopalnagar, Khayanadhi, Siddha-I
8-12km	Baishnabchak, Deriachak, Bhogpur, Siddha- II, Brindabanchak

Table 2 : Climate data for the year 2014, 2013 and 2012

Month	Temperature (ºC)						Relative humidity (%)						Rainfall(mm)		
	2014		2013		2012		2014		2013		2012		2014	2013	2012
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.			
January	24.3	12.5	25.0	12.3	23.9	13.4	92.2	44.6	93.4	46.1	88.7	46.0	0	2.3	0
February	28.0	14.3	27.9	14.4	27.2	15.0	94.6	40.5	88.4	46.0	91.2	45.2	0	0	1.8
March	32.5	20.1	32.6	21.0	33.0	21.9	91.8	48.6	91.3	54.3	93.5	56.8	6.4	7.1	12.0
April	33.1	23.2	33.4	22.8	33.4	19.9	92.7	62.2	94.2	59.7	91.4	58.9	145.6	22.9	48.7
May	35.6	24.7	36.1	24.6	35.7	25.1	93.4	64.7	95.1	60.2	95.7	66.4	80.5	45.8	125.1
June	33.4	26.2	34.2	27.8	33.9	24.8	96.1	76.4	96.4	75.4	97.6	72.6	225.0	189.8	378.5
July	33.2	25.4	33.0	26.1	34.5	25.9	96.2	77.8	97.0	78.1	98.3	74.3	425.4	525.1	453.4
August	32.1	25.6	31.9	23.7	32.2	24.6	97.8	81.7	97.2	80.2	98.1	69.5	350.8	403.2	395.7
September	32.0	25.1	32.3	24.0	31.0	23.7	98.0	78.5	96.3	67.8	94.9	71.0	148.3	198.0	203.2
October	31.8	22.3	31.5	22.6	31.3	21.0	97.1	65.3	92.5	59.9	92.4	58.2	112.2	88.6	67.9
November	29.7	17.7	28.9	16.5	29.4	15.8	96.4	59.2	89.7	54.8	87.8	56.4	2.5	1.9	4.5
December	24.3	12.8	24.6	11.9	23.9	11.5	96.1	51.8	90.3	49.7	89.2	49.0	0	0	1.3

soil. In general, the soil of Kolaghat was silty loam dominated. Coarse fragment was not found in the areas of sampling or negligible (Table 3).

Soil pH is an important property which affects the availability of several plant nutrients. The pH of soils from different circles ranged from 5.98 to 8.01. The garden soil mixed with fly ash had slightly alkaline pH 7.43 – 7.62 (Tiwari *et al.*, 2013). Fly ash accumulated on the adjacent circles *i. e.*, Kola-I, Kola- II, Gopalnagar, Amulhanda, Sagarbarh, Pulsita and resulted increased soil reaction by changing soil pH. Addition of fly ash increased the pH of amendments from 6.15 to 7.05 (Gond *et al.,* 2013). It reflected that soil reaction of adjacent area (<4 km) to thermal power plant was alkaline (> 7.5) which reduced the production potential of crops needed for subsistence & economy in the locality. Soils become more alkaline due to alkaline nature of fly ash around coal based thermal power plant (Singh *et al.*, 1995; Basu *et al.,* 2009). The rest showed decreasing trend due to use of acidic inputs in farming. Cation exchange capacity is the most analytical information as far nutrient management is concerned. CEC value of minimum 10 meq100 gm^{-1} of soil might be a good soil for average crop production. Data showed that this value varied from 8.0 to 18.1 meq100 gm^{-1} of soil. In general, soils of Kolaghat retained good cation exchange capacity. The observed base saturation (BS) ranged from 79.3 to 94.2 %. This indicated that calcium, magnesium and potassium were present in high quantity. Soil organic carbon (OC) reflects the soil productivity, it varied from 0.36 – 0.81 %. In soil mixed with fly ash at the rate of 20 ton ha^{-1} organic carbon content was 0.36% (Sharma and Kalra, 2006). In most cases, organic carbon status was medium ranging from 0.50 to 0.75% (Table 3).

The climate and soil of Kolaghat block, especially in the areas within 4 km radius were influenced by fly ash emitted from thermal power plant. Thermal power stations were causing soil pollution leading to its defertilization and environmental pollution leading to climate change (Rind *et al*., 2013; Shamshad *et al.,* 2012; Avirneni and Bandlamudi, 2013). This is realized by unsuitability of several crop cultivations, whereas the circles beyond 4 km of radius were suitable for maximum crop cultivation without or with minor improvement of limiting factors of growth. Crops prefer suitable climate, topography, wetness, soil properties for their optimum growth and development which ultimately results in maximum production. The present features of land select appropriate crops need no improvement in the parameters. Some crops could grow in different circles of the block Kolaghat with minor amelioration of the factors. Generally, the crops which had the demand for both subsistence and economy were evaluated for crop suitability. Land suitability evaluation was conducted on ten specific

Table 3 : Status of different determining factors for evaluation of crop suitability around KTPP

Circle name	Climate (c)	Topography (t)	Wetness (w)		Soil physical character (s)			Soil chemical character (f)			
			Flood	Drainage	Depth (cm)	Surface texture	Coarse fragment	CEC meq $100g^{-1}$	pH	BS (%)	OC (%)
Kola-I	Sub-tropical	Medium 1-3%	No	moderate	> 100	sil	nil	16.1	7.58	94.2	0.36
Kola-II	Sub-tropical	Medium 1-3%	No	moderate	> 100	sil	nil	15.3	7.86	88.4	0.51
Gopalnagar	Sub-tropical	Low 1-2%	Moderate	poor	> 100	sil	nil	17.8	7.90	84.6	0.60
Baishnabchak	Sub-tropical	Low 0-1%	Moderate	poor	> 100	sicl	nil	12.4	6.41	79.3	0.81
Khayanadhi	Sub-tropical	Low 1-2%	Occasional	poor	> 100	sicl	nil	10.1	5.98	85.8	0.58
Pulsita	Sub-tropical	Medium 1-2%	Occasional	moderate	> 100	sil	nil	18.1	7.74	90.1	0.48
Sagarbarh	Sub-tropical	Low 0-1%	Occasional	poor	> 100	sicl	nil	16.7	7.91	89.2	0.52
Amulhanda	Sub-tropical	Low 0-1%	Moderate	moderate	> 100	sil	nil	17.3	8.01	86.6	0.64
Deriachak	Sub-tropical	Low 0-1%	Occasional	poor	> 100	cl	nil	9.2	5.95	78.5	0.71
Bhogpur	Sub-tropical	medium0-1%	Moderate	moderate	> 100	cl	nil	8.0	6.01	82.7	0.78
Siddha-I	Sub-tropical	Medium 1-3%	No	moderate	> 100	sicl	nil	11.3	6.05	86.3	0.64
Siddha-II	Sub-tropical	Medium 0-1%	Occasional	moderate	> 100	sil	nil	14.0	6.13	89.1	0.69
Brindabanchak	Sub-tropical	Medium 1-2%	Occasional	moderate	> 100	cl	nil	12.7	6.27	87.9	0.63
Fly ash	——-	——-	——-	——-	——-	ssi	nil	26.3	8.42	82.5	0.20

sil: silty loam; sicl: silty clay loam; cl: clay loam; ssi: sandy silt

Table 4: Orders of suitability for the crops with the limiting factors in different circles of Kolaghat Block

Circle name	Rice	Wheat	Maize	Sesame	Jute	Vegetable crops	Flowers
Kola-I	S2f	S2cf	S2f	S2f	S2f	S2cf	S2f
Kola-II	S2f	S2cf	S1	S1	S1	S2c	S1
Gopalnagar	S2f	S2cf	S1	S1	S1	S2f	S1
Baishnabchak	S1	S2c	S1	S1	S1	S1	S1
Khayanadhi	S1	S2c	S1	S1	S1	S1	S1
Pulsita	S2f	S2cf	S1	S1	S1	S2cf	S2f
Sagarbarh	S2f	S2cf	S1	S1	S1	S2cf	S1
Amulhanda	S2f	S2cf	S1	S1	S1	S2cf	S1
Deriachak	S1	S2c	S1	S1	S1	S1	S1
Bhogpur	S1	S2c	S1	S1	S1	S1	S1
Siddha-I	S1	S2c	S1	S1	S1	S1	S1
Siddha-II	S1	S2c	S1	S1	S1	S1	S1
Brindabanchak	S1	S1	S1	S1	S1	S1	S1

crop ranges generated from forty crops (Nethononda *et al.*, 2014) In the affected areas, Kola-I, Kola-II, Gopalnagar, Pulsita, Sagarbarh, Amulhanda of Kolaghat thermal power plant rice was moderately suitable with improvement of some soil properties such as soil pH and organic carbon. The circles which were beyond 4 km from the power plant were suitable for rice cultivation (Fig. 3). Wheat is one of the important cereal crops that prefers cold climate and supporting soil properties for its optimum growth. Cultivation of wheat is restricted in all the circles except Brindabanchak due to limitation of climate, soil pH and soil organic carbon. Being a fibre crop, jute thrives well in humid and warm climate. The areas near to the Kolaghat thermal power plant were more or less suitable for jute cultivation. Only Kola-I had moderate limitation of soil organic carbon. But jute is not growing there though the almost all circles had the potentiality for jute cultivation. Sesame is an oil seed crop that prefers warm climate. The present land scenario showed that sesame was highly suitable for all the circles, except Kola – I which needed moderate improvement in soil organic carbon as per physiological requirement of sesame. But sesame was cultivated in only 45 ha out of 10948.687 ha cultivated area. Vegetable crops are commercially cultivated during winter. These crops usually prefer prolonged cold and dry climate for their proper growth and development. The mean temperature and short duration of winter are above the congenial level of winter crops in the adjacent areas of Kolaghat thermal power plant due to emission fly ash flapping and shedding thereby. The circles namely, Kola – I, Kola- II, Gopalnagar, Pulsita, Sagarbarh, Amulhanda had limitation of climate, soil pH and

Table 5 : Percentage of acreage for different cultivated crops and evaluated suitable crops with their CI and cropping times per annum

Crop area	Rice (%)	Wheat (%)	Maize (%)	Sesame (%)	Jute (%)	Vegetable crops (%)	Flowers (%)	Others (%)
Present crop area with CI of 177.95%.	70.11	0.67	0.01	0.03	0.12	4.35	6.02	5.8
Cropping times per year	twice	once	once	once	once	thrice	thrice	once
Area for suitable crops with CI > 300 %	59.73	12.49	96.98	96.98	96.98	67.49	88.90	—-
Cropping times per year	thrice	once	thrice	once	once	thrice	thrice	—-

soil organic carbon. In rest of the circles cultivation of vegetable crops was possible. Flowers grow in different seasons. Biannual and perennial flowers are commercially cultivated. They all prefer moderate warm and humid climate for proper vegetative and reproductive growth. The climate and soil within the distance of 4 km from KTPP were influenced by emission of fly ash. All the circles were suitable for flower cultivation, except Kola- I and Pulsita where moderate improvement in soil organic carbon was needed. Maize is a day neutral crop having wide range of adaptability. As per physiological requirement of maize and present features of climate and soil properties, maize was suitable in all the circles, except Kola – I where organic carbon is a limiting factor. GIS model assessed crop suitability and produced pictorial presentation of these crops.

It was observed that rice was moderately suitable (S2) in the nearby circles like Kola-I, Kola-II, Gopalnagar, Amulhanda with limitations of soil fertility and wetness (Table 4). Wheat was limited suitable (S2) for growing in almost all the circles, except Brindabanchak. Maize, sesame, jute and flowers were suitable (S1) for potential production with minor constraints of soil fertility in the affected areas. Suitability of maize crop was evaluated by using GIS (Esa, 2014). Kola-I circle was moderately suitable (S2) for the same due to limitation of soil fertility. Vegetable crops also faced barriers of climate and soil fertility within 4 km of KTPP though rest of the circles was suitable (S1). Among these, no crop turned up permanently uncultivable (N).

Agriculture is losing its economic importance by adopting wrong crops in non-supporting areas. Selection of site specific suitable crops encourages sustainable agriculture which subsequently controls the use of fertilizers and pesticides. This evaluation shows diversification of crops and healthy crop rotation that nourishes the agricultural sustainability (Table 5). Out of total geographical area of 15480.51 ha, 10948.687 ha was cultivated. The 70.11 % area of Kolaghat was cultivated for rice, where as GIS model estimated 59.73 % area could be economically cultivated. Rice suitability was evaluated by using multi criteria evaluation approach and GIS (Maddahi *et al.,* 2014).Wheat was grown in 0.67 % area. Due to supportive soil and weather factors, 12.49 % land situated at 12 km away from KTPP was potential for wheat farming. Maize, sesame and jute were commercially viable with the potentials of 96.98 % area each though these were being grown in 0.01%, 0.03 % and 0.12% area respectively. Growing of vegetable crops was suitable (S1) in 67.49% of total cultivable land outside the affected areas. Flowers could be grown (S1) in 88.9 % of area including the affected circles. This evaluation of crop suitability increased the cropping intensity (CI) higher than 300% from 177.95 % under any suitable combination throughout the year. The CI was 176.55% in 2010 in Borodangi Mouza in Kolaghat Block (Dasgupta and Paul, 2011).This estimated potential of land with exact crops would consequently check soil erosion and suggest proper utilization of natural resources available in the areas which would lead to sustainable agriculture.

GIS Model determined the suitability of crops based on multiple climatic (rainfall, temperature, humidity) and land attributes (wetness, topography, soil characters) that assessed the potentiality of land for specific use. When analyzing with GIS and ecological planning methods, despite the size of the area, it is possible to select suitable sites to develop a specific productive activity (Malagrino e*t al*., 2008). GIS technology was associated with Multi-Criteria Evaluation (MCE) technique. Analysis of land suitability for thermal power plant was done by using multi-criteria evaluation approach (Sadeghi *et al.*, 2011). Geocoding tool was used to create geographic references on the scanned base map. The data were incorporated through integrating, digitizing, editing and manipulating processes. Data Based Management System (DBMS) ran Weighted Linear Combination (WLC) operation to assess the suitability of pixels by weighing and combining the governing factors of crop suitability. Each thematic layer represented an evaluation criterion and grid cells were valued according to their quality for a particular land use (Eastman and Labs, 1999). WLC also standardized all the criteria of optimum crop production. An analytical hierarchy order was developed by assigning numerical values on relative importance of each factor. After summing the overlying maps together for each level of hierarchy, a spatial comparison was then undertaken between the crop suitability classes (namely N2, N1, S3, S2 and S1) and the corresponding pixels of land suitability indices (0, 1, 2, 3 and

4). Finally, the GIS Model determined the crop suitability and produced pictorial presentation. For judging crop potentiality, weighing and intensity ratings of the criteria for optimum growth of the particular crop were adjusted and suitability classes were evaluated (Fig.4).

Evaluation of different crop suitability suggested potential crops to be grown and would rectify malcropping which led poor yield and increase of barren land. The best crops which could thrive well were selected through the frame work of determination of crop suitability using the parameters analyzed and recorded data. This crop association implied agricultural sustainability through GIS model approach to determine the best alternative uses of land.

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