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INDEX

A

G

H

I

J

K

L

M

N

APPENDICES

Appendix-A

Supplementary Tables

1. Changes in Cropping area of Cereals from 1995-96 to 2020-21

Name of the blocks	Cropping area of Cereals in ha.										Relative Deviation (RD) in %				
	1995-96					2020-21									
	Autumn rice (Aus)	Winter rice (Aman)	Summer rice (Boro)	Wheat	Maize	Autumn rice (Aus)	Winter rice (Aman)	Summer rice (Boro)	Wheat	Maize	Autumn rice (Aus)	Winter rice (Aman)	Summer rice (Boro)	Wheat	Maize
Bamangola	50	8230	2050	1214	0	0	15000	5000	2200	1220	-100	82.26	143.9	81.22	0
Chanchal-I	650	11890	6680	1594	3	0	10850	3900	200	630	-100	-8.75	-41.62	-87.45	20900
Chanchal-II	330	14660	7590	2181	0	0	12750	9300	650	1725	-100	-13.03	22.53	-70.2	0
English Bazar	3420	6240	4980	1497	392	0	4650	2750	1990	9015	-100	-25.48	-44.78	32.93	2199.74
Gazole	1050	36500	5470	3036	86	25	32000	9000	4000	1930	-97.62	-12.33	64.53	31.75	2144.19
Habibpur	60	24010	3390	791	14	0	27500	7500	350	725	-100	14.54	121.24	-55.75	5078.57
Harish-Chandrapur-I	0	13000	8040	2236	75	0	9350	6490	17	3975	0	-28.08	-19.28	-99.24	5200
Harish-Chandrapur-II	0	18390	10500	4046	269	0	12890	5425	25	7660	0	-29.91	-48.33	-99.38	2747.58
Kaliachak-I	1190	6240	610	1262	141	0	450	210	650	1012	-100	-92.79	-65.57	-48.49	617.73
Kaliachak-II	2000	30	500	572	732	0	500	186	800	3980	-100	1566.67	-62.8	39.86	443.72
Kaliachak-III	2540	1320	1740	4851	171	0	970	50	125	4935	-100	-26.52	-97.13	-97.42	2785.96
Manikchak	3450	860	1000	7262	2730	20	800	1000	6500	2750	-99.42	-6.98	0	-10.49	0.73
Old Malda	1270	3370	2260	1077	100	0	10650	5000	430	3310	-100	216.02	121.24	-60.07	3210
Ratua-I	1300	1950	4570	5957	1439	0	6620	5480	310	3370	-100	239.49	19.91	-94.8	134.19
Ratua-II	600	6390	6000	853	529	0	6470	4300	0	1560	-100	1.25	-28.33	-100	194.9

Source: District Statistical Handbook, 1997; Agricultural Census, 1995-96 and PAO, Maldah (2021)

2. Changes in Cropping area of Pulses from 1995-96 to 2020-21

Name of the blocks	Cropping area of Pulses in ha.								Relative Deviation (RD) in %			
	1995-96				2020-21							
	Gram	Masoor	Maskalai	Khesari*	Gram	Masoor	Maskalai	Khesari	Gram	Masoor	Maskalai	Khesari
Bamangola	0	0	20	730	10	250	40	30	0.00	0.00	100.00	-95.89
Chanchal-I	49	132	10	200	0	610	450	10	-100.00	362.12	4400.00	-95.00
Chanchal-II	40	28	300	200	0	2300	337	10	-100.00	8114.29	12.33	-95.00
English Bazar	1502	583	0	0	1020	1930	5697	890	-32.09	231.05	0.00	0.00
Gazole	277	91	720	0	110	1500	355	15	-60.29	1548.35	-50.69	0.00
Habibpur	45	236	0	240	50	300	243	150	11.11	27.12	0.00	-37.50
Harish-Chandrapur-I	16	21	150	230	0	335	298	10	0.00	1495.24	98.67	-95.65
Harish-Chandrapur-II	33	149	30	0	0	240	480	10	0.00	61.07	1500.00	0.00
Kaliachak-I	165	161	70	130	1	40	310	50	-99.39	-75.16	342.86	-61.54
Kaliachak-II	433	614	220	520	60	300	785	120	-86.14	-51.14	256.82	-76.92
Kaliachak-III	234	1619	3800	50	5	120	175	20	-97.86	-92.59	-95.39	-60.00
Manikchak	1106	933	6250	4	50	600	3200	350	-95.48	-35.69	-48.80	8650.00
Old Malda	129	17	60	110	6	600	470	10	-95.35	3429.41	683.33	-90.91
Ratua-I	253	388	5010	1060	0	2990	2865	10	-100.00	670.62	-42.81	-99.06
Ratua-II	774	489	1040	0	0	230	720	10	-100.00	-52.97	-30.77	0.00

Khesari*= data year 2003-04

Source: District Statistical Handbook, 1997; Agricultural Census, 1995-96 and PAO, Maldah (2021)

3. Changes in Cropping area of Oilseeds and cash crops from 1995-96 to 2020-21

Name of the Blocks	Cropping area of Oilseeds and cash crops in ha.								Relative Deviation (RD) in %			
	1995-96				2020-21							
	Rapeseed & Mustard	Jute	Sugarcane	Potato	Rapeseed & Mustard	Jute	Sugarcane	Potato	Rapeseed & Mustard	Jute	Sugarcane	Potato
Bamangola	2904	5	0	708	5785	270	0	750	99.21	5300	0	5.93
Chanchal-I	400	5602	0		3450	4000	0	540	762.5	-28.6	0	0
Chanchal-II	1441	4054	0	185	1505	3160	0	570	4.44	-22.05	0	208.11
English Bazar	197	106	45	278	2665	770	500	190	1252.79	626.42	1011.11	-31.65
Gazole	5078	1861	20	820	8500	1550	185	4000	67.39	-16.71	825	387.8
Habibpur	1282	66	0	381	3970	500	0	350	209.67	657.58	0	-8.14
Harishchandrapur-I	1055	3095	0	462	815	2925	0	325	-22.75	-5.49	0	-29.65
Harishchandrapur-II	270	4217	14	45	595	3220	0	510	120.37	-23.64	-100	1033.33
Kaliachak-I	83	119	73	19	385	250	223	10	363.86	110.08	205.48	-47.37
Kaliachak-II	563	125	322	8	200	900	160	20	-64.48	620	-50.31	150
Kaliachak-III	269	2487	412	69	170	5200	6	15	-36.8	109.09	-98.54	-78.26
Manikchak	140	2417	328	380	1175	4600	700	120	739.29	90.32	113.41	-68.42
Old Malda	198	255	0	0	4750	750	0	2500	2298.99	194.12	0	0
Ratua-I	258	3803	55	238	820	2315	0	585	217.83	-39.13	-100	145.8
Ratua-II	11	474	6	246	440	1700	0	330	3900	258.65	-100	34.15

Source: District Statistical Handbook, 1997; Agricultural Census, 1995-96 and PAO, Maldah (2021)

4. Block wise ranking of crops in 1995-96

Sl. No.	Crop	Bamangola	Chanchal-I	Chanchal-II	English Bazar	Gazole	Habibpur	Harishchandrapur-I	Harishchandrapur-II	Kaliachak-I	Kaliachak-II	Kaliachak-III	Manikchak	Old Maldah	Ratua-I	Ratua-II
1	Autumn rice (Aus)	6	5	6	3	6	8	11	13	3	1	3	3	3	7	6
2	Winter rice (Aman)	1	1	1	1	1	1	1	1	1	11	7	9	1	5	1
3	Summer rice (Boro)	3	2	2	2	2	2	2	2	4	6	5	7	2	3	2
4	Wheat	4	4	4	5	4	4	4	4	2	4	1	1	4	1	4
5	Maize	9	10	12	7	11	10	8	6	7	2	11	4	8	6	7
6	Gram	10	8	9	4	9	9	10	9	5	7	10	6	7	10	5
7	Masoor	11	7	10	6	10	6	9	7	6	3	6	8	10	8	8
8	Maskalai	7	9	7	13	8	11	7	10	11	9	2	2	9	2	3
9	Khesari	12	12	13	12	13	13	13	12	13	13	13	13	13	13	13
10	Rapeseed and Mustard	2	6	5	9	3	3	5	5	9	5	9	12	6	9	11
11	Jute	8	3	3	10	5	7	3	3	8	10	4	5	5	4	9
12	Sugarcane	13	13	11	11	12	12	12	11	10	8	8	11	12	12	12
13	Potato	5	11	8	8	7	5	6	8	12	12	12	10	11	11	10

Source: District Statistical Handbook, 1997; Agricultural Census, 1995-96

5. Block wise ranking of crops in 2020-21

Sl. No	Block name	Bamangola	Chanchal-I	Chanchal-II	English Bazar	Gazole	Habibpur	Harishchandrapur-I	Harishchandrapur-II	Kaliachak-I	Kaliachak-II	Kaliachak-III	Manikchak	Old Maldah	Ratua-I	Ratua-II
1	Autumn rice (Aus)	13	13	13	13	12	11	13	12	13	13	13	13	13	13	11
2	Winter rice (Aman)	1	1	1	3	1	1	1	1	3	5	3	7	1	1	1
3	Summer rice (Boro)	3	3	2	4	2	2	2	3	8	8	8	6	2	2	2
4	Wheat	4	9	7	6	5	7	9	9	2	3	6	1	9	9	10
5	Maize	5	5	5	1	6	4	3	2	1	1	2	4	4	3	4
6	Gram	11	12	11	8	11	13	11	11	12	11	12	12	11	11	13
7	Masoor	8	6	4	7	8	8	6	8	10	6	7	9	7	4	8
8	Maskalai	9	8	9	2	9	9	8	7	5	4	4	3	8	5	5
9	Khesari	10	10	10	9	13	10	10	10	9	10	9	10	10	10	9
10	Rapeseed and Mustard	2	4	6	5	3	3	5	5	4	7	5	5	3	7	6
11	Jute	7	2	3	10	7	5	4	4	6	2	1	2	6	6	3
12	Sugarcane	12	11	12	11	10	12	12	13	7	9	11	8	12	12	12
13	Potato	6	7	8	12	4	6	7	6	11	12	10	11	5	8	7

Source: PAO, Maldah (2021)

6. Block wise crop diversification index in Maldah district (1995-96 and 2020-21)

Name of the Blocks	1995-96			2020-21		
	The cultivated area of x crops in %	Number of x crops	Crop Diversification Index	The cultivated area of x crops in %	Number of x crops	Crop Diversificati on Index
Bamangola	86.85	3	28.95	84.39	3	28.13
Chanchal-I	89.49	3	29.83	90.1	4	22.52
Chanchal-II	85.38	3	28.46	68.25	2	34.13
English Bazar	76.09	3	25.36	60.38	3	20.13
Gazole	72.35	3	24.12	78.36	3	26.12
Habibpur	90.50	2	45.25	84.06	2	42.03
Harishchandrapur-I	85.74	3	28.58	92.67	4	23.17
Harishchandrapur-II	97.87	4	24.47	94.01	4	23.50
Kaliachak-I	85.78	3	28.59	69.53	4	17.38
Kaliachak-II	54.68	3	18.23	60.92	2	30.46
Kaliachak-III	70.1	4	17.53	85.96	2	42.98
Manikchak	73.32	4	18.33	77.98	4	19.49
Old Maldah	91.31	4	22.83	83.26	4	20.82
Ratua-I	76.68	4	19.17	84.07	5	16.81
Ratua-II	71.16	2	35.58	79.12	3	26.37

Source: District Statistical Handbook, 1997; Agricultural Census, 1995-96 and PAO, Maldah (2021)

7. Comparison of total operating cost among marginal, small and large farmers

Major crops	Marginal (₹/ha.)	Small (₹/ha.)	Large (₹/ha.)	Average return in ₹/ha
Winter rice (aman)	36630	38150	39646	38142
Summer rice (boro)	37940	39150	41846	39645
Wheat	10940	10550	12146	11212
Maize	17940	18350	20146	18812
Lentil (masoor)	6440	6150	9946	7512
Urad (maskalai)	5940	5750	9346	7012
Rapeseed & mustard	11340	11850	13346	12179
Jute	32350	33850	41746	35982
Potato	135340	134850	140346	136845

(Calculated by the researcher based on field survey, 2020-21)

8. Comparison of total labour requirement among marginal, small and large farmers

Major crops	Marginal (number/ha.)	Small (number/ha.)	Large (number/ha.)	Average in number/ha.
Winter rice (aman)	135	142	153	143
Summer rice (boro)	135	142	149	142
Wheat	50	46	48	48
Maize	59	61	60	60
Lentil (masoor)	54	48	47	50
Urad (maskalai)	56	51	53	53
Rapeseed & mustard	53	51	49	51
Jute	139	146	150	145
Potato	96	105	99	100

(Calculated by the researcher based on field survey, 2020-21)

9. Comparison of gross profit of the marginal, small and large farmers

Major crops	Marginal (₹/ha)	Small (₹/ha)	Large (₹/ha)	Average return in ₹/ha
Winter rice (aman)	53586	55328	59314	56076
Summer rice (boro)	58276	60328	66114	61573
Wheat	20660	19928	23814	21467
Maize	75560	76650	84854	79021
Lentil (masoor)	13430	13750	10254	12478
Urad (maskalai)	12930	12150	9854	11645
Rapeseed & mustard	26430	25250	26854	26178
Jute	135150	127250	141454	134618
Potato	229660	226150	229654	228488

(Calculated by the researcher based on field survey, 2020-21)

10. Comparison of net profit of the marginal, small and large farmers

Major crops	Marginal (₹/ha.)	Small (₹/ha.)	Large (₹/ha.)	Average return in ₹/ha
Winter rice (aman)	48324	49606	52135	50021
Summer rice (boro)	52975	54576	61119	56223
Wheat	13669	13534	18210	15137
Maize	69359	70272	79510	73047
Lentil (masoor)	3324	4738	5466	4509
Urad (maskalai)	2839	3150	3834	3274
Rapeseed & mustard	18677	18567	22214	19819
Jute	125267	116907	137462	126545
Potato	219187	215277	222204	218889

(Calculated by the researcher based on field survey, 2020-21)

11. Comparison of the return to operating cost among marginal, small and large farmers

Major crops	Marginal (return/₹1/ha.)	Small (return/₹1/ha.)	Large (return/₹1/ha.)	Average return/₹1/ha.
Winter rice (aman)	1.46	1.45	1.5	1.47
Summer rice (boro)	1.54	1.54	1.58	1.55
Wheat	1.89	1.89	1.96	1.91
Maize	4.21	4.18	4.21	4.2
Lentil (masoor)	2.09	2.24	1.03	1.66
Urad (maskalai)	2.18	2.11	1.05	1.66
Rapeseed & mustard	2.33	2.13	2.01	2.15
Jute	4.18	3.76	3.39	3.74
Potato	1.7	1.68	1.64	1.67

(Calculated by the researcher based on field survey, 2020-21)

12. Comparison of the return to total cost of different crops in the study area

Major crops	Marginal (₹1/ha.)	Small (₹1/ha.)	Large (₹1/ha.)	Average return/₹1/ha.
Winter rice (aman)	1.15	1.13	1.11	1.13
Summer rice (boro)	1.23	1.22	1.30	1.25
Wheat	0.76	0.80	1.03	0.86
Maize	2.87	2.84	3.12	2.95
Lentil (masoor)	0.20	0.31	0.37	0.29
Urad (maskalai)	0.18	0.21	0.25	0.21
Rapeseed & mustard	0.98	1.00	1.24	1.07
Jute	2.97	2.65	3.01	2.87
Potato	1.50	1.48	1.50	1.49

(Calculated by the researcher based on field survey, 2020-21)

13. Comparison of the return to family labour, land, management per day of different crops in the study area

Major crops	Marginal (₹/day/ha)	Small (₹/day/ha)	Large (₹/day/ha)	Average return in ₹/day/ha.
Winter rice (aman)	595	615	659	623
Summer rice (boro)	648	670	735	684
Wheat	230	221	265	239
Maize	540	548	606	564
Lentil (masoor)	149	153	114	139
Urad (maskalai)	144	135	109	129
Rapeseed & mustard	220	210	224	218
Jute	1126	1060	1179	1122
Potato	1914	1885	1914	1904

(Calculated by the researcher based on field survey, 2020-21)

14. Cronbach's alpha coefficient of the driving forces of ALU change for the different farmers category

Variable	Marginal farmer	Small farmer	Large farmer
Ecological or biophysical	0.713	0.783	0.723
Economic	0.829	0.851	0.716
Socio-cultural	0.733	0.775	0.721
Technological or institutional	0.829	0.789	0.835

(Calculated by the researcher based on field survey, 2020-21)

15. Cronbach's alpha coefficient of the different farmers livelihood assets influenced by ALU change

Variable	Marginal farmer	Small farmer	Large farmer
Physical and cultural assets	0.733	0.765	0.741
Human assets	0.779	0.838	0.822
Social assets	0.738	0.713	0.881
Financial assets	0.767	0.817	0.718

(Calculated by the researcher based on field survey, 2020-21)

Appendix-B

: RESEARCH QUESTIONNAIRE:

TRENDS AND PATTERNS OF AGRICULTURAL LAND USE IN MALDAH DISTRICT, WEST BENGAL

A. GENERAL INFORMATION:

1) Sl. No.: _____________ 2) Date of Interview: ___________________

3) Block: _______________________ 4) Name of the Village/Mouza: ___________________

5) Head of the Family: **Male/Female**

6) Respondent's detail:

Name	Sex (M/F)	Age	Marital Status (M/S)	Educational level	Primary occupation	Employment status	Monthly income (Rs.)

7) Religion: **i) Hindu ii) Muslim iii) Christian iv) Others**

8) Caste: **Gen/S.C/S. T/O.B.C-A/O.B.C-B**

9) Family type: **Joint/Nuclear**

10) No. of family members: i) **Male:** ________ ii) **Female:** _________ **iii) Total:** _________

11) How do you consider yourself?

Option	**Response**
11.1. Very poor	
11.2. Poor	
11.3. Lower middle-income level	
11.4. Middle income level	
11.5. Higher middle-income level	
11.6. Rich	
11.7. Very rich	

12) Amount of monthly expenditure:

Items	**Monthly expenditure in Rs.**
12.1. Food/drinks	
12.2. Heating/ Electricity	
12.3. Clothing	
12.4. Health	
12.5. Education	
12.6. Travel/ Entertainment	
12.7. Others (Specify)____	

13) Do you have any savings? **Yes/No**

If yes, then types of savings: **Govt. /Private/ Post office/ others**

14) Amount of annual savings (Rs.): ____________________

15) Does your household currently have a loan? **Yes/No**

If yes, then amount (Rs.): ___________________ Purpose: ___________________________

16) No. of family members engaged in agriculture**:**

i) Male: _________ ii) Female: _________ iii) Total: __________

17) How long have you involved with farming and agro-related activities?

i) <10 years ii) 10-15 years iii) 16-20 years iv) >20 years

18) Annual family income from agriculture: **i) <60,000 ii) 60,000-100,000 iii) 100000-150000**

iv) 150000-200000 v) >2000000

B. <u>INFORMATION ON AGRICULTURAL LANDUSE:</u>

19) Size of land holding: **i) < 7.50 Bigha (Marginal) ii) 7.50 to 15.00 Bigha (Small) iii) <15.00 Bigha (Large)**

20) Agricultural land use pattern with sowing and harvesting season

Sl. No.	Name of the Crops	Area in Bigha	Yield (kg/Bigha)	Sowing season	Harvesting season
21.1.					
21.2.					
21.3.					
21.4.					
21.5.					

22) Details of irrigation facilities

Sl. No.	Modes of irrigation	Area covered (Bigha)
22.1.	Tank	
22.2.	Well	
22.3.	Deep tube well (DTW)	
22.4.	Swallow tube well (STW)	
22.5.	Pond	
22.6.	RLI	
22.7.	Others	

23) Farmland description: **i) Own land ii) Share cultivation iii) Lease land**

24) Types of crops you cultivate: **cash crop/Food crop/Both**

25) Do you prefer Hybrid varieties? **Yes/No**

26) Do you have a Kishan Credit card? **Yes/ No**

27) Do you receive any assistance from the agricultural department? **Yes/No.**

If yes, Type: ____

28) have you received any agricultural loans? **Yes/No**

If yes, give particulars:

Department	Amount received	Year	Duration	Performance
28.1. Individual				
28.2. Village council				
28.3. Village co-operative bank				
28.4. National bank				

29) Doses of fertilizer:

Sl. No.	Name of the Crops	Fertilizer in kg per Bigha				
		UREA	Single Super Phosphate (SSP)	Triple Super Phosphate (TSP)	Muriate of potash (MOP)	Diammonium Phosphate (DAP)
29.1.						
29.2.						
29.3.						
29.4.						
29.5.						

30) Doses of pesticides per Bigha: **i) <300 ml ii) 300-600 ml iii) 600-900 ml iv) >900 ml**

C. INFORMATION ON DRIVING FORCES AND IMPACTS:

31) Driving forces of agricultural land use change

31.1 Socio-cultural drivers

Sl. No.	Particulars	Level				
		Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
31.1.1	Growth of population					
31.1.2	Migration					
31.1.3	Higher Education					
31.1.4	Farmer’s age					
31.1.5	Farmer's succession					
31.1.6	Farmer's attitude					
31.1.7	Area of operational land holding					
31.1.8	Recreation and tourism					
31.1.9	Societal demand for other services					
31.1.10	Growing demand					
31.1.11	Neighbour cultivation					

31.2 Economic drivers:

Sl. No.	Particulars	Level				
		Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
31.2.1	Shortage of Irrigation facilities					
31.2.2	Urbanisation					
31.2.3	Inadequacy of labour					
31.2.4	Scarcity of big pond/water reservoir					
31.2.5	In access to road					
31.2.6	Unavailability of market centre					
31.2.7	Fluctuation of market price					
31.2.8	High cost of manures					
31.2.9	High cost of fertilizers					
31.2.10	Unavailability of crop loan					
31.2.11	Inadequate credit facility					
31.2.12	Malpractices of Merchant					
31.2.13	Arbitrary deduction by the merchant or wholesaler agents					

31.3 Technological and institutional drivers:

Sl. No.	Particulars	Level				
		Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
31.3.1	Lack of mechanization					
31.3.2	Lack of land improvement					
31.3.3	Inadequacy of new breed and cultivars					
31.3.4	Shortage of highbred varieties					
31.3.5	Inadequacy of fertilizer and pesticides					
31.3.6	Lack of tenure/ownership security					
31.3.7	Lack of production subsidies					
31.3.8	Lack of land management subsidies					
31.3.9	Lack of agricultural land consolidation					
31.3.10	Lack of proper land use plan					

31.4 Ecological or bio-physical drivers:

Sl. No.	Particulars	Level				
		Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
31.4.1	Lack of soil fertility					
31.4.2	Increasing Soil erosion					
31.4.3	Not suitable to present climate					
31.4.4	Pest attack					
31.4.5	Flood					
31.4.6	Drought					
31.4.7	Weed					

32. Impact of agricultural land use change on Farmer's livelihood assets

38.1 Human Assets:

Sl. No.	Particulars	Level				
		Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
32.1.1	Increased knowledge of production					
32.1.2	Enhanced skill in production					
32.1.3	Increased working capacity					
32.1.4	Improved educational level					
32.1.5	Improved family health					
32.1.6	Enhanced Punctuality in working					
32.1.7	Increased Innovation thinking					

32.2 Social Assets:

Sl. No.	Particulars	Level				
		Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
32.2.1	Increased interaction with fellow farmers					
32.2.2	Increased interaction with farmers outside the village					
32.2.3	Built linkage with research and development institutions					
32.2.4	Increased interaction with agricultural labour					
32.2.5	Increased involvement in social activities					
32.2.6	Increased interaction with agro-based industries					
32.2.7	Increased interaction with other organizations					
32.2.8	Decreased labour migration					
32.2.9	Increased farmers attitude					

32.3 Physical and Cultural Assets

Sl. No.	Particulars	Level				
		Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
32.3.1	Decreased soil fertility					
32.3.2	Increased productivity					
32.3.3	Increased cultivation area					
32.3.4	Increased water consumption					
32.3.5	Increased pressure on irrigation					
32.3.5	Decreased pressure on livestock					
32.3.6	Improved housing condition					
32.3.7	Increased use of agricultural machinery					
32.3.8	Increased use of transportation					
32.3.9	Increased availability of labour					
32.3.10	Increased household amenities like T.V and other electronic equipment					

32.4 Financial Assets

Sl. No.	Particulars	Level				
		Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
32.4.1	Increased Cash income					
32.4.2	Increased Credit Availability					
32.4.3	Increased On-farm Income					
32.4.4	Increased Off-farm Income					
32.4.5	Decreased production cost					
32.4.6	Raised fund assistance					
32.4.7	Increased Savings					

D. <u>INFORMATION ON COST AND RETURN:</u>

33) Name of the crop: ___________________________

33.1) Cost on fixed assets:

Sl. No.	Particulars	Own				Rent/Bigha
		Year of purchase/ Construction	Purchase/ construction value (Rs.)	Lifespan	Maintenance cost (Rs.)/year	
33.1.1	Storeroom					
33.1.2	Well, /Bore Well/Sub-mersible					

33.1.3	Tractor					
33.1.4	Power generator					
33.1.5	Electric motor					
33.1.6	Power sprayer					
33.1.7	Oil Engine Pump set					
33.1.8	Electric Pump set					
33.1.9	Irrigation channel					
33.1.10	Bullock					
33.1.11	Bullock cart					
33.1.12	Country plough					
33.1.13	Any others					

33.2) Cost on labour:

Sl. No.	Particulars	No of family labour per Bigha per crop		No. of hired labour per Bigha per crop		Wages per day (Rs.)		Total cost (Rs.)
		M	F	M	F	M	F	
33.2.1	Land preparation							
33.2.2	Planting							
33.2.3	Fertilizers							
33.2.4	Pesticides							
33.2.5	Removal of diseased plant & Weeding							
33.2.6	Irrigation							
33.2.7	Harvesting							
33.2.8	Others							

33.3) Cost on materials:

Sl. No.	Particulars	Quantity per Bigha	Price (Rs.)/Kg	Total amount (Rs.)
33.3.1	Seeds			
33.3.2	Organic fertilizers			
33.3.3	Chemical fertilizers			
33.3.4	Pesticides			
33.3.5	Others			

33.4) Cost on harvesting and marketing:

Sl. No.	Particulars	Amount in Rs.
33.4.1	Processing	
33.4.2	Watch and ward	
33.4.3	Packing	
33.4.4	Transport	
33.4.5	Market fee	
33.4.6	Commission to agent	
33.4.7	Loading/Unloading	
33.4.8	Others	

34) Cost on land tax: ________________

35) Have you taken crop insurance? Yes/No,

if yes, amount of premium ______________________

36) Returns:

Sl. No.	Name of the Crops	Main Product		By product	
		Maximum Price per quintal	Minimum price per quintal	Maximum Price per quintal	Minimum price per quintal
36.1					
36.2					
36.3					
36.4					
36.5					
36.6					

37) Give your suggestion for the agricultural development of the district:

a)

b)

c)

Signature of the respondent

Appendix-C

List of Abbreviations

ACF	Autocorrelation function
ADA	Additional director of Agriculture
AHP	Analytical hierarchy process
ALU	Agricultural land use
ATMA	Agricultural Technology Management Agency
ATMA	Agricultural Technology Management Agency
BAES	Bureau of Applied Economics and Statistics
BI	Built-up Index
CBA	Cost-benefit analysis
CDAP	Comprehensive District Agricultural Plan
CV	Coefficient of Variation
DCH	District Census Handbook
DNA	Data Not Available
DSH	District Statistical Handbook
ETM	Enhanced Thematic Mapper
FAO	Food and Agricultural Organization
FCC	False-colour composite
FYM	Farmyard manure
GDP	Gross Domestic Product
GIS	Geographic Information System
GSI	Geological Survey of India
Ha	Hectare
HDFC	Housing Development Finance Corporation Limited
HHS	Household Survey
HYV	High Yielding Varieties
IBI	Index based built-up Index
IMD	Indian Meteorological Department
ITA	Innovative Trend Analysis
MIDH	Mission of Integrated Development of Horticulture

MK	Mann-Kendall
mMK	Modified Mann-Kendall
MSS	Multispectral Scanner System
NABARD	National Bank for Agricultural and Rural Development
NBSS & LUP	National Bureau of Soil Survey and Land Use Planning
NDBI	Normalized Difference Built-up Index
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
NFSM	National Food Security Mission
NH	National Highway
NIR	Near infrared
NMOOP	National Mission on Oilseeds and Oil Palm
NMSA	National Mission for sustainable Agriculture
NPK	Nitrogen Phosphate and Potassium
OLI	Operational Land Imager
PAO	Principal Agricultural Office
PDF	Probability Distribution Function
PET	Potential Evapotranspiration
PI	Perception Index
PMKSY	Pradhan Mantri Krishi Sinchayee Yojana
RBV	Return-Beam Vidicon
RD	Relative deviation
RKVY	Rashtriya Krishi Vikas Yojana
RS	Remote Sensing
SAI	State of Agriculture in India
SAVI	Soil Adjusted Vegetation Index
SD	Standard Deviation
SOI	Survey of India
SPSS	Statistical Package for Social Sciences
SWIR	Short-wave Infrared
T.V	Television
TIRS	Thermal Infrared Sensor
TM	Thematic Mapper

UI	Urban Index
EBBI	Enhanced Built-up and Bareness Index
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WGS	World Geodetic System
GCA	Gross cropped area
NSA	Net sown area

Appendix-D

Glossary of the terms

Aman	Winter rice
Aus	Autumn rice
Beels	A beel is a lake-liked wetland with static water as opposed to moving water in rivers and canals-typically called khals in Bengali.
Bhadoi	local variety of Autumn rice
Boro	Summer rice
Doba	Low lying area subjected to water stagnation
Haal/Langol	Wooden plough
Hat	Periodic market
Kalbaishakhi	A thunderstorm events (nor-wester) occurs in between March to May in India
Kharif	The crops grown in the rainy season
Maskalai	Urad
Masoor	Lentil
Pykars	The middleman who buy crops directly from farmers
Rabi	The crops grown in the winter season
Zaid	The crops grown in between kharif and rabi season

Appendix-E
Copy of Certificates of Paper Presentation in a Seminar


Two Days National Seminar on
ENVIRONMENT, DEVELOPMENT AND SUSTAINABILITY
March 15-16, 2019
ORGANIZED BY
DEPARTMENT OF GEOGRAPHY & APPLIED GEOGRAPHY, UNIVERSITY OF NORTH BENGAL, JALPAIGURI CAMPUS
PARTICIPATION CERTIFICATE

31ST IGI CONFERENCE
AND NATIONAL SEMINAR ON
APPLICATIONS OF GEOSPATIAL TECHNOLOGY IN GEOMORPHOLOGY AND ENVIRONMENT

November 12-14, 2019

Organized by

DEPARTMENT OF GEOGRAPHY & APPLIED GEOGRAPHY
UNIVERSITY OF NORTH BENGAL
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PARTICIPATION CERTIFICATE

This is to certify Prof./ Dr./ Mr./Ms. Tapash Mandal of ______ attended/ chaired/ co-chaired (Technical Session) the 31st IGI Conference and National Seminar on "APPLICATIONS OF GEOSPATIAL TECHNOLOGY IN GEOMORPHOLOGY AND ENVIRONMENT" held at the Department of Geography & Applied Geography, University of North Bengal, Darjeeling during November 12-14, 2019 and presented the following paper(s): Channel profile aspects (CPA) for assessing channel characteristics: A study of Rayeng basin, Darjeeling Himalaya, West Bengal
2. Land suitability analysis for paddy cultivation through Geospatial technique: A case study of Malda District, West Bengal

Prof. Ranjan Roy
Organising Secretary
31st IGI Conference

Prof. D. K. Mandal
Convener
31st IGI Conference

Appendix-F

List of Publications

Mandal, T., & Saha, S. (2020). Land suitability analysis for paddy cultivation through geospatial technique: A case study of Malda district, West Bengal. *Application of Geospatial Technology in Geomorphology and Environment, IGI (NBU),* 286-294.

Mandal, T. & Saha, S. (2021). Spatio-temporal changes of cropping intensity in Maldah district, West Bengal, India. *Shodh Sanchar Bulletin, 11* (41), 54-59. January-March, 2021

Mandal, T., Das, J., Poddar, D., & Saha, S. (2021). Characterization of Spatial Variability of Soil Properties of Malda District in West Bengal, India. In *Agriculture, Food and Nutrition Security* (pp. 61-77). Springer, Cham.

APPLICATIONS OF GEOSPATIAL TECHNOLOGY IN GEOMORPHOLOGY AND ENVIRONMENT

ENLIGHTENMENT TO PERFECTION

SERB, New Delhi ICSSR, New Delhi

D. K. Mandal
R. Roy
Editors

APPLICATIONS OF GEOSPATIAL TECHNOLOGY IN GEOMORPHOLOGY AND ENVIRONMENT

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Land Suitability Analysis for Paddy Cultivation through Geospatial Technique: A Case Study of Malda District, West Bengal

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Abstract
Improvement and maintenance of land resource are the basic decision making tool for sustainable crop production. The production of paddy is happentually low and if there exists any deficiency of information on the best combination of influencing factors. With this view in mind, the main objective of this study is to evaluate the land suitability of Malda district using Multi-Criteria Evaluation (MCE). For developing the land suitability map variables of soil, climate and topography were considered. For ranking the different suitability factors an Analytical Hierarchical Process (AHP) was used and the subsequent weights were utilized to construct the suitability map layers in Arc GIS 10.1 (trial Version.) platforms. The IDW (Inverse Distance Weightage) interpolation method has been used to show the spatial distribution of the suitability site in the study area. The assessment reveals that most of the areas (more than 70%) of the district are highly and moderately suitable for paddy cultivation, though the maximum soils of the district are neutral and slightly acidic in character. Therefore, economic growth of agricultural sector can be attained by cultivating paddy crop in highly and moderately suitable areas and performing diversification of slightly suitable areas to crops other than paddy.

Keywords: Land suitability, Sustainable crop production, MCE, AHP, IDW

Introduction

Rice is the staple food crop in Malda district as well as whole West Bengal. Thus, improving rice production can be attained mainly through farming practices that are eco-friendly and economically efficient. As population and cultivation of cash crops continue to increase it consequently cause decreasing of per capita land allocation for rice. The optimum utilization of available land resources for efficient agricultural production is becoming increasingly noticeable and really almost mandatory. Therefore, in order to confirm the optimum production of rice crops one has to grow the crops, where the varieties suit best and for which first and the leading condition is to carry out the study on analysis of land suitability (Ahamed et al. 2000). Suitability is a function of crop requirement and land characteristics (Mustafa et al. 2011). Matching the environmental characteristics with the crop requirements gives such suitability. It is generally conveyed by a hierarchical system of the numerous orders and classes (Malczewski, 2004). Multi-criteria decision making (MCDM) or multi criteria evaluation is the important technique which has been used for land suitability analysis. However, land suitability analysis has to be carried out in such a way that local requirements and situations are reflected well in the concluding decision (Prakash, 2003). Hence, this study aimed to make out the suitability of the selected farm sites/areas for rice production with a view to know the physical set up of land suitability for rice crop cultivation using a MCDM with Analytical Hierarchical Process (AHP) and GIS approach.

Study Area

The entire study area falls in Malda district lies between latitudes of 24˚40´20˝N to 25˚32´08˝N and longitudes of 87˚45´50˝E to 88˚28´10˝E. Total areal coverage of the district is 3,733 sq. Km. The district is surrounded by Murshidabad district in the south, Uttar and Dakshin Dinajpur in the north, international border of Bangladesh in the east, and Santhal Parganas of Jharkhand and Purnea of Bihar in the west and the south-western boundary is delineated by the river Ganga. On the basis of relief characters the district can be divided into three zones a. *Tal*, located in the northern part of Kalindri River and north-western part of Mahananda river b. *Diara*, located in the southern part of Kalindri River and South-western part of Mahananda River and c. *Barind*, located in the eastern part of Mahananda River.

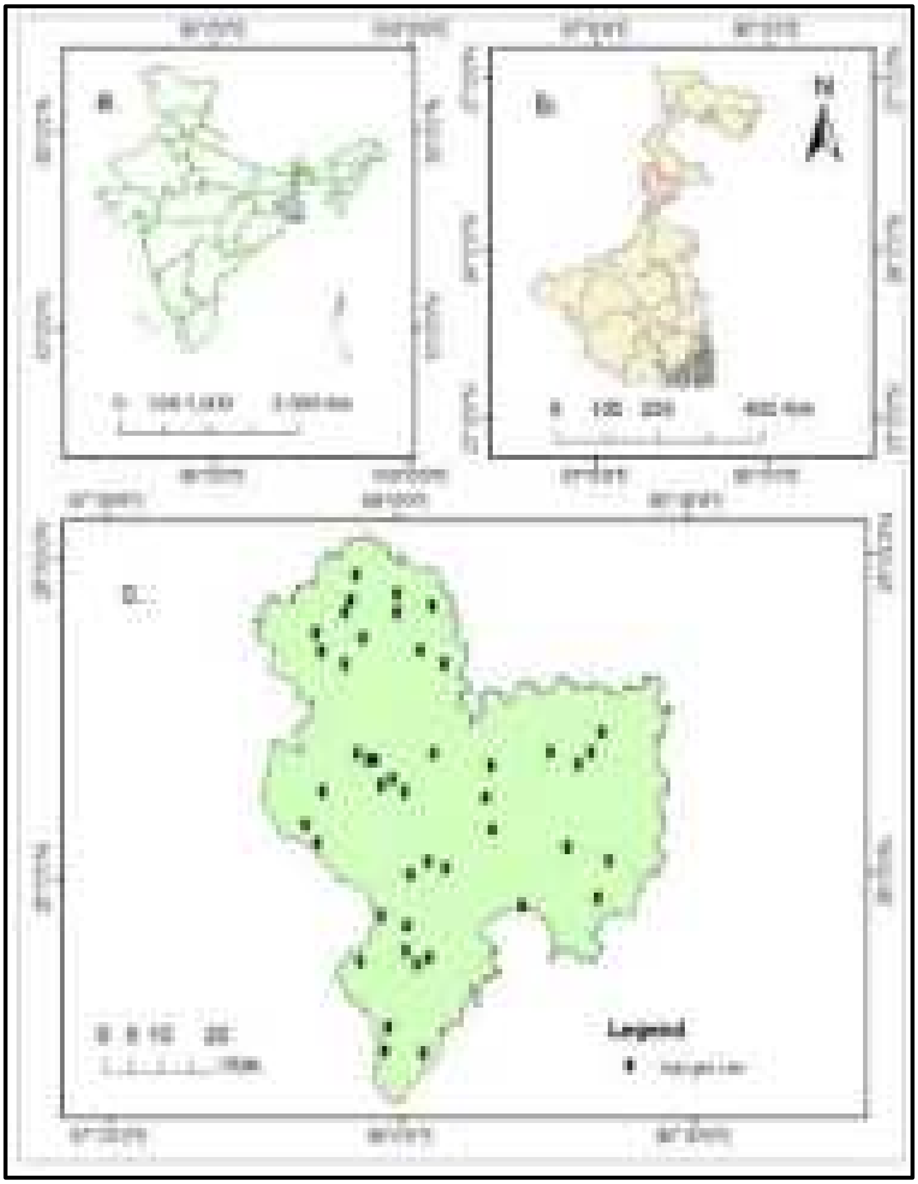

Figure 1 Location Map of the study area with sample sites.

The entire district is covered by alluvium soil which is of two different periods showing different physical and physiographic features (Census of India, 2011). According to the broad classification the district has three different kinds of soils namely i) Red soils (77700 hectare) ii) *Do-ash* soils (17130 hectares) and iii) *Matial* soils (243540 hectares). Geologically the district is belonging to alluvium formation. The district is associated with four different geomorphic features such as active delta plain, alluvial plain, meander flood plain and marshy or inundated plain. The most rainfall occurs during the month of July to the middle of September in the district as like the country. The annual rainfall of the district is 1,485.2 mm which conforms to a very good chance of agriculture.

Objective

Performing suitability class delineation in view of paddy cultivation in the district based on selected multi criteria model building.

Materials and Methods

Multi-Criteria Decision Making (MCDM)

Multi-Criteria decision making can be understood as a method that combines and transforms a sum of geographical data input into a subsequent decision output (Drobne and Lisec, 2009). In this method, each and every criterion is given a weight to denote its unaffected importance in the occurrence (Chow and Sadler, 2010). In this study Slope, Physical (soil texture) and chemical (soil pH) properties of soil and climate (rainfall and temperature) were chosen for land suitability analysis of rice cultivation based on local expert knowledge with literature inputs and data availability.

Table 1 Standardized Criteria used for Paddy Cultivation

Parameter	S1	S2	S3	N1	N2
Slope (%)	0-4	4-8	8-20	20-25	>25
Elevation (m)	<50	51-100	101-150	151-200	>200
Soil pH	5.5-7.3	7.3-7.8	4.5-5.5	-	<4.5 or > 7.8
Texture	C, SC, SCL	S, CL	SL, L	Sandy L	Sandy
% of C	>2	1.5-2	0.8-1.5	<0.8	-
Rainfall (mm)	>160	140-160	120-140	100-120	<100
Temperature (°C)	30-36	24-30 °c	18-24 °c	12-18 °c	<12 °c

Source: (Sys et al., 1991)

*S1= High suitable, S2=Moderate suitable, S3=Marginal suitable,
N1= presently not suitable, N2=permanently not suitable, C=Clay, S=Silt, L=Loam

Analytical Hierarchy Process (AHP)

The analytical hierarchy process (AHP) is the utmost accepted procedure and is considered as the most dependable multi-criteria decision making technique. The process was applied to a set of factors to establish a hierarchical structure by providing a weight for each factor in the complete decision making process (Kiker et al., 2005). The AHP provides an operational ground for computing the strong comparison of design factors in a pairwise process, and thus reduces the difficulty of the decision-making process (Saaty, 1990). Weights were used to identify the priorities of factors (slope, elevation, and soil pH, and soil texture, % of Carbon, rainfall, and temperature). The subsequent AHP weights were used to find out the priority of each factor for weighted overlay application using GIS. The values of pairwise comparisons in the AHP are determined according to the scale introduced by Saaty (1980). However, in the application of the AHP method it is important that the weights derived from a pairwise comparison matrix are consistent. The Consistency ratio (CR) is calculated by computing ratio of Consistency Index (CI) and Random Index (RI) to indicate the likelihood that the matrix judgments were generated randomly (Saaty, 1977; Park et al., 2011).

Results and Discussion

The basic four criteria associated with slope were judged to reach to the composite identification of suitability categorization. The most characteristic findings are dominantly contrasting i.e. more the dominance of sand or silt or clay showed identical areal associations and where the associations of commonalities is most promising suitable classes were clustered. As per moving average graphs sand is more fluctuating from one sample to the other compared to less fluctuations for clay and moderate for silt (Fig. 3).Overall distribution of pH is not very much variable and average appearance of organic carbon is very nominal and unpromising and attributes no parametric validity to identify suitability criterion.

The variability of temperature pattern (Fig.5) is not so high and ranging between 17-35°C and signifies the chances of optimum condition for paddy cultivation throughout the year as tropical warmth is better suited for paddy cultivation and attributes good weightage to signify suitability class for paddy. The R^2 is interpreting almost no variability except some slight lowering in character from December to February.

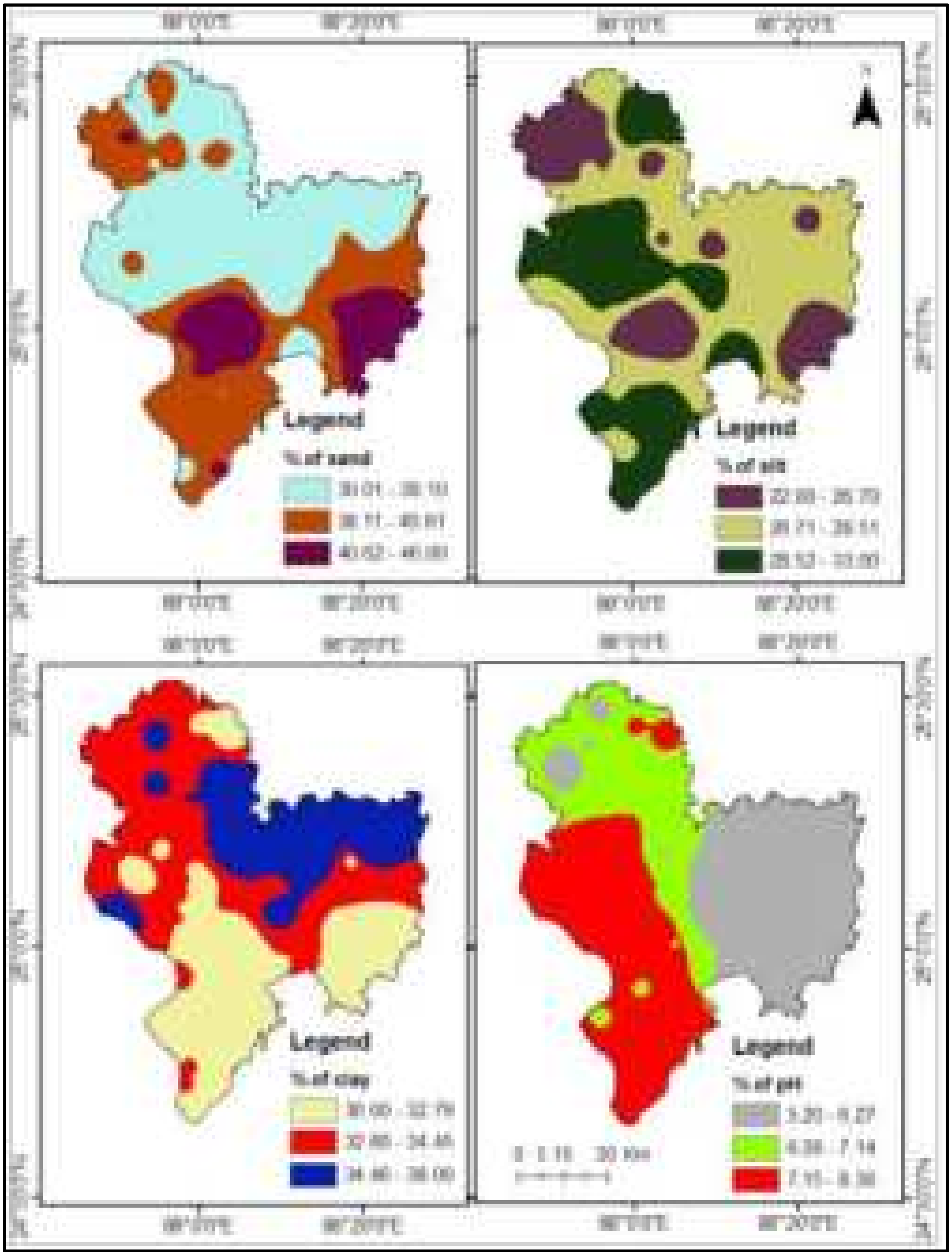

Figure 2 Distribution Patterns of suitability parameters with their Minimum Average Appearance (MAA) in Malda district.

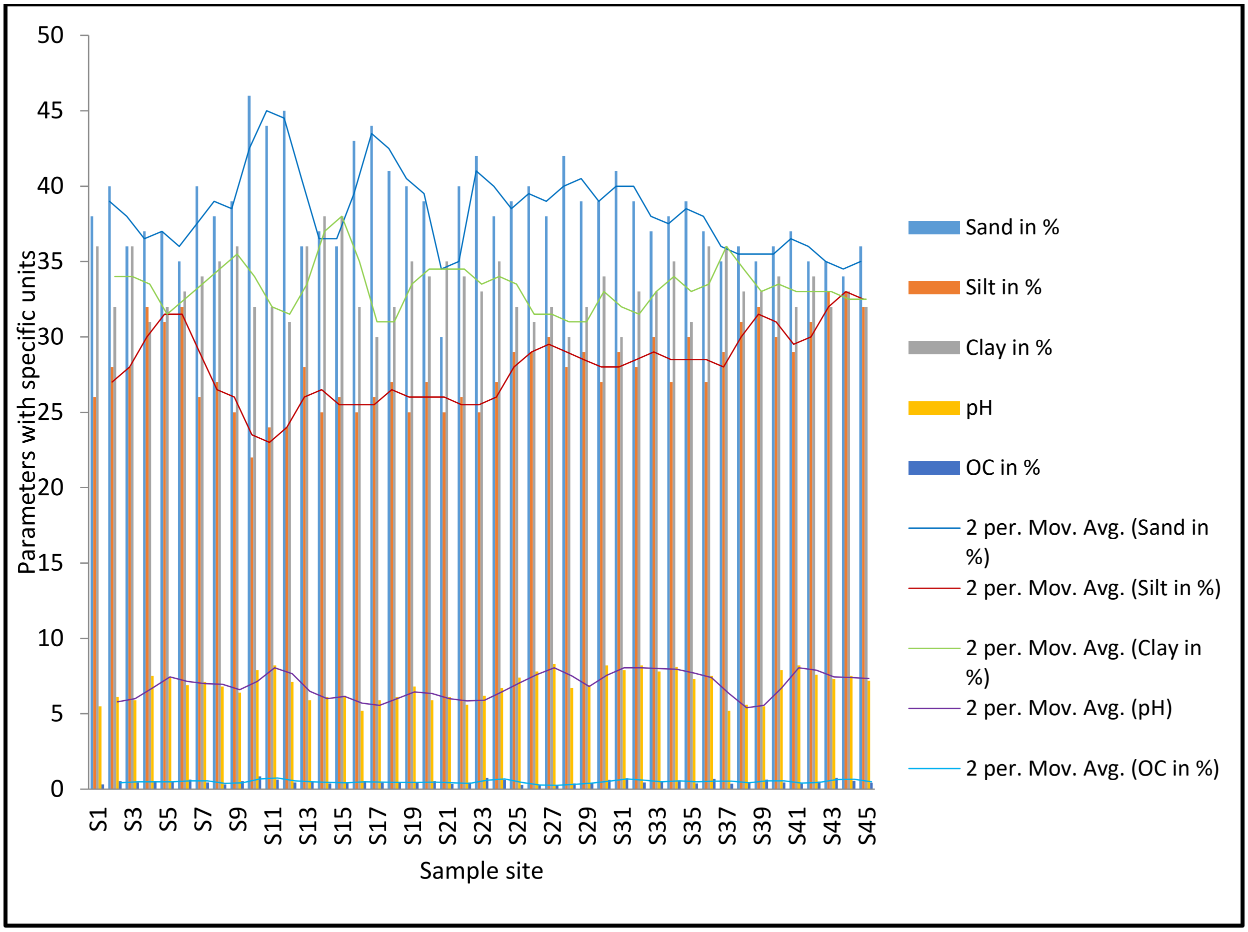

Figure 3 Physico-Chemical properties of sample soils and their 2 per gap Moving Average of appearance
Source: Interpolated on the basis of World Soil Grid data and samples tested in the Pedological Laboratory, Dept. of Geography and Applied Geography, NBU, 2019

But huge variability is found in case of rainfall pattern in the district which interprets varying weightage loading in a block wise manner to show the degree of suitability (Fig. 5).

Parts of Harischandrapur I, Old Malda, Englishbazar and Gazole are receiving suitable 1 category of soil as per AHP model study. More inertia to be turning into promisingly suitable land was due to prevalence of farm lands having silt and sandy clay loam, dominated by moderate percentage of pH. Whereas the Diaras with low lands, marshes and bogs are suited from physiographic point of view and with optimal aquatic supports but sand dominance in Kaliachak I, II and III is reasonably turning the block lands into a marginally suitable one. More contrasts have been found in Manikchak Ratua II, Bamongola and slightly low in case of Habibpur showing mix-ups of S2 and S3 categories which indicated the variegated sand, silt and clay compositions in these blocks and varieties of crop practices. From the overall point of view the availability of S2 category is maximum in respect to their areal coverage of > 75 % are characterized by moderate slope factor with averagely 6% slope,75 feet (22.5 m) of average elevation, neutral pH (7.6) and loamy in character with maximum of sand and clay mixtures and replacing silts. Moreover the class is averagely receiving moderate to high rainfall regime of 150 cm on an average and wet moist temperature regime ranging between 24-30°C.The % of carbon though is moderately low and appearing with as nominal as 1.5-2.0 %, thus traditional varieties with seasonal manure replacement have been suitable than specialized crop practices and that also has become the eliminatory reason of other cash crops and qualifying rice as dominant one instead of high demand of cash crops.

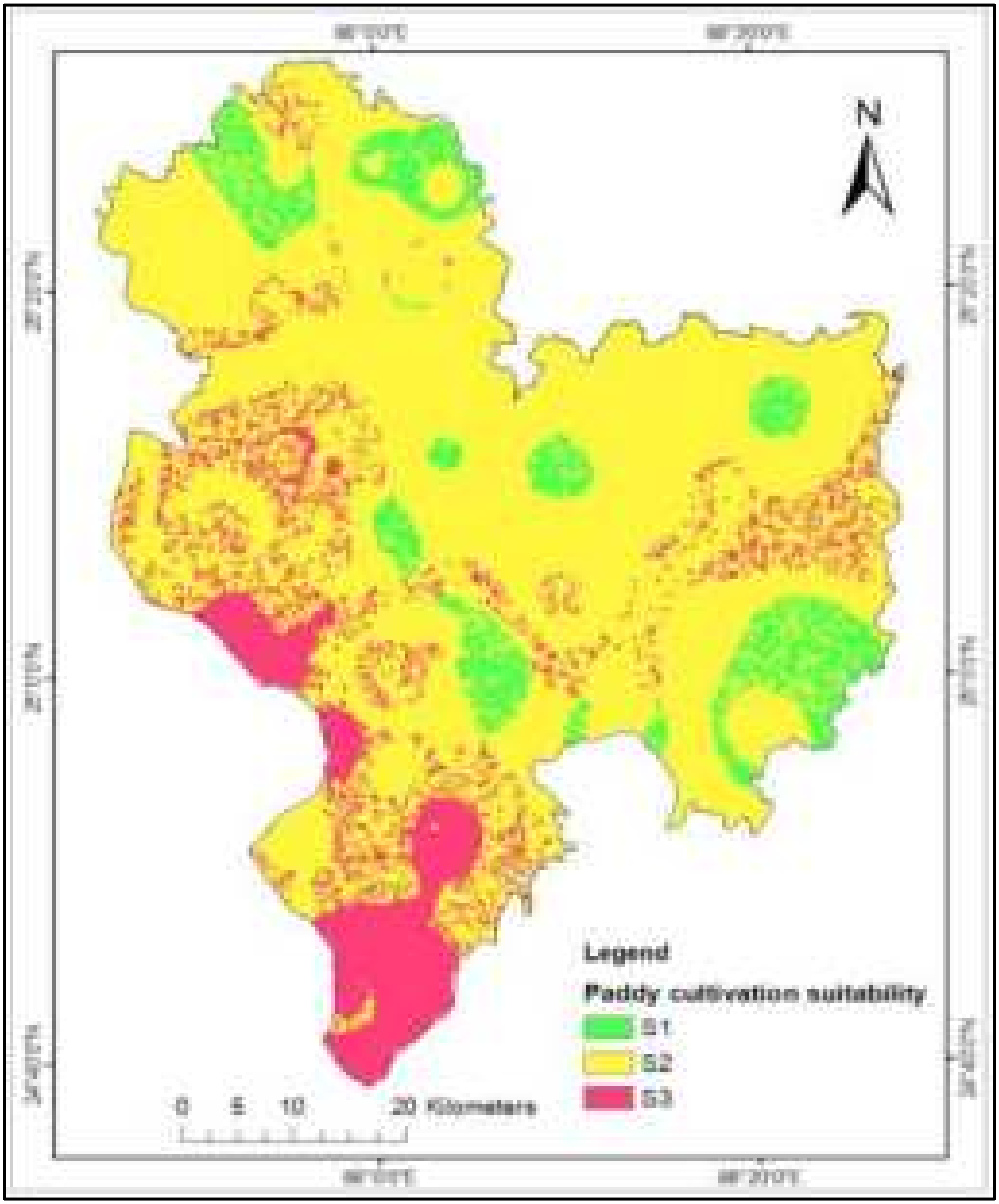

Figure 4 Land suitability condition of Malda district based on minimum average parametric criteria.

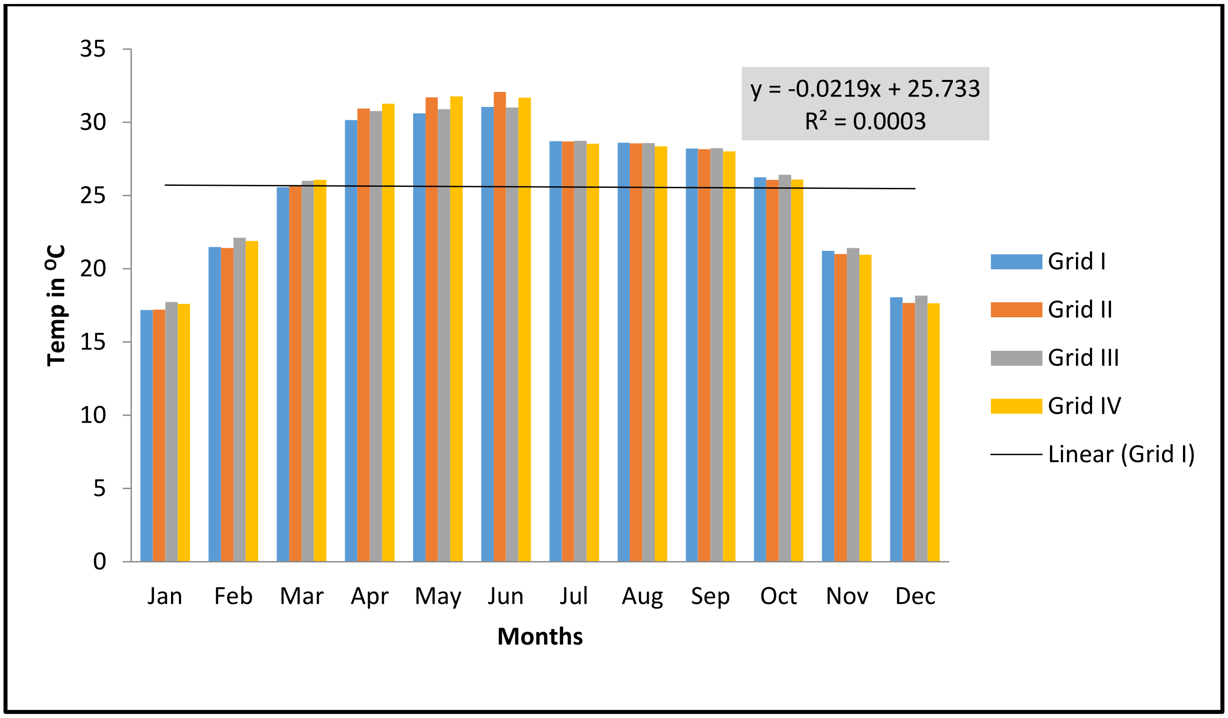

Figure 5 Month-wise mean rainfall condition in Malda district 2017
Source: Power.l arc nasa.gov/data-access-viewer (Data access October 2019)

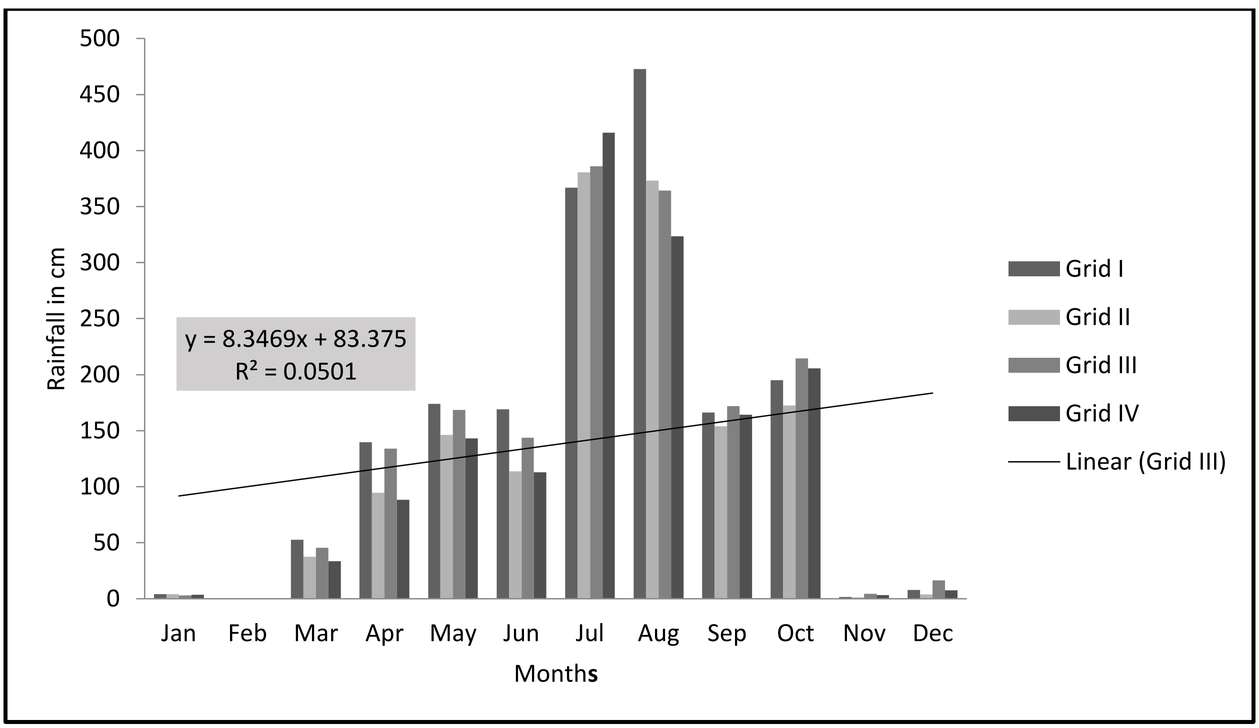

Figure 6 Month-wise mean Temperature condition in Malda district 2017
Source: Power. l arc nasa.gov/data-access-viewer (Data access October 2019)

Plate 1 & 2 Executions of Soil Sample collection in the field and processing of Soil samples for further Laboratory treatment

Table 2 Area wise suitability class of Malda district.

Code	Class	CI	Description	Area in sq. km	Area in %
S1	High suitable	≥ 80	More favourable for paddy	341.01	9.15
S2	Moderately suitable	60-80	Some restriction to be sustainable for paddy	2817.81	75.49
S3	Marginal suitable	≤ 60	Major restriction to be sustainable for paddy	573.65	15.36
Total				3732.47	100.00

Source: Computed by authors, 2019

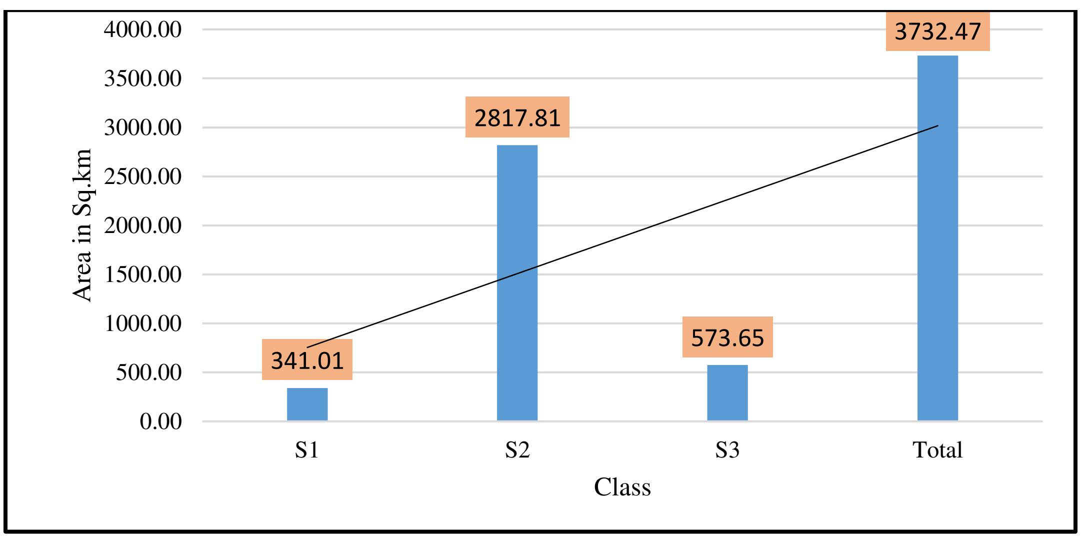

Figure 7 Suitability class wise areal share in Malda district.

Conclusion

In respect to the entire district scenario the availability of higher suitable class is very less but moderately suitable class area is high though the marginally suitable class areas are belonging to the riverine and sand dominated parts of river Ganga i.e. in the Diara belt. Clustering of classes is highly discrete for S3 class whereas S2 (Fig. 7) class is well prevalent covering most areas of the district.

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SPATIO-TEMPORAL CHANGES OF CROPPING INTENSITY IN MALDAH DISTRICT, WEST BENGAL, INDIA

Tapash Mandal*
Snehasish Saha**

ABSTRACT

Agricultural development of any region can be attained through the intensification of the crops in an insufficient area. In such cases, the intensity of cropping plays a more significant role. Higher cropping intensity specifies that the area is cropped more than once and vice versa.Therefore, this study investigates the changing pattern of the intensity of cropping practices in the Maldah district from 2003-04 to 2013-04. The data relating to cropareas have been collected from the District Statistical Handbook of Maldah for the specific time frame under study. Rao and Brookfield's (1977-78) cropping intensity method has been used in this study. The results show that the medium cropping intensity region dominates the study area, followed by the low and high-intensity regions. The variability of cropping area is also clear from the study. This is due to the variation of relief, rainfall, temperature, and different agricultural inputs. The results of this study will be used for regional agricultural planningand agricultural development of the district.

Keywords : Agriculture, Cropping Intensity, Agricultural Inputs, Maldah

1. Introduction :

Cropping intensity playsa crucialrolein the efficiency assessment of agricultural land use (Neumann et al., 2010). It refers to nurturing many crops during an agricultural year in the same agricultural land. The intensity of crops provides the most delicate measure of specific crops' areal strength and makes a vision into the geographical actuality of cropping structure. According to Pretty et al. (2003), cropping intensity is crucial for farmers' crop production and food security, particularly small landholder farmers; it is also highly sensitive to irrigation patterns and inter-annual rainfall variability.The nature of the economy of any region, whether it is subsistence or commercial or market-oriented farming, is influenced by the intensity of crops. By identifying the relative significance of different crops in any areal unit, the planning method can be more logically accepted for the ideal use of the existing land for cultivation.

The degree of the productive capacity of land mainly enriched through the utilization of modern technology is shown by cropping intensity. However, it results from numerous factors of physical (viz. rainfall, the fertility of land) and cultural or socio-economic (viz. labour force, population pressure). Thus, it helps the agricultural scientist in agricultural planning by providing the agricultural prosperity index. However, there is an increasing tendency of population density in the district, recommends increasing the magnitude of the agricultural land or cropping intensity through enhancing crop production. Several remote sensing approacheslike MODIS and Landsat with 250 m and 30 m resolution, respectively, have been used to measure cropping practices, crop types, and intensity of cropping on Spatio-

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temporal perspectives (Xiao et al., 2005; Biradar and Xiao, 2011). However, these methods may not help crop intensity mapping inthe case of small landholders where land is lesserin size than the spatial resolution of the enthusiasticallyexisting satellite-based data (Jain et al., 2013).Rao and Brookfield's (1977-78) methodhas also been used successfully in various research to determine the cropping intensity. It is a straightforward and scientific technique for the identification of cropping intensity regions. According to Roy (2009), it is animprovedtechnique forcalculating cropping intensity than the other traditional methods.In this technique, the duration of each crop has been taken into consideration and successfully used by several researchers and geographers (Dayal, 1978; Roy, 2009; Chhetri, 2011).

Therefore, to analyze the intensity of cropping, Rao and Brookfield's (1977-78) method has been used in this study. Fifteen community development blocks of Maldah district were quantified and mapped by choropleth using the data for 2003-04 and 2013-14. Eleven major crops, rice (aus, aman, and boro), wheat, maize, gram, masoor, maskalai, khesari, rapeseed & mustard, jute, sugarcane, and potato, are considered to identify the cropping intensity.To develop the method effortlessly,these crops are multiplied by theirmean duration of the production period. The more prolonged crop halts in the field, the greater the agricultural inputs, labour, and irrigation water.

2. Study area :

The Maldah district has been chosen as a study area to analyze the changing pattern of cropping intensity. The district has 15 community development blocks within two sub-divisions, Chanchal and Maldah Sadar. The district is stretched from latitudes of 24°40′20″N to 25°32′08″N and longitudes of 87°45′50″E to 88°28′10″E (Fig.1). The whole study areacovered 3,73,300 ha, out of which the net sown area is 28,3714 ha (76.00%). Based on physiography, the district can be categorized into three zones a. *Tal*, located in the northern part of river Kalindri, and the north-western part of Mahananda River b. *Diara* is situated in the southern part of the river Kalindri River, and the South-western part of river Mahananda and c. *Barind* is located in the eastern part of the Mahananda river.The average annual rainfall in the district is 1,546.59 mm (1981 to 2020), and the average annual temperature varied from 25.1° C in 2000 to 27.37° C in 1994.

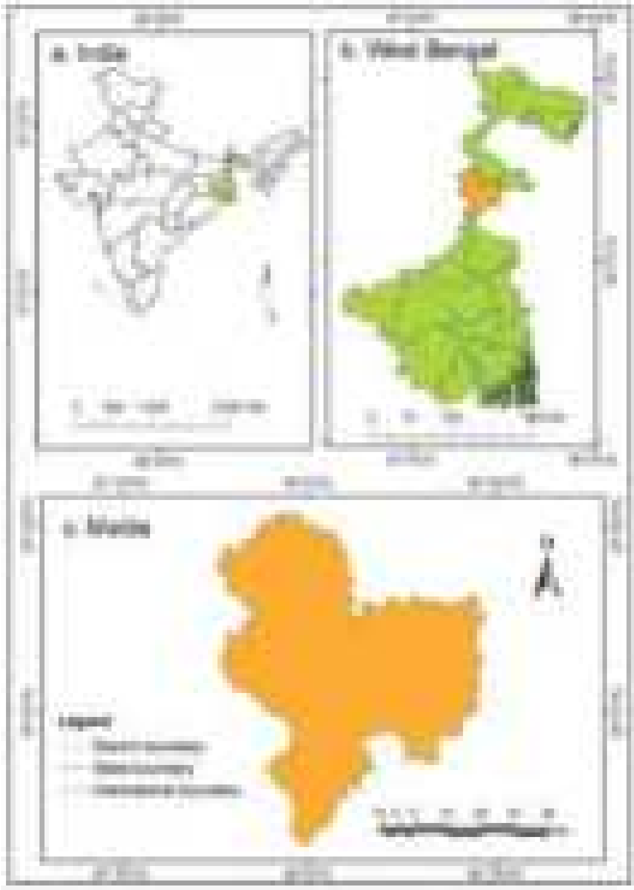

Fig.1: Location map of the study area a. India b. West Bengal c. Maldah

3. Database and Methodology :

The datasets used in this study have been collected from the District Statistical Handbook for 2004 to 2014. Some of the exploratory statistics of the crops are presented in Table 1. These statistics delivered the dataset'smaximum, minimum, average, standard deviation (SD), and co-efficient of variation (CV). The software Arc 10.8 and SPSS 26 were used for mapping and analyzing purposes.

Rao and Brookfield's (1977-78) cropping intensity method has been used in this study. This technique of cropping intensity is calculated as follows:

$$Ki = \sum_{i=1}^{n} \frac{a_{1i} d_1 + a_{2i} d_2 + \cdots a_{ni} d_n}{Q}$$

Where,

I_c representsthe index of cropping intensity

A_{ci} represents the area ofi^{th} crop

d_i representsthe duration of i^{th} crop

Q represents Netset sown area

4. Results and Discussion :

4.1 Exploratory statistics of the major crops :

Table 1 shows descriptive statistics, such as mean minimum, mean maximum, average, standard deviation (SD), co-efficient of variation (CV) of the principal crops. The average cultivated area varied from 3,097.5 ha± 1,633.4 (Sugarcane) to 1, 36,208.9 ha± 19963.77 (winter rice) with CV 52.73% and 14.66% respectively (Table 1).The SD of the crops varied from 971.91 hawith CV 35.04% (Khesari) to 19963.77 hawith CV 14.66% (Winter rice). On the other hand, the mean minimum and mean maximum cropping areas varied from 156ha(Maskalai) to 73,094 ha (winter rice) and 4,552ha(Khesari) to 149613ha (winter rice), respectively. The calculated CV indicates medium to the high variability of the area under different crops in the study region since it varied from 8.41% (summer rice) to 191.04% (maskalai).

Table 1 : Some Exploratory Statistics of the major crops of Maldah District

[unit: Ha]

Name of the Crops	Minimum	Maximum	Mean	SD	CV (%)
Autumn Rice (Aus)	2381	17986	7179.05	4750.06	66.17
Winter Rice(Aman)	73094	149613	136208.9	19963.77	14.66
Summer Rice(Boro)	53650	72795	64650.95	5434.7	8.41
Wheat	39486	55094	45946.14	3962.44	8.62
Maize	3371	20690	10975.5	5290.57	48.2
Gram	2262	8266	4241.91	2160.28	50.93
Lentil/Masoor	3217	8070	5175.59	1627.6	31.45
Maskalai/Urad	156	16797	2660.09	5081.79	191.04
Khesari	1253	4552	2774.09	971.91	35.04
Rapeseed &Mustard	21092	38903	32224.41	5425.59	16.84
Jute	18021	27913	23121.18	2760.74	11.94
Sugarcane	1234	7026	3097.5	1633.4	52.73
Potato	2254	9714	4229.27	2306.77	54.54

4.2. Changes in Cropping Intensity Region :

The Spatio-temporal variations in the cropping intensityinclude changes of land-use under various cropping patterns and the alterationof the cropping systems.The English Bazar CD block had the lowest cropping intensity value of 3.65 in 2003-04, and Old Maldah reported the highest cropping intensity value of 4.02 in the same year. During 2013-14, the high intensity of cropping is noticed in the Kaliachak II (4.14) CD block, and the lowest is in Kaliachak III (3.60) (Table 2).

Block-wise cropping intensity changes from 2003-04 to 2013-14have been presented in Table2.

Maximum and minimum positive change has been observed in Kaliachak II (+0.29) and Chanchal I (+0.03) CD block, respectively. At the same time, the maximum and minimum negative change has been noticed in Kaliachak III (-0.27) and Habibpur (-0.05) CD block. However, the cropping intensity has significantly inclined regionally by 53.33% and declined by 46.67% from 2003-04 to 2013-14. This declining trend revealed that the degree of land fragmentation under single and triple cropping usage has deteriorated. Also increasing tendency of cropping intensity was observed for double-cropped land, and these areas are concentrated mainly in the Tal and Diara region.

Table 2: Block wise changing pattern of cropping intensity in Malda District

Name of the Block	Cropping Intensity		Changes
	2003-04	2013-14	
Bamangola	3.96	3.82	-0.14
Chanchal-I	3.89	3.92	+0.03
Chanchal-II	3.91	3.76	-0.15
English Bazar	3.65	3.93	+0.28
Gazole	3.91	3.85	-0.06
Habibpur	3.97	3.92	-0.05
Harishchandrapur-I	3.87	3.91	+0.04
Harishchandrapur-II	3.92	3.98	+0.06
Kaliachak-I	3.66	3.86	+0.20
Kaliachak-II	3.85	4.14	+0.29
Kaliachak-III	3.87	3.60	-0.27
Manikchak	3.75	3.66	-0.09
Old Malda	4.02	3.86	-0.16
Ratua-I	3.68	3.75	+0.07
Ratua-II	3.80	3.92	+0.12

The mighty factors contributing to the cropping intensity changes are slightly complicated in the district. Long-term climate change is the most influencing factor that affects cropping intensity intensively.

The warming climate influences crop production, crop association, and crop distributions (Zhang et al., 2018). The socio-economic factor also affects the pattern of cropping intensity changes (Yan et al., 2015). This factor works in two ways; firstly, implementation of a sequence of innovative agricultural strategies during the initial stages of the 21st century and which helped the cultivators and intensified farmer's interest.

These strategies were supposed to raise the farmers' income in terms of turnover by reducing agricultural tax and raising grain prices with increasing agricultural subsidies. Secondly, urban expansion and the growing trend of out-migration agricultural workers from few blocks of the study area led to the low intensity of cropping.

It also may be inferred that the trend of the out migrant population is consistent in those areas where cropping intensity is low. Soil erosion and over-irrigation also play a significant role in the Spatio-temporal changes in cropping intensity.

Using the results, a sheet of index scale has been prepared to differentiate the district into high, medium, and low categories of crop-intensity regions and was mapped (Fig. 2).

Low cropping intensity (<3.75) is mainly found in the English Bazar, Ratua I, and Kaliachak I CD block, whereas high cropping intensity (>3.92) was found in the Bamangola, Habibpur, and Old Maldah CD block; however, the other rest of the blocks were falling under medium (3.75-3.92) cropping intensity zone during the assessment year 2003-04.

On the other hand, in 2013-14, low cropping intensity (<3.75) was observed in Kaliachak III and Manikchak block, whereas high cropping intensity (>3.92) was found in the Harishchandrapur II, English Bazar, and Kaliachak I CD block, however, the rest of the block of the district was under medium (3.75-3.92) cropping intensity zone. The obtained results also revealed that the number of blocks under low cropping intensity has reduced from 2003-04 to 2013-14 (Fig. 2). Only Manikchak and Kaliachak III were in this category in 2013-14.

These two blocks were in the medium category of cropping intensity in 2003-04. There were nine blocks in the medium cropping intensity category (3.75-3.92) in 2003-04.

The number of blocks of this category increased in 2013-14. Although, there were three blocks with high cropping intensity (>3.92) classes in both the year (2003-04 and 2013-14) (Fig. 2).Fig. 2 also shows changing pattern of cropping intensity, and these changing values are categorized into three classes, viz. negative changes (0.00 to -0.27), low positive changes (0.00 to <+14), and high positive changes (0.14 to 0.29).

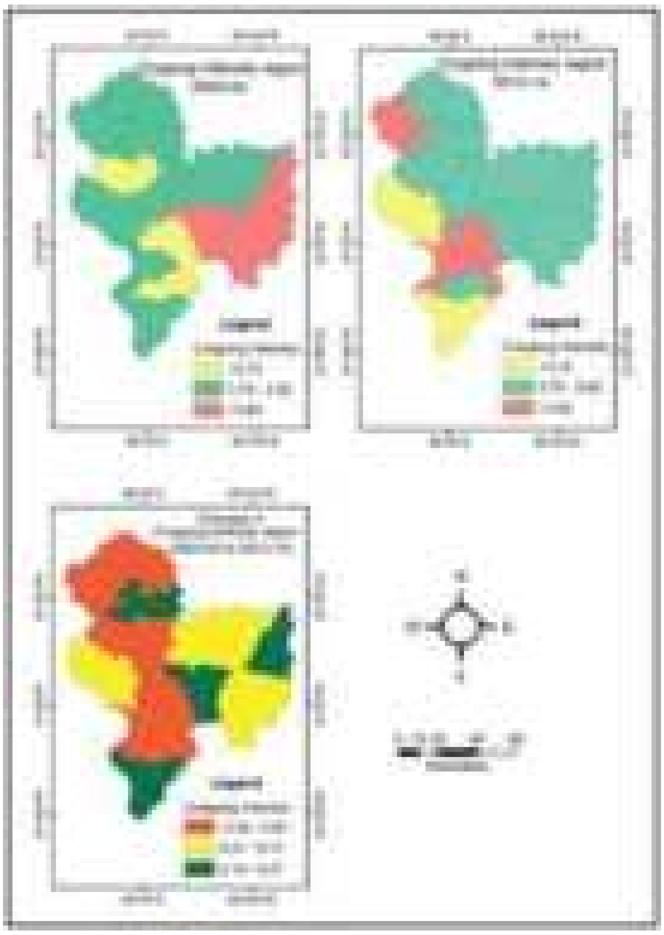

Fig 2: Changing pattern of cropping intensity region of Maldahdistrict

5. Conclusion :

The present study has focused on the changing pattern of cropping intensity of the comparatively highly populous district.The cropping intensity pattern of the Maldah district has significantly changed from one block to another. Though, the study area has been dominated by medium cropping intensity in both years. It revealed significant portions of the district having a medium percentage of agricultural products.The cropping intensity of any region highly depends on crop combination. So, increasing crop combination is also an essential task to increase the cropping intensity of the study region. It allows the farmers to produce various crops on their farmland, takingthe farmers from the risk of crop damage. Also, overutilization of fertilizers and pesticides, excessive extraction of groundwater for irrigation makes the soil infertile, causing a declining trend in cropping intensity in some portions of the district. Therefore, a suitable balance is mandatory between sustainable cropland production and environmental amenities. The government should take the necessary steps to improve and implement the agricultural inputs to enhance cropping intensity in the case of the inferior to low-performance blocks in the study area. This initiative will also reduce the disparity of the cropping intensity in the district.

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Chapter 4
Characterization of Spatial Variability of Soil Properties of Malda District in West Bengal, India

Tapash Mandal, Jayanta Das, Debapriya Poddar, and Snehasish Saha

Abstract Understanding soil fertility status is crucial for fertilizer management and sustainable crop production. A study was conducted in the Malda district of West Bengal in 2019 to evaluate the nutrient status of surface soil. A total of 45 composite surface soil samples were collected at a depth of 15 cm, and the actual location of the sampling sites was detected by GPS. The soil fertility parameters such as soil pH, available nitrogen (N), available phosphorus (P), available potassium (K), organic carbon (OC), electrical conductivity (EC), available boron (B), available zinc (Zn), available iron (Fe), available manganese (Mn), available copper (Cu), and available sulfur (S) were analyzed and categorized as low, medium, and high using nutrient index (NI). The spatial distribution of parameters was mapped by inverse distance weighted (IDW) interpolation method. The coefficient of variation (CV) showed that P, K, EC, B, and Cu were highly heterogeneous (CV > 33%). The soil pH reveals that most of the surface soil samples of the study area are neutral and slightly acidic. Available phosphorus, potassium, iron, manganese, and sulfur are more or less satisfactory, whereas widespread deficiencies were observed for nitrogen (54.25%), organic carbon (65.76%), boron (100%), zinc (64.31%), and copper (7.5%) in the study area. More precisely, multinutrient deficiencies were observed in Barind region of the study area that noticeably influenced the productivity of crops.

Keywords Soil fertility · Nutrient index · Sustainable crop production · Malda

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4.1 Introduction

Soil is an important natural resource for the production of crops, plant growth, subsistence of life, and the socioeconomic development of human beings (Mandal et al. 2020). It is dynamic in nature, and its trend is determined by the interaction between chemical, biological, physical, and anthropogenic processes (Salgado-Velázquez et al. 2020). Knowledge of soil characteristics, soil fertility, distribution, and potential is extremely important for the strategic setting of irrigation, agricultural management, and optimum land use planning (Das and Bhattacharya 2015). However, for normal growth and accomplishment of their life cycle, plants require more or less 18 essential elements. Among these, 15 are taken from the soil as mineral form by plants or supplementary as fertilizers. Soil nitrogen (N), phosphorus (P), and potash (K) are the primary macronutrients of the soil and are used in great quantities, which set the fertility status of a soil. Available calcium (Ca), magnesium (Mg), and sulfur (S) are the secondary elements, required in smaller amounts than the primary nutrients, whereas boron (B), iron (Fe), zinc (Zn), manganese (Mn), and copper (Cu) are micronutrient elements that normally occur in very small amounts in both soils and plants, but their role is equally important as the primary or secondary nutrients (Khadka et al. 2019). A deficiency of one or more of the above nutrients can lead to severe retardation toward growth, yield, and crop quality. Hence, for a better understanding of plant growth and the present soil fertility status and trend, wide-ranging knowledge of soil nutrients is mandatory (Dafonte et al. 2010).

However, the fertility of soil may vary from place to place to a bigger regional scale, probably due to the variation in soil-forming factors, which can be termed as intensive and external factors. Precipitation, crop rotation, soil management practices, slopes, soil characteristics, etc. are such soil-forming intensive and external factors that create varied soil fertility from one region to another (Cambardella and Karlen 1999). This may impact on the crop productivity and agricultural practices of any region in different ways. Soil survey helps to identify such extent of problems and potentials, which in turn help to work out the suitability of land for agricultural and non-agricultural uses (Aandahl 1958; Sehgal 1996). Thus, assessment of soil fertility may be the most elementary decision-making tool to plan effective land use systems (Havlin et al. 2010) to maintain soil dynamics to increase agricultural production and crop management performance (MacCarthy et al. 2013). Moreover, several parts of the district are experiencing the problems of arsenification, overuse of chemical fertilizers, intensive farming with traditional plus modern technology, and waterlogging. Therefore, it is very indispensable to evaluate the spatial variation and distribution of soil fertility properties of the district.

There are various methods available for evaluating the soil quality status and the spatial variability of soil fertility parameters in a region; among these, soil testing is most popular (Panda 2010). But the technique normally follows merged soil samples collectively forming into one mean sample collected from the field of proximal geographic locations. Hence, the results of such soil testing are not appreciated for site-specific recommendations and successive monitoring (Pulakeshi et al. 2012).

Maull's Griddle method, nutrient index, soil quality index, etc. are also being used by some researchers to identify soil fertility status where the specific soil nutrient status has been categorized into three groups, e.g., low, medium, and high (Mitchel 1977). However, for soil and water resources, improvement and management of some modern geospatial technologies, e.g., Global Positioning System (GPS) and Geographic Information System (GIS) have played an important role due to its immense potential (Rao et al. 1997; Das 2004; Majhi 2018). Geospatial techniques are very useful for acquiring the knowledge of distribution, characteristics, and variability of soil fertility for sustainable farming practices in an appropriate and precise manner (Liu et al. 2014; Desavathu et al. 2018). For agricultural productivity, enhancement, and management, it also plays an important role by site-specific management practices. Several researchers have more popularly assessed the soil fertility distribution using *inverse distance* weighted (IDW) *method*. Its simplicity and robustness make it the best interpolation methods (Goovaerts 1997, 2000; Cressie 2015).

4.2 Study Area

The study is conducted in Malda district covering 15 community development blocks from both the subdivisions, Chanchal and Malda Sadar. Malda, the gateway of North Bengal, lies between latitudes of 24°40′20″N to 25°32′08″N and longitudes of 87°45′50″E to 88°28′10″E. The district is surrounded by Murshidabad district in the south; North and South Dinajpur districts in the north; international border of Bangladesh in the east; Santhal Parganas of Jharkhand and Purnia of Bihar in the west; and the river Ganga in the southwestern boundary. The total geographical area of Malda district is 373,300 ha, out of which 283,714 ha (76.00%) is under net sown area. The main crops are grown in the summer monsoon season (June–September) which include rice (*Oryza sativa*), maize (*Zea mays*), jute (*Corchorus* species), sugarcane (*Saccharum officinarum*), and maskalai (*Vigna mungo*). In winter or retreat monsoon season (November–February), wheat (*Triticum aestivum*), gram (*Cicer arietinum*), masoor (*Lens culinaris*), khesari (*Lathyrus sativus*), rapeseeds (*Brassica juncea*), mustard (*Brassica campestris*), and potato (*Solanum tuberosum*) are the major crops of the district. The average annual rainfall of the district is 1485.2 mm for the period of 2000–2015, and the mean annual temperature varies from 27.2 to 30.6 °C (2000–2015). The cropping intensity of the district is very high (196%) and, therefore, dependency on the nutrient status of the soil is seriously concerned.

Based on relief characters, the district can be divided into three physiographic zones *Barind*, *Tal*, and *Diara*. *Barind* tract is rising and falling in nature, covering the district's 34.45% cultivable land. *Tal* is a low-lying region subject to seasonal deluge by the rivers, mostly during the rainy season, covering 32.34% of cultivable land. Diara is the result of fluvial actions maximum of the river Ganga, partially by Fulahar, Kalindri, Mahananda, etc. occupying 30.21% of the total cultivable land.

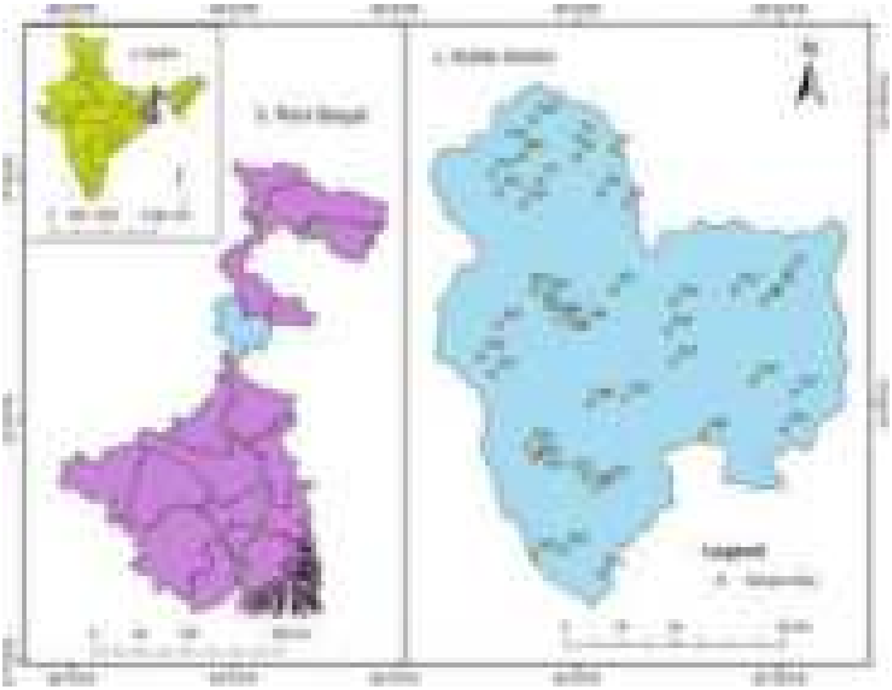

Fig. 4.1 Location map of the study area. (**a**) India, (**b**) West Bengal, and (**c**) Malda district with location of sample sites

Since the study area is located on the western portion of the alluvium-filled cracks in between the Rajmahal Hills on the west and the Garo Hills on the east, the entire area is covered by alluvium soil, which is of two different ages displaying different physical and physiographic characteristics (Sengupta 1969). *Barind* region is dominated by older alluvium, and Tal and Diara are dominated by newer alluvium. The district is divided into three different soil groups, i.e., (1) old alluvium soils (77,700 ha), (2) Vindhyan alluvial soils (17,130 ha), and (3) Ganga alluvial soils (243,540 ha). On the other hand, the district is receiving the major agricultural tracts of char lands of Ganga, i.e., parts of bars and flood plains associated with Mahananda-Tangan, Tangan-Punarbhava, and Fulahar-Ganga interfluves (Fig. 4.1).

4.3 Material and Methods

4.3.1 Collection of Soil Samples

A systematic survey has been conducted over the study area, and composite surface soil samples (0–15 cm depth) were collected from 15 community development blocks of Malda district. A composite soil sample of 8 to 10 core fixtures was followed and mixed for specific mean sampling. A total of 45 soil samples were incorporated from the various mouzas based on cluster sampling according to the variability of the crop production. Soil samples of high agricultural lands on an observation basis were considered as intake sites. The sample locations were tagged on the base map using a handheld GPS receiver during the autumn and winter since 2017–2019. After collecting, the samples were air-dried under the shade, processed and passed through a 2 mm sieve to get a homogeneous and uni-representative grade of solum, and sent to the laboratory.

4.3.2 Soil Sampling Analysis

The composite soil samples were tested in the District Soil Testing Laboratory, Malda, and Pedological Laboratory, Department of Geography and Applied Geography, NBU. The test results were used after simplification to maintain the association of degree of homogeneity in data character. However, the different soil parameters were tested using the following methods (Table 4.1).

Afterward, descriptive statistical computations on simplified and rounded off datasets were performed to assess the degree of variability for detailed study. The main objective of the study was to characterize the spatial variability of the soil properties in Malda district based on nutrient elements. The *nutrient index* (NI) method has been applied to evaluate soil characteristics. In this method, the individual nutrient status has been categorized into three groups: low, medium, and high. The basic and central theme of this method is constructed better by Parker et al. (1951) and is represented below:

Table 4.1 Soil properties and their measuring methods

Soil parameter	Methods	Reference
Soil pH	pH meter	Eckert and Sims (1995)
Available N	Kjeldahl	Bremner and Mulvaney (1982)
Available P_2O_5	Byer's method	Byers et al. (2005)
Available K_2O	Ammonium acetate	Jackson (1967)
Organic carbon	Walkley and Black method	Walkley and Black (1934)
Electrical conductivity	Electrical conductivity meter	Rhoades and Corwin (1981)
Available B	Hot water	Berger and Truog (1939)
Available Zn	DTPA	Lindsay and Norvell (1978)
Available Fe	DTPA	Lindsay and Norvell (1978)
Available Mn	DTPA	Lindsay and Norvell (1978)
Available Cu	DTPA	Lindsay and Norvell (1978)
Available S	Turbidimetric	Verma et al. (1977)

$$NI = \frac{(N_l \times 1) + (N_m \times 2) + (N_h \times 3)}{N_t}$$

where:

NI: Nutrient index
N_l: Number of samples of low nutrient category
N_m: Number of samples of medium nutrient category
N_h: Number of samples of high nutrient category
N_t: Total number of sample

On the other hand, the IDW interpolation method was used to generate the spatial variability maps of the different soil properties. The R 3.5.1 and Arc 10.3 software for Windows have been used for statistical analysis and mapping purposes.

4.4 Results and Discussion

4.4.1 Descriptive Statistics of the Soil Properties

Table 4.2 depicts some statistical analysis parameters of different soil parameters, such as maximum, minimum, mean, range, first quartile, third quartile, mean, median, standard deviation (SD), standard error, variance, coefficient of variation (CV), skewness (C_S), and kurtosis (C_K) of 45 soil samples. According to the criteria recommended by Wilding (1985), there are three variable classes, i.e., most (>35%), moderate (15–35%), and least (<15%) in the district. The analysis of variability reveals the phosphorus, potassium, and electrical conductivity are extremely variable, whereas pH is least variable. The rest of the fertility parameters are moderately variable in the district (Table 4.2). In general, soil pH and organic carbon (OC) are considered as the stable parameters of soil (Bouma and Pinke 1993). Skewness is a measure of the degree of symmetry or asymmetry in any given dataset. As per results, the skewness of the different soil fertility parameters of the study area varied from −0.64 (boron) to 1.16 (electrical conductivity). So, it can be inferred that the data are skewed in nature since the value of the skewness coefficient (Karl Pearson's) is not smaller than zero and the majority of the soil parameters are positively skewed. Additionally, most of the parameter's mean is greater than the median of the datasets, enough provision as skewed. Comparable results are obtained from the kurtosis of the time series data and varied from −1.35 for nitrogen to 1.99 for copper. Since the values are lesser and greater than zero, the kurtosis is not mesokurtic (normal distribution).

Table 4.2 Descriptive statistical analysis of the sample soil properties of Malda district

Statistic	pH	N	P	K	OC	EC	B	Zn	Fe	Mn	Cu	S
Data size	45	45	45	45	45	45	45	45	45	45	45	45
Maximum	8.30	372.40	222	549	0.84	0.79	0.12	0.81	9.30	4.20	0.52	5.10
Minimum	5.20	131.30	16	18	0.25	0.07	0	0.28	5.20	2.30	0.09	2.20
Range	3.10	241.10	206	531	0.59	0.72	0.12	0.53	4.10	1.90	0.43	2.90
First quartile	6.10	231.30	64	188	0.42	0.17	0.07	0.42	6.30	2.60	0.18	3.20
Third quartile	7.60	348.60	125	281	0.55	0.33	0.11	0.61	7.8	3.40	0.28	4.20
Mean	6.88	280.39	92.60	244.58	0.49	0.29	0.08	0.51	7.08	3.10	0.24	3.76
Median	6.90	241.60	80	228	0.46	0.26	0.08	0.52	6.8	3.10	0.23	3.8
Standard deviation	0.93	66.16	45.53	100.06	0.14	0.16	0.03	0.14	1.16	0.57	0.08	0.74
Standard error	0.14	9.86	6.79	14.92	0.02	0.02	0.01	0.02	0.17	0.09	0.01	0.11
Variance	0.85	4279.98	2026.55	9790.02	0.02	0.02	0.01	0.02	1.31	0.32	0.01	0.53
Coefficient of variation (%)	0.13	0.23	0.49	0.41	0.27	0.53	0.31	0.28	0.16	0.18	0.33	0.19
Skewness	−0.15	0.11	0.75	0.95	0.5	1.16	−0.64	0.03	0.6	0.45	0.97	0.11
Kurtosis	−1.21	−1.35	0.20	1.57	−0.03	1.12	0.65	−0.73	−0.75	−0.82	1.99	−0.64

4.4.2 Spatial Distribution of the Soil Properties

The widespread variability of the soil fertility parameters is categorized into different classes to determine and demarcate the regions with their deficiency for their better management. The soil fertility parameters are grouped into different categories with the help of the nutrition index range, representing their amount in soil, and the area of each class.

4.4.2.1 Soil Reaction (pH)

The NI of sample soils for soil pH and their spatial variability are presented in Table 4.3 and Fig. 4.2a. The obtained results reveal the soil pH of the study area is ranged from moderately acidic (5.20) to slightly alkaline (8.30), which slightly differ from the standard limit for majority of the crops. From the agrarian point of view, soil pH ranging between 6.5 and 7.5 is optimum to maintain soil fertility (Daji et al. 1996; Dhale and Prasad 2009). From the areal coverage, it is observed that the majority of the soils in this area are neutral (48.75%) in character, followed by slightly acidic (33.54%), slightly alkaline (17.16%), and moderately acidic (0.55%) (Table 4.3). The neutral soils are mainly found in the middle-western and north-western part of the district covering parts of Gazole, Chanchal I, Chanchal II, Ratua II, Kaliachak II, and English Bazar and a little portion of Old Malda, Habibpur, Manikchak, and Kaliachak I and II blocks (Fig. 4.2a). Due to heavy rainfall in the monsoon season and high temperature in the summer, washing of soil has resulted in deacidification with increasing neutrality. Neutral to slightly acidic, and slightly alkaline, soil in the study area is quite prevalent. However, slightly acidic soil is comparatively higher than the other two types in the study area due to agroforestry and agricultural practices. Kaliachak II and III are having slightly alkaline soil owing to bank erosion and prolonged agri-practices and rainwash effects. However, Vasu et al. (2017) emphasize the nature of parent material, use of fertilizer, and microtopography for spatial variation of pH in an area.

4.4.2.2 Available Nitrogen (N)

From the analysis of available N content in the study area, it is found that there are two classes as low and medium are exist, and they are summarized in Table 4.3 and Fig. 4.2b. The estimated value of the available N content in the district varies from 130 to 370 kg/ha on average. It is also inferred from the results that the available N is low or deficit in the major portion (54.25%) of the study area with values <280 kg/ha, covering vast parts of Bamangola, Gazole, Habibpur, Kaliachak I, and Old Malda and a little part of English Bazar, Manikchak, Ratua I, Harishchandrapur I, and Chanchal I (Fig. 4.2b). The severe scarcity of nitrogen in the study area is observed mainly due to insufficiency of organic carbon content and increased rate of

Table 4.3 Parameter-wise soil nutrient index classes and their salient features

Parameter	Value	Rating	Area (sq km)	Percentage of area
Soil pH (%)	5.2–5.5	Moderately acidic	20.47	0.55
	5.5–6.5	Slightly acidic	1251.98	33.54
	6.5–7.5	**Neutral**	**1819.98**	48.75
	7.5–8.30	Slightly alkaline	640.57	17.16
Available nitrogen (kg/ha)	131–280	**Low**	**2025.23**	54.25
	280–372	Medium	1707.76	45.75
Available phosphorus (kg/ha)	<45	Low	58.33	1.56
	45–90	Medium	1607.4	43.06
	>90	**High**	**2067.28**	55.38
Available potassium (kg/ha)	<500	Low	362.33	9.71
	500–750	**Medium**	**3298.79**	88.37
	>750	High	71.89	1.93
Organic carbon (%)	<0.50	**Low**	**2454.76**	65.76
	0.50–0.75	Medium	1270.4	34.03
	>0.75	High	7.85	0.21
Electrical conductivity (dS/m)	<0.28	**Low**	**2157.41**	57.79
	0.28–0.40	Medium	1328.3	35.58
	>0.40	High	247.29	6.62
Boron (mg/kg)	<0.03	Low	12.96	0.35
	0.03–0.06	Medium	117.85	3.16
	0.06–0.09	**High**	**3236.28**	86.69
	>0.09	Very high	365.91	9.8
Zinc (mg/kg)	<0.41	Very low	337.77	9.05
	0.41–0.54	**Low**	**2400.86**	64.31
	0.54–0.67	Medium	963.07	25.8
	>0.67	High	31.3	0.84
Iron (mg/kg)	<6.23	Low	437.11	11.71
	6.23–7.25	**Medium**	**1747.76**	46.82
	7.25–8.27	High	1410.76	37.79
	>8.27	Very high	137.37	3.68
Manganese (mg/kg)	<2.77	Low	292.91	7.85
	2.77–3.25	**Medium**	**2706.74**	72.51
	3.25–3.72	High	673.91	18.05
	>3.72	Very high	59.44	1.59
Copper (mg/kg)	<0.20	Low	280.12	7.5
	0.20–0.30	**Medium**	**3347.65**	89.68
	0.30–0.40	High	94.82	2.54
	>0.40	Very high	10.4	0.28
Sulfur (mg/kg)	<2.93	Low	54.23	1.45
	2.93–3.65	Medium	1166.37	31.24
	3.65–4.37	**High**	**2382.36**	63.82
	>4.37	Very high	130.04	3.48

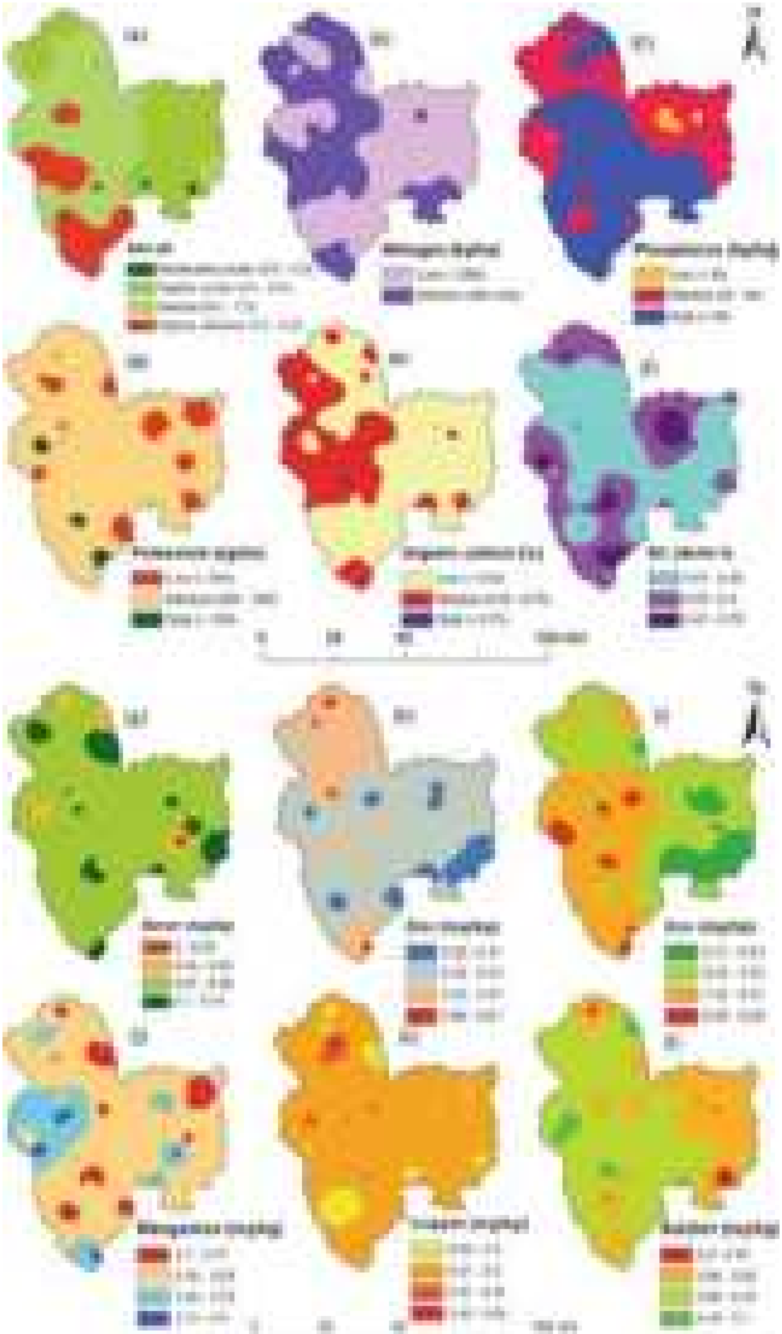

Fig. 4.2 Soil fertility parameters and their spatial distribution in Malda district. (**a**) Soil pH, (**b**) nitrogen, (**c**) phosphorus, (**d**) potassium, (**e**) organic carbon, and (**f**) electrical conductivity, (**g**) boron, (**h**) zinc, (**i**) iron, (**j**) manganese, (**k**) copper, and (**l**) sulfur

mineralization; however, lack of nitrogen fertilizer application to comprehensive nutrient crops especially maize and existence of high sulfur in the soil are considered as the reason of N deficiency (Vasu et al. 2017). On the other hand, medium available N is found in all the areas except the parts mentioned above, whereas low nitrogen content is expected to be more coinvestigated. The areal coverage of medium available N is 45.75%, and surprisingly, there is no portion in this district with a high level of available N (expectedly 400 kg/ha), and thereby yield rate is hampered to produce healthy and nutritious crops.

4.4.2.3 Available Phosphorus (P)

The results of the P availability obtained from NI are presented in Table 4.3 and Fig. 4.2c. The estimated value of the availability of P content in this region varies from 16 to 222 kg/ha (Table 4.2). From the spatial distribution, it is found that 55.38% are covered by high concentration of available P observed at the middle and southern part of the district and 43.06% are covered by a medium concentration especially found at north-eastern, north-western, and western part of the district. The comparatively healthier availability of P is mainly due to dissolution of Ca-P in the soil with deep-rooted crops under neutral soil reaction (Pal et al. 2012). Simultaneously, only 1.56% area of the total district is observed with a low concentration of available P found in the middle part of the Gazole and western part of Bamangola block (Fig. 4.2c).

4.4.2.4 Available Potassium (K)

The NI of available K and its spatial distribution are summarized in Table 4.3 and Fig. 4.2d. The assessed value reveals the available K in the study area ranges from 18 to 549 kg/ha (Table 4.2). It is also experienced from the results that the major soils (88.37%) have a medium available K content, observed at almost every block of the district, except some pockets of Gazole, Bamangola, Habibpur, English Bazar, Manikchak, Chanchal II, and Harishchandrapur II. High potassium availability is found only at 1.93% of the region, scattered over the district. However, a tiny part of Kaliachak I and Kaliachak III, located in the southern part of the district, and Manikchak, located in the western part, is included in this group. Whereas 9.71% area has been observed with low available K, scattered over the district especially in the north-western part including Gazole, Bamangola, and Chanchal II blocks. On the other hand, Habibpur, English Bazar, Harishchandrapur II, and Manikchak blocks are also considered potassium-deficit blocks (Fig. 4.2d). The poor cation exchange capacity may be the one causing factor of the deficiency of K (Srinivasarao et al. 2014).

4.4.2.5 Organic Carbon (OC)

The estimated value of the organic carbon in the district varies from 0.25% to 0.84%, summarized in Table 4.2. The magnitude of the average OC reveals the study area is dominated very low contention is the case of commonality. Organic carbon in the soil of the whole of India is very poor (Venkanna et al. 2014). Most of the area (65.76%) of the district has low organic carbon content, located in the northern, eastern, and southern part of the district covering blocks of Harishchandrapur I, Chanchal I and II, Gazole, Bamangola, Habibpur, Old Malda, English Bazar, and Kaliachak I and III (Fig. 4.2e). Heavy showers are responsible for washing out the surface and subsurface organic compounds creating further deficits.

4.4.2.6 Electrical Conductivity (EC)

The results show that the average value of EC in this region is 0.29 dS/m and ranged from 0.07 to 0.79 dS/m (Table 4.1). It is also found from the estimated results that most soils of the district are with low (57.79%) electrical conductivity, and a very little parts are with high electrical conductivity (6.62%). The low level of electrical conductivity is prevalent in the north-western to the south-eastern part of the district, and high EC has been observed in very little portions of Gazole, Kaliachak II and III, Manikchak, and Harishchandrapur I blocks (Fig. 4.2f). The fluctuation of soil electrical conductivity depends on the amount of soil moisture detained by particles of soils. However, the soils of the study area are free from strong salinity as all the collected sample values of EC are <1. It is so typical that if the EC is high in the substrate flushing, the soil with irrigation water is necessary. Similarly, if it is low, it indicates that some supplementary inputs especially salts and other nutrients are necessary.

4.4.2.7 Available Boron (B)

Boron is another typical and essential trace element of the soil. The concentration of boron in the study area ranges from 0.00 to 0.12 mg/kg, with an average of 0.08 mg/kg. However, the outcome of areal exposure shows a large quantity of the soil (86.69%) of the district has the optimum availability of boron content, experienced at every block of the district. The highest level of boron is concentrated in the north-eastern, north-western, eastern, and some middle part of the study area in a scattered manner, whereas the rest of the part of the district are observed with medium (3.16%) and low (0.35%) available boron. This is a key element for agriculture as soil pH, calcium, soil texture, organic matter, and moisture content are influenced by the availability of boron in soil (Orlov 1992).

4.4.2.8 Available Zinc (Zn)

The NI of available Zn and its spatial distribution are summarized in Table 4.3 and Fig. 4.2h. The assessed value clearly reveals the proportion of the available Zn in this region varies from 0.28 to 0.81 mg/kg. Except for the northern and southern parts of the study area, the entire region is enclosed with the soil of low (57.79%) share of zinc content. Medium concentration (25.80%) has been found in all the areas except the parts mentioned above, where low zinc content is observed. The yield of flowers and fruits is considerably reduced and delayed if Zn deficiency persists.

4.4.2.9 Available Iron (Fe)

The results of the NI of available Fe and its spatial distribution are presented in Table 4.3 and Fig. 4.2i. In the study area, the availability of iron ranges from 5.20 to 9.30 mg/kg (Table 4.2). Nearly half (46.82%) of the study area is enclosed with the medium concentration of iron, observed mainly at the northern and eastern part of the district. On the other hand, approximately one third (37.79%) of the area experienced high concentration of Fe, mainly observed in the west and southwestern part of the district. In contrast, only 3.86% of the area is observed with a very high concentration of iron found in the western part of the study area but in a scattered manner.

4.4.2.10 Available Manganese (Mn)

The existing Mn content in the study area varies from 2.30 to 4.20 mg/kg (Table 4.2); however, the results of NI and its spatial variation are presented in Table 4.3 and Fig. 4.2j. The assessed results show the medium quantity of available Mn is experienced for the majority of the portion (72.5%) of the district covering a vast part of Bamangola, Gazole, Habibpur, Kaliachak I and II, English Bazar, Old Malda, Harishchandrapur I and II, and Chanchal I and II. On the other hand, high available manganese (18.5%) is found in the little part of the western, southern, and eastern portion of the study area. The areal coverage of a very high concentration of Mn (1.59%) is significantly less than others.

4.4.2.11 Available Copper (Cu)

The analysis results of Cu and its spatial distribution in the study area are presented in Tables 4.2 and 4.3 and Fig. 4.2k. The estimated results reveal most of the area (89.68%) of the district is covered with the medium quantity of the copper blend soil. However, very high absorption of copper in the soil occupied merely 0.28% of the region, located only in the very little proportion of the northern part of the study area.

A very low (7.50%) concentration of the nutrient is found in the eastern, south-western, and northern parts of the district in a diffused manner. In the present study, the availability of copper has varied from 0.09 to 0.52 mg/kg with an average of 0.24 mg/kg.

4.4.2.12 Available Sulfur (S)

Sulfur in the study area ranges from 2.20 to 5.10 mg/kg, with an average of 3.76 mg/kg (Table 4.2). More than half (63.82%) of the study area is covered with the soil of good absorption of S except the eastern part of the study area. On the other hand, the medium quantity of sulfur is associated with 31.24% of the whole study area (Fig. 4.21l). The rest of the area is covered with the soil of a very high percentage of sulfur content. Surprisingly, there is hardly any evidence of existing soil with a low and very low concentration of sulfur in this district. The possible reason behind poor availability of S content in the study area is low organic matter and acidic soil pH (Hareesh et al. 2014).

4.5 Conclusion

This study explored the characterization of the soil properties and its spatial variability in Malda the district. The assessment revealed most of the soils (49%) of the district are neutral, followed by slightly acidic (34%). The low status of organic carbon is noticed in 65.76% of the area. The available nitrogen and potassium in the soils are of low to medium category. However, higher content of phosphorus has been observed in 55.38% of soils. A deficiency was observed in boron in the whole study area and zinc in about 75% of areas. The availability of iron, copper, and manganese in soils was observed almost permissible. Precise inspection proves that Tal and Diara regions are comparatively more fertile than the Barind tract. Fertilizer recommendations can be made for maximum crop yields. Improper agriculture practices, intensive farming, monoculture, cropping pattern, and over-irrigation are responsible for the deterioration of soil quality in some portion of the study area. To overcome the adverse effect of the chemical fertilizers in cultivation, efforts should be made to probe ahead for integrated nutrient management (INM). Under this approach, the best available option lies in the complementary use of biofertilizers, organic manures in suitable combinations for chemical fertilizers. "Organic agriculture" system should be inculcated which begins to consider potential environmental and social impacts by eliminating the use of synthetic inputs such as synthetic fertilizers, pesticides, etc. The camps, rallies, and training programs for the farmers should be arranged for increasing awareness regarding the benefits of organic agriculture, biofertilizers, etc. in better crop production and thereby improving soil fertility and nutrient status.

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