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Analysis of cropping intensity and irrigation intensity in North Twenty Four Parganas district, West Bengal, India

Abstract

An attempt has been made in this paper to analyse the spatio-temporal variations of cropping intensity and irrigation intensity, and their relationship, in North Twenty Four Parganas district in West Bengal, India from 1996/97 to 2015/16. The relationship between cropping intensity and irrigation intensity has been assessed using partial correlation, residual mapping and hierarchical cluster analysis. One-way ANOVA has been conducted for testing the equality of cluster means. Temporal analysis from 1996/97 to 2015/16 has shown a low positive correlation between cropping intensity and irrigation intensity for the entire district. Analysis at Agricultural Block level has revealed that cropping intensity decreased in many cases even after an increase in irrigation intensity. In general, cropping intensity has increased with the increase in irrigation intensity in the Coastal Saline Region and the Ichhamati Basin, whereas cropping intensity has increased even after a decrease in irrigation intensity in the Gangetic Plains Region in the district.

Keywords

Cropping intensity • hierarchical cluster analysis • irrigation intensity • ANOVA • residual mapping

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Introduction

Cropping intensity and irrigation intensity are two significant indicators for measuring the agricultural development of a region. Cropping intensity essentially determines the nature of crop production and the cropping pattern, the scope for crop diversity and crop rotation, opportunities with regard to farming incomes, and rural employment. The availability of irrigation water and its proper usage largely controls the extent of cropping intensity. In-depth study of cropping intensity and recognizing its patterns are significant tasks for agricultural geographers as 'the concept of intensity has been used extensively in the literature to explain the spatial organization of agriculture' (Dayal 1978, p. 289). Cropping intensity is considered a significant measure of food security, and net production in a region is largely dependent on it (Jain et al. 2013). Taking initiatives to increase cropping intensity is one of the well-established strategies to enhance farm productivity and rural employment. However, existing agro-ecological conditions and the nature of input utilization in agriculture largely determine the level of cropping intensity. Considering all farm inputs, the availability of irrigation water and its effective use largely control the extent of cropping intensity. Based on the study in Nepal, Kaini, Gardner and Sharma (2020) stated that within an irrigated area, the conversion of subsistence farming into commercial farming enhances cropping intensity. In the analysis of global patterns of cropping intensity, Siebert, Portmann and Döll (2010) observed that low cropping intensity has been found in arid regions without irrigation facilities and high cropping intensity in areas where irrigation water is available. Bhattarai, Sakthivadivel and Hussain (2002) stated that the scope of employment opportunities and the poverty levels in rural areas are influenced by variations in the cropping intensity between irrigated and unirrigated regions. They also mentioned that migration from low cropping intensity regions, resulting from rainfed agriculture or poorly developed irrigation systems, to regions with available irrigation water is a common scenario in the rural economies of Asian countries. Dhawan (1988) highlighted the spatio-temporal correspondence between cropping intensity and irrigation ratio (ratio of gross irrigated area to net sown area) in India. He further mentioned that cropping intensity in India rose from 114.7% to 123.6% during the period from 1960/61 to 1980/81, whereas the irrigation ratio increased from 16.9% to 28.6% in the same period. Similarly, Dhawan and Datta (1992) confirmed that the rise in cropping intensity is closely associated with the expansion of irrigation in all of India. Sharma (2015, p. 13) wrote that in India, 'the rate of increase in total cropped area was higher (3.53%) during the 2000s compared with 1990s (2.1%) mainly due to increase in area under irrigation'. He also stated that cropping intensity in India has increased from 128.9% to 138% from the early 1990s to 2011/12 due to the substantial expansion of the area under irrigation. Narayanamoorthy, Alli and Suresh (2015, p. 334) opined that an 'irrigation facility allows the farmers to use the land more intensively throughout the year with higher level of cropping intensity, which is not possible under un-irrigated land'. They also expressed that 'given the highly inelastic supply of land and reduced net sown area, the future growth of agriculture will have to heavily rely on irrigation facility as it allows for multiple cropping on the same piece of land' (Narayanamoorthy, Alli & Suresh 2015, p. 334). Hussain and Hanjra (2004, p. 13) stated that 'cropping intensity, crop productivity, labor productivity and employment, and household income are all higher in irrigated than rainfed

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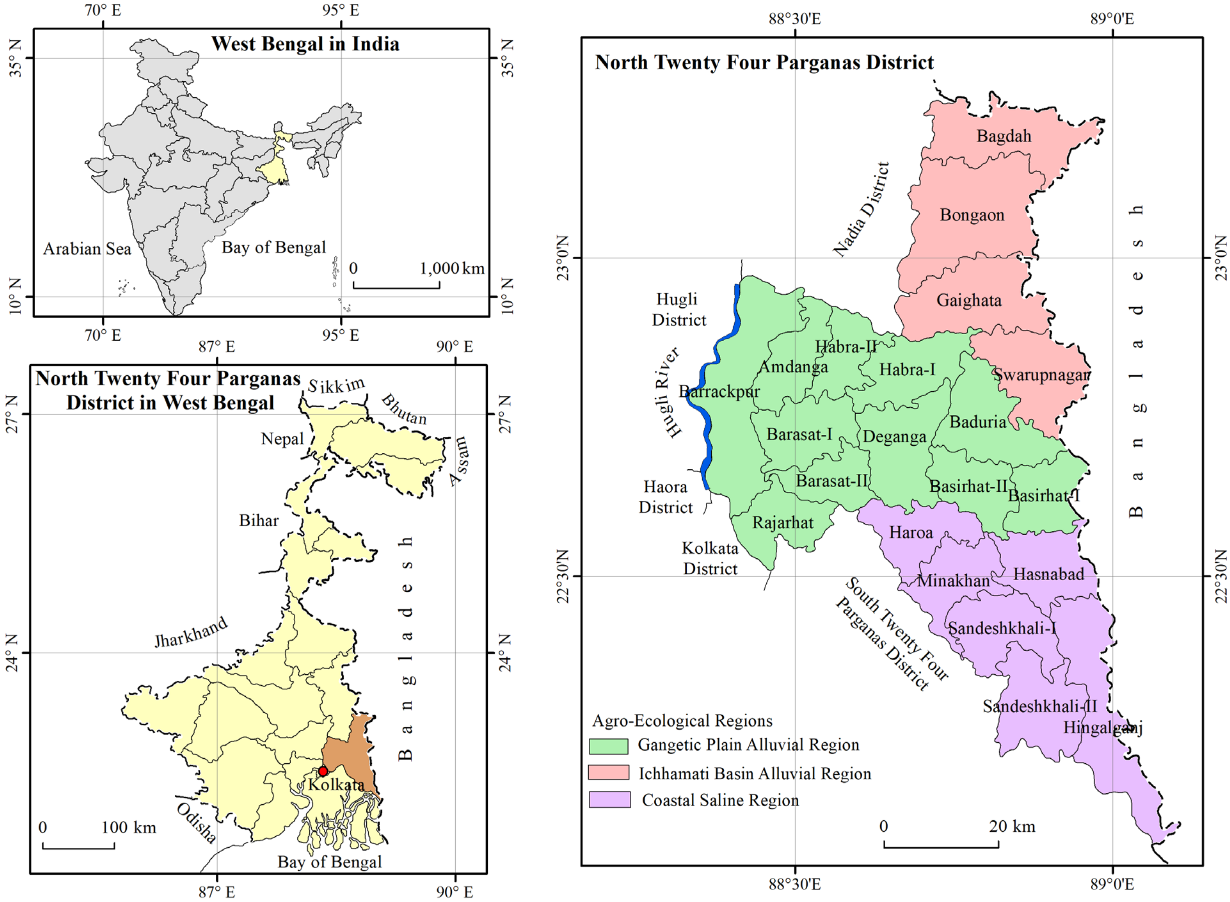

Figure 1. Location map of the study area
Source: Government of India 2011

settings'. According to Biradar and Xiao (2011, p. 368), 'irrigation and multiple-cropping agriculture in India has been a key component of economic development and poverty alleviation'.

The literature available on cropping intensity, irrigation intensity and their spatial correspondence are mainly concentrated at sub-national, national, and global levels. Therefore, an in-depth study on irrigation intensity and cropping intensity, as well as their association at district level, is essential for the design of a location-specific and comprehensive plan for agricultural development. In this context, an attempt has been made in this paper to analyse the spatio-temporal variations of cropping intensity and irrigation intensity, and their relationship, in North Twenty Four Parganas district, West Bengal, India during the 1996/97 to 2015/16 period.

Study area

North Twenty Four Parganas district extends from 22°08′ N to 23°16′ N latitudes and 88°18′ E to 89°04′ E longitudes (Fig. 1). The district covers an area of approximately 4,094 km². Physiographically, the study area is located in the Lower Gangetic Delta region of West Bengal and it shares an international boundary with Bangladesh in the east. The entire study area experiences a hot and humid tropical monsoon climate. As per the 2011 Census report, the total population of the district was recorded as 10,009,781 persons, of which 42.73% live rurally (GoI 2011). The participation rate for rural work was reported as 36.43%, and 53.78% of this population was directly engaged in agriculture (GoI 2011). The rural main work participation rate was recorded as 28.65% in 2011, of which 53.53% were engaged in agriculture (GoI 2011). The rural main work participation rate fluctuated from 28.17% in 1991 to 27.88% in 2001 (GoI 1991; GoI 2001). Of the total rural main workers, the agricultural workforce comprised 66.65% in 1991 and 49.48% in 2001 (GoI 1991; GoI 2001). The district is divided into 22 Community Development Blocks (CD Blocks) and 21 Agricultural Blocks. Two CD Blocks, namely Barrackpur-I and Barrackpur-II, are jointly known as one Agricultural Block, namely Barrackpur. The boundaries of the remaining 20 CD Blocks are identical to those of the Agricultural Blocks. The conversion of agricultural lands into non-agricultural uses restricts the horizontal expansion of agriculture in this district (DPD, GoWB 2010; Sahana, Ahmed & Sajjad 2016; Dhali, Chakraborty & Sahana 2018). The increase in population and the urban expansion, due to it being in close proximity to Kolkata city, accelerate this conversion. The population density in rural areas increased from 980 persons/km² in 1991 to 1,277 persons/km² in 2011 (Table 3) and urban population increased from 51.23% to 57.27% during the same period (GoI 1991; GoI 2011). The continuous influx of undocumented migrants from Bangladesh to North Twenty Four Parganas district also increased population pressure (Gillan 2002; Datta et al. 2008; Ghosh 2011). Moreover, croplands are being converted by fish farming in this district (DPD, GoWB 2010). The study area suffers from problems such as devastating floods, drainage congestion and acute waterlogging. Out of 21 Agricultural Blocks, six of them, namely Hingalganj, Hasnabad,

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Sandeshkhali-I, Sandeshkhali-II, Haroa and Minakhan, are part of the Indian Sundarbans delta, which is exposed to severe cyclones and the intrusion of saline water in agricultural fields (Danda et al. 2011; Sánchez-Triana et al. 2014; Sahana, Ahmed & Sajjad 2016).

Methodology

This study is mainly based on secondary data which have been collected from the Office of the Deputy Director of Agriculture, Government of West Bengal, North Twenty Four Parganas district, West Bengal, India and the Office of the Registrar General & Census Commissioner, Government of India.

Cropping intensity has been calculated following the formula of dividing the gross cropped area by the net cropped area in a given agricultural year (i.e. 1 April to 31 March) and multiplying by 100 (BAES, DPSPM, GoWB 2015).

Irrigation intensity has been calculated using the formula of dividing the gross irrigated area area by the gross cropped area in a given agricultural year and multiplying by 100 (Reddy & Reddy 1992).

The temporal trend in the relationship between cropping intensity and irrigation intensity, in the area under high-yielding varieties (HYVs) of cereals and chemical fertilizers at district level, has been examined using partial correlation.

The Ordinary Least Squares (OLS) technique (Helsel & Hirsch 2002) has been used to examine the spatio-temporal relationship between cropping intensity and irrigation intensity in North Twenty Four Parganas district for the years 1996/97 and 2015/16. Based on residual values, two residual maps (1996/97 and 2015/16) have been drawn to visualize the relationship between cropping intensity and irrigation intensity in the study area.

Hierarchical cluster analysis (Murtagh & Legendre 2014; Oehl et al. 2003; Ward 1963) has been performed to identify the homogeneity among 21 Agricultural Blocks in the study area in terms of two cluster variables – cropping intensity and irrigation intensity. The Ward method with squared Euclidean distances has been used in the hierarchical cluster analysis (Murtagh & Legendre 2014; Ward 1963). The Ward method is based on the error sum of squares (ESS) with the following objective function (Ward 1963, p. 237):

$$ESS = \sum_{i-1}^{n} x_i^2 - \frac{1}{n}\left(\sum_{i-1}^{n} x_i\right)^2$$

where, x_i indicates the score of the *i*th individual.

Squared Euclidean distance (Jobson 1992, p. 487)

$$d_{rs}^2 = \sum_{j=1}^{p} \left(x_{rj} - x_{sj}\right)^2$$

where,
'the rth and sth rows of the data matrix X will be denoted by ($x_{r^1}, x_{r^2}, \dots, x_{r^p}$) and ($x_{s^1}, x_{s^2}, \dots, x_{s^p}$) , respectively. These two rows correspond to the observations on two objects for all p variables. The quantity d_{rs}^2 will be referred to as the squared Euclidean distance' (Jobson 1992, p. 487).

Finally, for testing the equality of cluster means, one-way ANOVA has been conducted (Jobson 1992).

Results and discussion

Spatio-temporal variations in cropping intensity

In North Twenty Four Parganas district, cropping intensity increased from 209.29% in 1996/97 to 228.06% in 2015/16. During this study period, the increase in cropping intensity was recorded as 8.97% due to the effective use of modern technological inputs in agriculture (Table 1). Partial correlation indicates that the temporal change in cropping intensity is positively associated with irrigation intensity, the area under HYVs of cereals to total cereals area, and the use of chemical fertilizers (Table 2). During the study period, of these three modern technological inputs, the relationship between cropping intensity and the use of chemical fertilizers is moderately positive and statistically significant. Cropping intensity of 21 Agricultural Blocks in North Twenty Four Parganas district for the years 1996/97 and 2015/16 has been presented in Table 4. In 1996/97, the highest cropping intensity was reported as 277.41% in Gaighata and the lowest as 110.37% in Hingalganj Agricultural Blocks. Whereas, in 2015/16, the highest cropping intensity of 271.26% and the lowest of 111.80% were recorded in Amdanga and Sandeshkhali-II Agricultural Blocks, respectively. Over a period of 20 years, out of 21 Agricultural Blocks in this district, a negative change in cropping intensity was observed in five Agricultural Blocks, namely Sandeshkhali-II, Habra-I, Sandeshkhali-I, Gaighata and Minakhan (Table 4). During the period from 1996/97 to 2015/16, the rate of maximum negative change in cropping intensity was observed as -23.60% in Sandeshkhali-II, followed by Habra-I (-11.34%) and Sandeshkhali-I (-5.61%) Agricultural Blocks. A decrease in cropping intensity was observed in these Agricultural Blocks in spite of an increase in the use of modern technological inputs, namely irrigation water, HYVs of cereals and chemical fertilizers in Sandeshkhali-I and Sandeshkhali-II Agricultural Blocks, and the use of HYVs of cereals and chemical fertilizers in Habra-I Agricultural Block (Table 4). This decrease in cropping intensity in these Agricultural Blocks resulted from the occurrence of floods and waterlogged conditions due to heavy rainfall during the monsoon season in 2015 (DMS, North Twenty Four Parganas District 2017).

During the entire study period, the rate of maximum positive change in cropping intensity was reported as 51.57% in Barasat-I, followed by Barasat-II (36.46%) and Barrackpur (33.63%) Agricultural Blocks. In Barasat-I Agricultural Block, this positive change in cropping intensity is the outcome of the combined effects of the increasing use of irrigation water and of HYVs of cereals and chemical fertilizers. The expansion of the area under irrigation, seeds of HYVs, and the application of chemical fertilizers support multiple cropping which ultimately enhances cropping intensity (Bezbaruah & Roy 2002). In the case of Barasat-II and Barrackpur Agricultural Blocks, in spite of a decrease in irrigation intensity, cropping intensity increased, resulting from the significant increase in the use of HYVs of cereals and chemical fertilizers (Table 4).

Based on the cropping intensity of the Agricultural Blocks, North Twenty Four Parganas district was divided into the following three cropping intensity zones for 1996/97 and 2015/16 (Fig. 2).

(i) Low cropping intensity zone (cropping intensity <164.89%, i.e. < Mean-1SD)
(ii) Moderate cropping intensity zone (cropping intensity 164.89 – 264.03%, i.e. Mean ±1SD).
(iii) High cropping intensity zone (cropping intensity >264.03%, i.e. > Mean +1SD).

In both 1996/97 and 2015/16, three Agricultural Blocks, namely Hingalganj, Minakhan and Sandeshkhali-II, were categorized within the low cropping intensity zone, whereas, during this period Haroa and Hasnabad Agricultural Blocks shifted from the low to moderate zone of cropping intensity. All these five Agricultural Blocks are situated in the Coastal Saline Region, which is part of the Indian Sundarbans delta and prone to severe natural disasters, such as cyclones, erosion and inundation (DPD,

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Table 1. Net cropped area, gross cropped area, gross irrigated area, cropping intensity, irrigation intensity, area under HYVs of cereals to total cereals area and use of chemical fertilizers, i.e. NPK, in North Twenty Four Parganas district (1996/97 to 2015/16)

Years	Net Cropped Area (hectares)#	Gross Cropped Area (hectares)#	Cropping Intensity (%)*	Gross Irrigated Area (hectares)#	Irrigation Intensity (%)*	Area under HYVs of Cereals to Total Cereals Area (%)#	Use of Chemical Fertilizers, i.e. NPK (kg/hectare)#
1996/97	222 050	464 735	209.29	286 032	61.55	85.81	120
1997/98	222 050	467 193	210.40	286 032	61.22	85.79	125
1998/99	222 050	468 525	211.00	286 032	61.05	84.23	144
1999/00	222 050	471 412	212.30	265 894	56.4	52.94	167
2000/01	222 050	466 615	210.14	194 587	41.7	89.92	139
2001/02	222 050	472 966	213.00	195 689	41.37	90.67	151
2002/03	222 050	455 424	205.10	189 720	41.66	90.6	165
2003/04	222 050	464 084	209.00	198 745	42.83	92.18	161
2004/05	222 050	447 852	201.69	200 475	44.76	92.49	173
2005/06	222 050	500 434	225.37	245 178	48.99	94.4	179
2006/07	222 050	472 966	213.00	189 689	40.11	92.61	171
2007/08	225 000	483 750	215.00	193 987	40.1	95.79	165
2008/09	225 000	503 437	223.75	195 940	38.92	97.09	168
2009/10	225 000	462 712	205.65	195 940	42.35	95.53	185
2010/11	225 000	478 597	212.71	195 940	40.94	92.47	188
2011/12	225 000	479 250	213.00	197 058	41.12	95.37	189
2012/13	225 000	482 400	214.40	198 994	41.25	95.72	197
2013/14	220 182	481097	218.50	256 478	53.31	96.09	217
2014/15	220 182	493 207	224.00	287 459	58.28	95.97	224
2015/16	220 182	502 154	228.06	311 109	61.95	96.93	230

Sources:
** Calculated by the authors.*
 # Office of the Deputy Directorate of Agriculture (Admn.), Government of West Bengal, Barasat, North Twenty Four Parganas District, West Bengal, India.

Table 2. Partial correlation between cropping intensity and selected independent variables

Dependent Variable	Independent Variables*	Correlation	Significance (2-tailed)	Degrees of Freedom
Cropping Intensity (%)	Irrigation Intensity (%)	0.363	0.138	16
	Area under HYVs of Cereals to Total Cereals Area (%)	0.210	0.402	16
	Use of Chemical Fertilizers, i.e. NPK (kg/hectare)	0.500	0.035**	16

** partial correlation with each of the independent variables is done taking rests as control variables.*
***statistically significant at 5% level.*

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Table 3. Agro-ecological regions, density of rural population, net cropped area, gross cropped area and gross irrigated area in North Twenty Four Parganas district

Sl. Nos.	Agricultural Blocks	Agro-Ecological Regions (area in km²)	Density of Rural Population* (persons/km²)			Net Cropped Area (hectares)#		Gross Cropped Area (hectares)#		Gross Irrigated Area (hectares)#	
			1991	2001	2011	1996/97	2015/16	1996/97	2015/16	1996/97	2015/16
1	Amdanga	Gangetic Plains (1410.35)	1001	1190	1364	8995	8995	19794	24400	13502	15923
2	Barasat-I		1593	2146	2146	6320	6320	11270	17082	5625	9564
3	Barasat-II		1295	1483	1710	9730	9730	18603	25385	10660	14259
4	Barrackpur		1562	1763	1715	7570	7570	14647	19574	9120	10768
5	Deganga		1143	1362	1553	12000	12569	26397	30996	21000	22289
6	Habra-I		1027	1472	1646	8808	8808	20677	18333	14745	10765
7	Habra-II		837	1226	1344	8000	8000	19268	21109	17104	12802
8	Rajarhat		1749	1945	1835	3958	1370	8318	3565	3015	2554
9	Baduria		1008	1378	1567	12390	13490	32818	35924.5	25820	21200
10	Basirhat-I		1090	1321	1436	7400	9133	15860	20058	8800	11123
11	Basirhat-II		1224	1507	1715	8595	8174	17627	19076	9687	10801
12	Haroa	Coastal Saline Region (1028.62)	989	1195	1403	9100	8953	14725	19038	7785	9713
13	Hasnabad		972	1160	1306	11020	8600	17067	16000	7570	7812
14	Hingalganj		618	655	694	14200	14200	15673	16506	4880	5910
15	Minakhan		874	1064	1267	11400	7194	15608	9570.5	6665	3895
16	Sandeshkhali-I		665	771	902	8064	7559	14334	12681.5	6600	6556
17	Sandeshkhali-II		603	691	816	7730	9830	11312	10990	3620	3865
18	Swarupnagar	Ichhamati Basin (1082.91)	917	1054	1179	13120	13083	32299	34276	26210	19445
19	Bagdah		819	941	1041	14800	17754	34115	43128.3	27310	33443
20	Bongaon		874	1022	1131	22940	22940	60187	61494.5	30074	44291
21	Gaighata		1021	1187	1173	15910	15910	44136	42966.2	26240	34131
District Total			980	1171	1277	222050	220182	464735	502154	286032	311109

Sources:
** Government of India (GoI) 2011, Office of the Registrar General & Census Commissioner, Ministry of Home Affairs, Census of India, 1991,2001 and 2011, India. Available from: <https://censusindia.gov.in> [20 June 2019].*
 # Office of the Deputy Directorate of Agriculture (Admn.), Government of West Bengal, Barasat, North Twenty Four Parganas District, West Bengal, India.

GoWB 2010). Monocropped areas dominate in this delta region due to the high salinity in the soil and water and an uneconomic underground irrigation system (Guha 2000). During this study period, the cropping intensity increased in Haroa Agricultural Block, resulting from the increasing use of HYVs of cereals and chemical fertilizers, whereas in Hasnabad Agricultural Block the increase in irrigation intensity and use of HYVs of cereals and chemical fertilizers enhanced cropping intensity (Table 4).

During the study period, three Agricultural Blocks, namely Amdanga, Barasat-I and Bongaon, shifted from moderate to high cropping intensity zones. In Amdanga and Barasat-I Agricultural Blocks, although irrigation decreased slightly, the use of HYVs of cereals and chemical fertilizers increased during this period. The increase in the use of modern technological inputs may be attributed as the reason Bongaon Agricultural Block moved from a medium to a high cropping intensity zone. In this Agricultural Block, irrigation intensity increased by 44.13%, the use of chemical fertilizers by 95.96%, and HYVs of cereals by 3.36% during this period (Table 4). Baduria and Gaighata Agricultural Blocks maintained their high status of cropping intensity and the remaining 11 Agricultural Blocks retained their moderate status of cropping intensity during the study period. In 1996/97, the irrigation intensity, the area under HYVs of cereals and the use of chemical fertilizers in Baduria Agricultural Block were higher than the district average. Whereas, in Gaighata Agricultural Block, the area under HYVs of cereals and the use of chemical fertilizers

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Table 4. Cropping intensity (X), irrigation intensity (Y), residuals (X and Y), area under HYVs of cereals to total cereals area and use of chemical fertilizers, i.e. NPK, in North Twenty Four Parganas district (1996/97 and 2015/16)

Sl. Nos.	Agricultural Blocks	Cropping Intensity (%) X *		Irrigation Intensity (%) Y *		Residuals (X and Y)*		Area under HYVs of Cereals to Total Cereals Area (%)#		Use of Chemical Fertilizers i.e. NPK (kg/hectare)#	
		1996/ 97	2015/ 16	1996/ 97	2015/ 16	1996/ 97	2015/ 16	1996/ 97	2015/ 16	1996/ 97	2015/ 16
1	Amdanga	220.06	271.26	68.21	65.26	-2.3	20.71	86.37	98.43	124.63	223.87
2	Barasat-I	178.32	270.28	49.91	55.99	-9.89	51.53	90.51	98.96	140.37	246.5
3	Barasat-II	191.19	260.89	57.3	56.17	-10.81	41.52	82.44	98.19	119.82	240.68
4	Barrackpur	193.49	258.57	62.27	55.01	-17.77	43.17	86.99	95.06	147.81	292.58
5	Deganga	219.98	246.61	79.55	71.91	-23.54	-26.77	91.11	99.55	143.69	244.91
6	Habra-I	234.75	208.14	71.31	58.72	6.62	-19.98	95.19	100.00	171.88	308.82
7	Habra-II	240.85	263.86	88.77	60.65	-19.85	29.13	95.02	99.60	132.71	267.94
8	Rajarhat	210.16	260.22	36.25	71.64	47.43	-12.24	86.41	98.44	145.11	360.45
9	Baduria	264.87	266.3	78.68	59.01	23	37.18	95.39	99.14	155.04	233.36
10	Basirhat-I	214.32	219.62	55.49	55.45	15.71	2.7	93.41	99.36	129.26	221.28
11	Basirhat-II	205.08	233.37	54.96	56.62	7.46	12.45	90.79	98.00	143.13	241.46
12	Haroa	161.81	212.64	52.87	51.02	-31.92	10.95	71.68	91.84	100.92	209.61
13	Hasnabad	154.87	186.05	44.35	48.83	-22.98	-8.12	78.34	99.88	64.74	203.19
14	Hingalganj	110.37	116.24	31.14	35.81	-42.82	-33.26	64.37	90.67	42.88	150.39
15	Minakhan	136.91	133.03	42.7	40.7	-37.85	-33.25	77.35	92.85	87.58	165.34
16	Sandeshkhali-I	177.75	167.77	46.04	51.7	-3.25	-36.26	67.53	95.32	83.93	171.73
17	Sandeshkhali-II	146.34	111.8	32	35.17	-8.47	-35.51	42.68	76.57	59.67	153.37
18	Swarupnagar	246.18	261.99	81.15	56.73	-0.3	40.69	84.89	100.00	120.13	217.01
19	Bagdah	230.51	242.92	80.05	77.54	-13.93	-49.79	93.8	99.48	106.26	214.49
20	Bongaon	262.37	268.07	49.97	72.02	74.05	-5.71	95.05	98.24	117.93	231.09
21	Gaighata	277.41	270.06	59.45	79.44	71.4	-29.15	93.72	100.00	127.42	240.94
District Total		209.29	228.06	61.55	61.95	-	-	85.81	96.93	120.39	230.11

Sources:
** Calculated by the authors.*
 # Office of the Deputy Directorate of Agriculture (Admn.), Government of West Bengal, Barasat, North Twenty Four Parganas District, West Bengal, India.

were higher than the district average. In 2015/16, irrigation intensity was slightly lower than the district average in Baduria Agricultural Block; however, this Block maintained high cropping intensity due to an increase in the use of chemical fertilizers and HYVs of cereals.

From 1996/97 to 2015/16, the net cropped area in this district decreased by 1,868 hectares, whereas the gross cropped area increased by 37,418.5 hectares. The conversion of agricultural land for shrimp cultivation, brick kilns and the occurrences of natural calamities were responsible for this reduction of net cropped area (DPD, GoWB 2010). In addition, agricultural land was reduced due to the expansion of urban settlements and commercial activities in this district (Dhali, Chakraborty & Sahana 2019; Bera & Das Chatterjee 2019; Das & Angadi 2020, Dhar et al. 2019). However, with the significant use of modern technological inputs in agriculture, cropping intensity increased in this district from 1996/97 to 2015/16. During this period, the increase was reported as 0.65% in irrigation intensity, 12.96% in the area under HYVs of cereals, and 91.66% in the use of chemical fertilizers in the entire district (Table 1).

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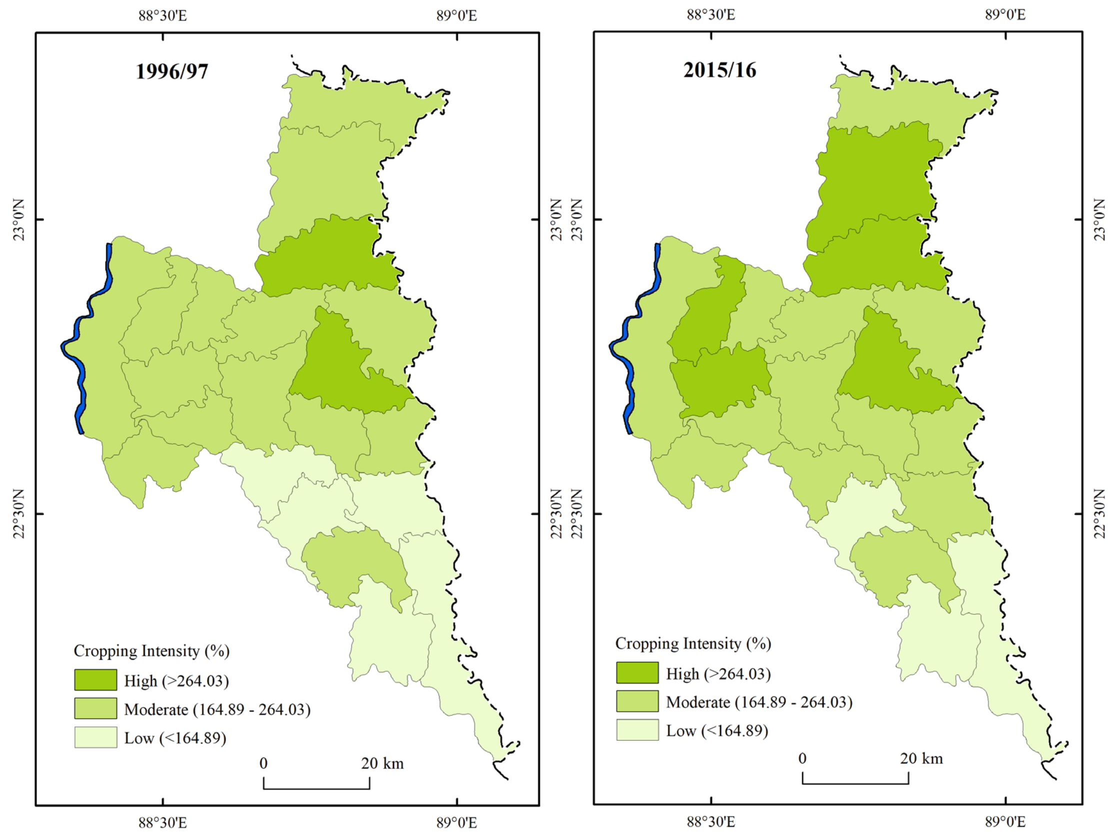

Figure 2. Cropping intensity zones in North Twenty Four Parganas district (1996/97 and 2015/16)
Source: authors' maps based on data obtained from the Office of the Deputy Directorate of Agriculture (Admn.), GoWB, Barasat, North Twenty Four Parganas District, West Bengal, India

Spatio-temporal variations in irrigation intensity

In North Twenty Four Parganas district, the main source of irrigation water is ground water, which contributes to 93.28% of the total gross irrigated area in the district (DLIC, PMKSY & DM, North Twenty Four Parganas 2016). Irrigation intensity in this district was reported as 61.55% in 1996/97 and 61.95% in 2015/16 (Table 1). In 1996/97, the highest irrigation intensity was observed as 88.77% in Habra-II and the lowest as 31.14% in Hingalganj Agricultural Blocks. The highest irrigation intensity was found to be 79.44% in Gaighata and the lowest to be 35.17% in Sandeshkhali-II Agricultural Blocks in 2015/16 (Table 4). This study has revealed that intra district variations in irrigation intensity are highly perceptible; however, the progress in irrigation development in the entire district is almost constant.

Based on irrigation intensity, North Twenty Four Parganas district has been divided into the following three irrigation intensity zones for the years 1996/97 and 2015/16 (Fig. 3).

(i) Low irrigation intensity zone (irrigation intensity <43.43%, i.e. < Mean-1SD)
(ii) Moderate irrigation intensity zone (irrigation intensity 43.43% –72.66%, i.e. Mean ±1SD).
(iii) High irrigation intensity zone (irrigation intensity >72.66%, i.e. > Mean +1SD).

During the study period, a negative change in irrigation intensity was reported in 12 Agricultural Blocks and a positive change in the remaining nine Agricultural Blocks in this district. From 1996/97 to 2015/16, the maximum rate of negative change in irrigation intensity was found to be -31.68% in Habra-II, followed by Swarupnagar (-30.09%) and Baduria (-25%) Agricultural Blocks. During this period, the maximum rate of positive change in irrigation intensity was observed as 97.63% in Rajarhat, followed by Bongaon (44.13%) and Gaighata (33.62%) Agricultural Blocks.

Agricultural Blocks in the Coastal Saline Region suffer mostly from a paucity of irrigation water. In this region, out of the total gross cropped area, only 41.84% in 1996/97 and 44.53% in 2015/16 were irrigated. More than 50% of agricultural lands were kept as fallow lands, after harvesting the rainfed paddy grown in monsoon season in this region (DLIC, PMKSY & DM, North Twenty Four Parganas 2016).

Relationship between irrigation intensity and cropping intensity

Two residual maps have been drawn to examine the relationship between cropping intensity and irrigation intensity in the study area for the years 1996/97 and 2015/16 (Fig. 4). The residual lines with '0' value on the map indicate the perfect relationship between cropping intensity and irrigation intensity. The areas with positive residual values on the map mean that both the agro-ecological conditions and the use of modern technological inputs in agriculture, apart from irrigation water, are conducive to increasing cropping intensity. Areas with negative residual values denote that, in spite of the use of irrigation water, cropping intensity is not substantial, which may be attributed to the adverse agro-ecological conditions and the use of other farm inputs at a lower rate.

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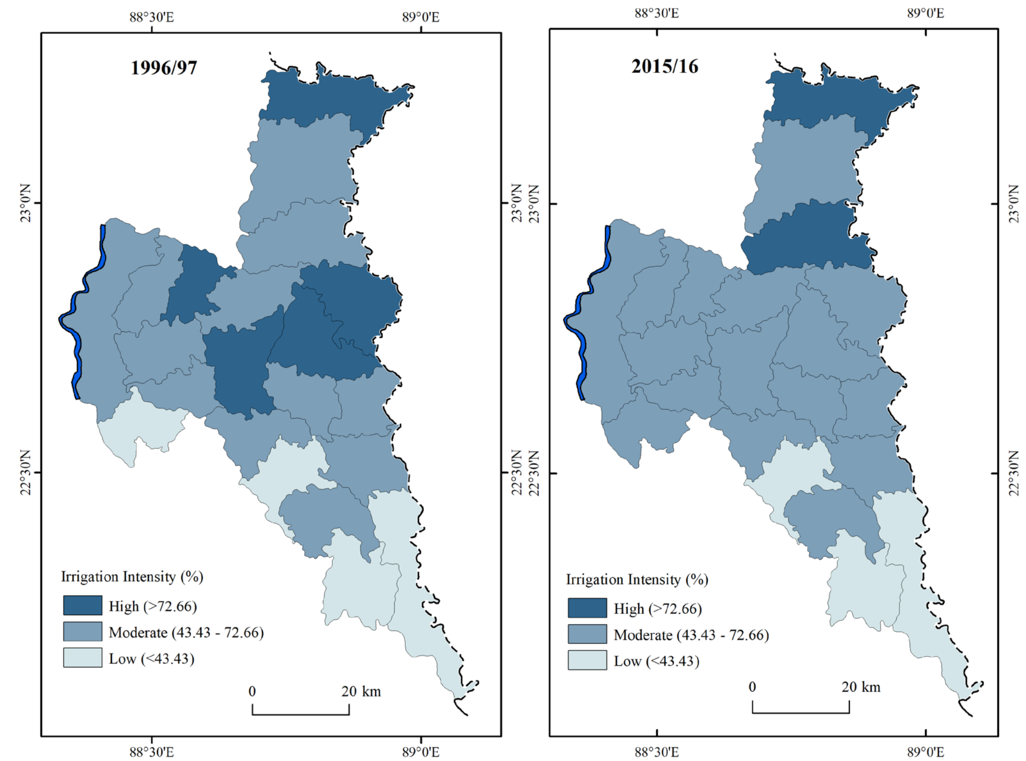

Figure 3. Irrigation intensity zones in North Twenty Four Parganas district (1996/97 and 2015/16)
Source: authors' maps based on data obtained from the Office of the Deputy Directorate of Agriculture (Admn.), GoWB, Barasat, North Twenty Four Parganas District, West Bengal, India

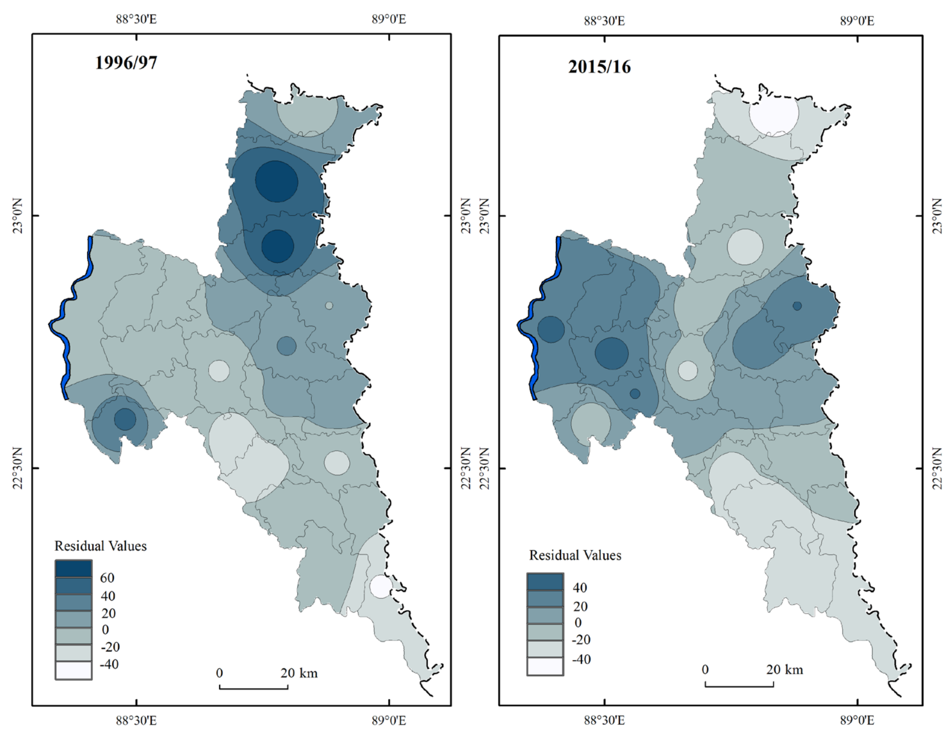

Figure 4. Relationship between irrigation intensity and cropping intensity in North Twenty Four Parganas district (1996/97 and 2015/16)
Source: authors' maps based on data obtained from the Office of the Deputy Directorate of Agriculture (Admn.), GoWB, Barasat, North Twenty Four Parganas District, West Bengal, India

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Table 5. Cluster criteria and association of Agricultural Blocks in North Twenty Four Parganas district (1996/97 and 2015/16)

Clusters	Cluster Criteria	1996/97 Agricultural Blocks	2015/16 Agricultural Blocks
1	Moderate to high cropping intensity and irrigation intensity	Amdanga, Deganga, Habra-I, Habra-II, Baduria, Swarupnagar and Bagdah	Amdanga, Barasat-I, Barasat-II, Barrackpur, Deganga, Habra-II, Rajarhat, Baduria, Swarupnagar, Bagdah, Bongaon and Gaighata
2	Moderate cropping intensity and irrigation intensity	Barasat-I, Rajarhat, Haora, Hasnabad, Hingalganj, Minakhan, Sandeshkhali-I and Sandeshkhali-II	Habra-I, Basirhat-I, Basirhat-II, Haroa, Hasnabad and Sandeshkhali-I
3	Low cropping intensity and moderate irrigation intensity	Barasat-II, Barrackpur, Basirhat-I, Basirhat-II, Bongaon and Gaighata	Hingalganj, Minakhan and Sandeshkhali-II

Sources: calculated by the authors

Table 6. ANOVA (1996/97)

		Sum of Squares	df	Mean Square	F	Sig.
Cropping Intensity (1996/97)	Between Groups	25691.975	2	12845.987	15.772	.000
	Within Groups	14660.781	18	814.488		
	Total	40352.756	20			
Irrigation Intensity (1996/97)	Between Groups	4952.253	2	2476.127	54.635	.000
	Within Groups	815.789	18	45.322		
	Total	5768.042	20			

Sources: calculated by the authors

In 1996/97, residual lines with ‘0’ values passed through Bagdah, Basirhat-I, Basirhat-II, Deganga, Habra-II and Rajarhat, Barasat-I, Barasat-II and Barrackpur Agricultural Blocks in the district. Positive lines crossed through Rajarhat, Bagdah, Bongaon, Gaighata and the central part of Baduria Agricultural Blocks, and negative lines passed through the Agricultural Blocks lying in the Indian Sundarbans delta and the central part of Deganga Agricultural Block.

In 2015/16, the relationship between irrigation intensity and cropping intensity changed in the district. In this period, ‘0’ residual lines passed through Gaighata, Deganga, Habra-I, Basirhat-I, Basirhat-II, Haroa and Rajarhat Agricultural Blocks. Residual lines with positive values passed through Swarupnagar and Baduria Agricultural Blocks and the western part of the district. Residual lines with negative values crossed through the northern and southern parts of this district.

The hierarchical clustering using the Ward method, based on two cluster variables, namely irrigation intensity and cropping intensity, was performed to show the nature of homogeneity of the 21 Agricultural Blocks in North Twenty Four Parganas district for the years 1996/97 and 2015/16. Three clusters with cluster criteria, and their corresponding Agricultural Blocks in the study area, are presented in Table 5.

One-way ANOVA was conducted to determine the significant differences in the mean scores of cropping intensity and irrigation intensity across three clusters (i.e. cluster-1, 2 and 3) for the years 1996/97 and 2015/16, respectively.

From the Test of Homogeneity of Variances, it is evident that the Levene’s tests are not significant at 0.05 alpha level for both of the dependent variables (i.e. p =0.104 for cropping intensity and p =0.244 for irrigation intensity) in 1996/97. The ANOVA results in 1996/97 (Table 6) confirmed that the null hypothesis (i.e. all three clusters means are equal) is rejected in both cases. Hence, there are significant differences between clusters means in every case (for cropping intensity and irrigation intensity, p =0.000, i.e. <0.05).

Post-hoc tests (Tukey HSD) were conducted to identify which group mean was significantly different from each of the others (Table 7). It was confirmed, from the results of Post-hoc tests on cropping intensity, that cluster-1 is significantly different from cluster-2. Likewise, in cropping intensity, cluster-2 is significantly different from cluster-3. In cropping intensity, there is no statistically significant difference between cluster-1 and cluster-3. The Eta squared (η^2) is calculated as 0.6367, i.e. 63.67% variance is associated with cropping intensity.

In 1996/97, for irrigation intensity (Table 7), cluster-1 is significantly different from cluster-2. Cluster-1 is significantly different from cluster-3. Cluster-2 is significantly different from cluster-3. The Eta squared (η^2) is calculated as 0.8586, i.e. 85.86% variance is associated with irrigation intensity in 1996/97.

From the Test of Homogeneity of Variances, it is evident that the Levene’s tests are significant at 0.05 alpha level for both of the dependent variables (i.e. p =0.029 for cropping intensity and p=.005 for irrigation intensity) in 2015/16. Therefore, the assumption of homogeneity of variance was violated in both cases. Hence, Robust Tests of Equality of Means (Welch and Brown-Forsythe) were conducted (Table 8) and the adjusted F ratio in all cases were significant (i.e. p <0.001) and, therefore, the null hypothesis was rejected. The Welch and Brown-Forsythe tests results confirmed that there were significant mean

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Table 7. Post-hoc Tests (1996/97)

Tukey HSD (Multiple Comparisons)							
Dependent Variable	(I) Ward Method	(J) Ward Method	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Cropping Intensity (1996/97)	1	2	77.17661*	14.77046	.000	39.4800	114.8732
		3	12.76619	15.87776	.705	-27.7565	53.2888
	2	1	-77.17661*	14.77046	.000	-114.8732	-39.4800
		3	-64.41042*	15.41295	.002	-103.7468	-25.0741
	3	1	-12.76619	15.87776	.705	-53.2888	27.7565
		2	64.41042*	15.41295	.002	25.0741	103.7468
Irrigation Intensity (1996/97)	1	2	36.33821*	3.48421	.000	27.4459	45.2305
		3	21.67238*	3.74541	.000	12.1135	31.2313
	2	1	-36.33821*	3.48421	.000	-45.2305	-27.4459
		3	-14.66583*	3.63577	.002	-23.9449	-5.3868
	3	1	-21.67238*	3.74541	.000	-31.2313	-12.1135
		2	14.66583*	3.63577	.002	5.3868	23.9449

** The mean difference is significant at the 0.05 level.*
Sources: calculated by the authors

Table 8. Robust Tests of Equality of Means (2015/16)

		Statistic[a]	df1	df2	Sig.
Cropping Intensity (2015/16)	Welch	186.750	2	4.780	.000
	Brown-Forsythe	94.294	2	7.745	.000
Irrigation Intensity (2015/16)	Welch	43.072	2	8.316	.000
	Brown-Forsythe	38.153	2	17.286	.000
a. Asymptotically F distributed.					

Sources: calculated by the authors

differences between clusters for cropping intensity and irrigation intensity in 2015/16.

The Games-Howell test was conducted as the Post-hoc tests in 2015/16, as the equal variance was not assumed (Table 9). In 2015/16, the results of Post-hoc tests (Games-Howell) on cropping intensity show cluster-1 is significantly different from cluster-2. Cluster-1 is significantly different from cluster-3 in cropping intensity. In cropping intensity, cluster-2 is significantly different from cluster-3. The Eta squared (η^2) is calculated as 0.9284, i.e. 92.84% variance is associated with cropping intensity in 2015/16.

In comparison, cluster-1 is significantly different from cluster-2 in irrigation intensity in 2015/16. Cluster-1 is significantly different from cluster-3 in irrigation intensity. Cluster-2 is significantly different from cluster-3 in irrigation intensity. The Eta squared (η^2) is calculated as 0.6726, i.e. 67.26% variance is associated with irrigation intensity in 2015/16.

Conclusions

The analysis of cropping intensity and irrigation intensity in North Twenty Four Parganas district from 1996/97 to 2015/16 re-establishes the positive correlation between them. However, considering the temporal and spatial dimensions of this relationship within this district, the following two significant observations were obtained from this study. First, during the study period, the district as a whole reflected a low positive correlation between cropping intensity and irrigation intensity. This trend, derived from the partial correlation among various associated factors with cropping intensity, clearly indicates that cropping intensity in this district was also influenced by other technological inputs, most significantly chemical fertilizers and HYV seeds of cereals, along with irrigation. Second, considering the spatial (Agricultural Block level) variations, two different trends in the relationship between cropping intensity and irrigation intensity were observed in North Twenty Four Parganas district during

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Table 9. Post-hoc Tests (2015/16)

Games-Howell (Multiple Comparisons)							
Dependent Variable	(I) Ward Method	(J) Ward Method	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Cropping Intensity (2015/16)	1	2	57.15417*	10.05702	.004	25.8715	88.4369
		3	141.39583*	6.96935	.001	109.9476	172.8441
	2	1	-57.15417*	10.05702	.004	-88.4369	-25.8715
		3	84.24167*	11.66894	.000	49.8575	118.6259
	3	1	-141.39583*	6.96935	.001	-172.8441	-109.9476
		2	-84.24167*	11.66894	.000	-118.6259	-49.8575
Irrigation Intensity (2015/16)	1	2	11.39083*	3.02058	.005	3.5875	19.1941
		3	27.88750*	3.12802	.000	19.4289	36.3461
	2	1	-11.39083*	3.02058	.005	-19.1941	-3.5875
		3	16.49667*	2.33231	.002	8.9642	24.0291
	3	1	-27.88750*	3.12802	.000	-36.3461	-19.4289
		2	-16.49667*	2.33231	.002	-24.0291	-8.9642

** The mean difference is significant at the 0.05 level.*
Sources: calculated by the authors

the study period: in the Agricultural Blocks of the Ichhamati River Basin and the Coastal Saline Region, cropping intensity and irrigation intensity have both increased; and, in the Agricultural Blocks of the Gangetic Plain Region, cropping intensity has increased in spite of a decrease in irrigation intensity.

In North Twenty Four Parganas district, the gradual shrinkage of the net cropped area was observed due to the continuous conversion of agricultural land for non-agricultural use during the study period. Simultaneously, the rapid increase in population in this district brought the challenges of sustaining agricultural production and ensuring food security to the fore. In this context, enhancing cropping intensity in the district emerged as the priority. Therefore, it has been suggested that a comprehensive plan for water resource management, comprising the improvement of irrigation and the management of floods is required in the district. Particularly in the Coastal Saline Region, where both irrigation intensity and cropping intensity are low compared to the rest of the district, special attention is needed for the overall improvement of irrigation intensity and cropping intensity. In the Coastal Saline Region, rainwater harvesting needs to be promoted to improve the availability of irrigation water.

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