

Irrigation Development and Agricultural Intensification in North-East India: A State Wise Analysis (2004-05 to 2022-23)

James Dev Verma*¹

¹ Assistant Professor, Department of Geography, Swami Vivekananda Mahavidyalaya, Mohanpur - 799 211, West Tripura, India

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Abstract

Irrigation development plays an important role in agricultural intensification by enabling repeated use of cultivated land and reducing dependence on rainfall. The present study examines irrigation development and its association with agricultural intensification across the eight states of North-East India during 2004-05 to 2022-23. Secondary time-series data on gross sown area, net sown area, gross irrigated area and net irrigated area were analyzed using absolute change, relative change, compound annual growth rate, irrigation ratios and cropping intensity. State-wise Pearson correlation coefficients were also estimated to assess the association between irrigated area and cropping intensity. The findings reveal substantial inter-state variation in irrigation development and agricultural intensification. At the regional level, gross irrigated area increased by 91.36% and net irrigated area by 101.30%, while cropping intensity increased from 132.54% to 142.09%. Correlation results showed predominantly positive associations between irrigated area and cropping intensity, although their strength varied across states. The study concludes that irrigation development is associated with greater agricultural intensification in North-East India, but the relationship is not uniform and is influenced by state-specific geographical and agricultural conditions.

Key words: Irrigation development, Agricultural intensification, Cropping intensity, Gross irrigated area, Net irrigated area, North-east India

Irrigation is an important determinant of agricultural intensification because it reduces dependence on rainfall and allows cultivated land to be used more than once during an agricultural year [5]. Where irrigation is limited, the scope for increasing gross cropped area through repeated cultivation is constrained by seasonal water availability. Thus, changes in irrigated area and cropping intensity provide complementary measures for examining the changing use of agricultural land. This relationship is particularly relevant to North-East India, where high rainfall does not necessarily ensure adequate water availability throughout the cropping year. Rainfall is strongly seasonal, while hilly terrain, fragmented holdings and difficult accessibility constrain the expansion of conventional irrigation infrastructure in several parts of the region [1], [8]. Agricultural conditions consequently differ sharply among the eight states, with the relatively intensive agricultural systems of the plains contrasting with predominantly rain-fed cultivation in several hill areas. Such differences make a state-wise assessment more informative than a regional average alone.

Previous studies have examined irrigation potential and crop intensification in selected areas of North-East India [8] and have assessed the relationship between irrigation intensity and cropping intensity at the district level in Assam [4]. Other studies have focused on particular cropping systems and technological interventions for intensification in the region [3], [7]. However, comparable evidence covering all eight North-Eastern states over a long period, while examining both the

expansion of irrigated area and changes in cropping intensity, remains limited. In particular, the extent to which changes in gross and net irrigated area have been accompanied by changes in irrigation coverage and repeated use of cultivated land has received less attention at the regional state level.

The present study addresses this gap by examining changes in gross irrigated area (GIA), net irrigated area (NIA), gross and net irrigation ratios, and cropping intensity across the eight states from 2004-05 to 2022-23. It further estimates state-wise Pearson correlation coefficients between irrigated area and cropping intensity to assess whether states experiencing changes in irrigated area also recorded corresponding changes in agricultural land-use intensity. The analysis therefore distinguishes between expansion of irrigated area, irrigation coverage relative to cultivated land, and the actual intensity of land use, providing a comparative assessment of irrigation development and agricultural intensification in North-East India. The findings also show that irrigation development has varied across the states and that its relationship with agricultural intensification has not been the same throughout the region.

MATERIALS AND METHODS

The study is based on secondary time-series data for the eight North-Eastern states of India, which include Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura, covering the period from 2004-05 to 2022-

*Correspondence to: James Dev Verma, E-mail: jameskarma@gmail.com; Tel: +91 9862123220

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23. State-wise annual data on gross sown area (GSA), net sown area (NSA), gross irrigated area (GIA) and net irrigated area (NIA) were obtained from the Handbook of Statistics on Indian States 2023-24, Reserve Bank of India [6]. The data are expressed in thousand hectares. The analysis examined temporal changes and inter-state variations in irrigation development and agricultural intensification.

Agricultural intensification was assessed primarily through cropping intensity, calculated as:

$$\text{Cropping Intensity (\%)} = (\text{Gross Sown Area} / \text{Net Sown Area}) \times 100$$

The extent of irrigation relative to cultivated area was assessed using gross and net irrigation ratios, calculated as:

$$\text{Gross Irrigation Ratio (\%)} = (\text{Gross Irrigated Area} / \text{Gross Sown Area}) \times 100$$

$$\text{Net Irrigation Ratio (\%)} = (\text{Net Irrigated Area} / \text{Net Sown Area}) \times 100$$

Absolute change and relative change were used to measure changes between the base year and terminal year. Relative change was calculated as:

$$\text{Relative change (\%)} = [(V_f - V_i) / V_i] \times 100$$

The compound annual growth rate (CAGR) was used to estimate the annual rate of change over the study period and was calculated as:

$$\text{CAGR (\%)} = [(V_f/V_i)^{1/(n-1)} - 1] \times 100$$

Where V_i is the value in the base year, V_f is the value in the terminal year and n is the number of observations. $n-1$

represents the number of annual intervals between the base and the terminal years.

Pearson's correlation coefficient was calculated separately for each state using annual observations to examine the association between irrigation development and agricultural intensification. The Pearson correlation coefficient was calculated as:

$$r = \frac{n(\sum XY) - (\sum X)(\sum Y)}{\sqrt{[n\sum X^2 - (\sum X)^2][n\sum Y^2 - (\sum Y)^2]}}$$

Where r is the correlation coefficient, X represents irrigated area (GIA or NIA), Y represents cropping intensity, and n is the number of annual observations. The relationships between gross irrigated area and cropping intensity, and between net irrigated area and cropping intensity, were examined to determine whether changes in irrigated area were accompanied by corresponding changes in the intensity of agricultural land use.

RESULTS AND DISCUSSION

Changes in gross and net sown area

The state-wise changes in gross sown area (GSA) and net sown area (NSA) between 2004-05 and 2022-23 are presented in (Table 1). The changes indicate considerable inter-state variation in the extent and direction of agricultural land use across North-East India. Gross sown area increased in all eight states during the study period, although the magnitude of increase varied substantially [6]. Mizoram recorded the highest relative increase in GSA (112.37%), followed by Tripura (72.60%) and Manipur (60.50%). Arunachal Pradesh recorded a 34.51% increase, while Meghalaya, Nagaland and Sikkim registered relatively moderate increases of 24.53%, 23.95% and 13.01%, respectively. Assam showed only a marginal increase of 3.54%.

Table 1 Changes in gross and net sown area in North-East India, 2004-05 to 2022-23

State	(Area in thousand hectares)									
	Gross sown area 2004-05	Gross sown area 2022-23	Change	Relative change (%)	CAGR (%)	Net sown area 2004-05	Net sown area 2022-23	Change	Relative change (%)	CAGR (%)
Arunachal Pradesh	255	343	88	34.51	1.66	202	253	51	25.25	1.26
Assam	3896	4034	138	3.54	0.19	2753	2744	-9	-0.33	-0.02
Manipur	238	382	144	60.50	2.66	238	382	144	60.50	2.66
Meghalaya	265	330	65	24.53	1.23	219	274	55	25.11	1.25
Mizoram	97	206	109	112.37	4.27	97	145	48	49.48	2.26
Nagaland	380	471	91	23.95	1.20	309	361	52	16.83	0.87
Sikkim	123	139	16	13.01	0.68	78	83	5	6.41	0.35
Tripura	281	485	204	72.60	3.08	280	255	-25	-8.93	-0.52

Note: CAGR is calculated for 18 annual intervals from 2004-05 to 2022-23

Source: Compiled from Handbook of Statistics on Indian States 2023-24, Reserve Bank of India

The pattern of net sown area was comparatively different. Manipur recorded the highest increase in NSA (60.50%), followed by Mizoram (49.48%), Arunachal Pradesh (25.25%), Meghalaya (25.11%) and Nagaland (16.83%). Sikkim registered a relatively small increase of (6.41%). In contrast, Assam and Tripura recorded declines in NSA of 0.33% and 8.93%, respectively. The CAGR (compound annual growth rate) results broadly correspond with these changes, with positive growth in NSA in six states and negative growth in Assam and Tripura. The divergence between changes in gross and net sown area is particularly relevant for understanding agricultural intensification. An increase in GSA

alongside a relatively smaller increase, or decline, in NSA suggests a greater role for repeated use of existing cultivated land, a pattern examined through cropping intensity in the subsequent analysis. The expansion of GSA across all eight states suggests an increase in annual cultivated area, but the differing patterns of NSA indicate that the contribution of repeated cropping varied considerably among the states.

Changes in gross and net irrigated area

Gross irrigated area (GIA) and net irrigated area (NIA) indicate the extent of land receiving irrigation and provide a basis for assessing changes in irrigation development. GIA

represents the total area irrigated during the agricultural year, including areas irrigated more than once, whereas NIA refers to the area irrigated at least once during the year. Changes in these two measures therefore provide an initial indication of the expansion of irrigation facilities and the spatial variation in irrigation development across the North-Eastern states. Data in (Table 2) presents the changes in GIA and NIA between 2004-05 and 2022-23. At the regional level, GIA increased from 590 thousand ha to 1,129 thousand ha, an absolute increase of 539

thousand ha or 91.36%, with a CAGR (compound annual growth rate) of 3.67%. NIA increased from 462 thousand ha to 930 thousand ha, representing an absolute increase of 468 thousand ha or 101.30%, with a CAGR of 3.96%. Thus, NIA (net irrigated area) expanded slightly faster than GIA over the study period, both in terms of percentage increase and annualized growth. The regional increase in NIA indicates a substantial expansion in the area receiving irrigation at least once during the agricultural year [6].

Table 2 Changes in gross and net irrigated area in North-East India, 2004-05 to 2022-23

State	(Area in thousand hectares)									
	GIA 2004-05	GIA 2022-23	Absolute change	Relative change (%)	CAGR (%)	NIA 2004-05	NIA 2022-23	Absolute change	Relative change (%)	CAGR (%)
Arunachal Pradesh	49	64	15	30.61	1.49	49	64	15	30.61	1.49
Assam	171	611	440	257.31	7.33	140	467	327	233.57	6.92
Manipur	54	57	3	5.56	0.30	54	57	3	5.56	0.30
Meghalaya	74	116	42	56.76	2.53	58	105	47	81.03	3.35
Mizoram	19	29	10	52.63	2.38	16	16	0	0.00	0.00
Nagaland	104	122	18	17.31	0.89	66	118	52	78.79	3.28
Sikkim	11	13	2	18.18	0.93	6	13	7	116.67	4.39
Tripura	108	117	9	8.33	0.45	73	90	17	23.29	1.17
North-East India	590	1129	539	91.36	3.67	462	930	468	101.30	3.96

Source: Compiled from Handbook of Statistics on Indian States 2023-24, Reserve Bank of India

Assam recorded the most pronounced expansion. GIA increased from 171 thousand ha to 611 thousand ha, an absolute increase of 440 thousand ha or 257.31%, with a CAGR of 7.33%. NIA increased from 140 thousand ha to 467 thousand ha, an absolute increase of 327 thousand ha or 233.57%, with a CAGR of 6.92%. Assam therefore recorded the largest absolute increases and the highest annualized growth rates in both GIA and NIA, making it the principal contributor to the expansion of irrigated area in North-East India.

Among the other states, Meghalaya, Nagaland and Sikkim recorded relatively high growth in NIA. Meghalaya's GIA increased by 42 thousand ha, from 74 to 116 thousand ha, representing a 56.76% increase with a CAGR of 2.53%, while NIA increased by 47 thousand ha, from 58 to 105 thousand ha, or 81.03%, with a CAGR of 3.35%. Nagaland recorded a comparatively small absolute increase in GIA of 18 thousand ha, from 104 to 122 thousand ha, representing 17.31% growth and a CAGR of 0.89%; in contrast, its NIA increased by 52 thousand ha, from 66 to 118 thousand ha, corresponding to 78.79% growth and a CAGR of 3.28%. Sikkim recorded the highest percentage increase in NIA, with an absolute gain of

only 7 thousand ha, from 6 to 13 thousand ha, representing 116.67% growth and a CAGR of 4.39%. Its GIA increased by just 2 thousand ha, from 11 to 13 thousand ha, or 18.18%, with a CAGR of 0.93%. Thus, while Sikkim recorded the highest proportional increase in NIA, the absolute scale of expansion was considerably smaller than that of Meghalaya and Nagaland.

The remaining states recorded comparatively modest or contrasting changes. Arunachal Pradesh recorded an absolute increase of 15 thousand ha in both GIA and NIA, with each increasing by 30.61% and a CAGR of 1.49%. Manipur experienced only a 3 thousand ha increase in both measures, corresponding to 5.56% growth and a CAGR of 0.30%. Tripura recorded an increase of 9 thousand ha in GIA, from 108 to 117 thousand ha, or 8.33%, with a CAGR of 0.45%, while NIA increased by 17 thousand ha, from 73 to 90 thousand ha, representing 23.29% growth and a CAGR of 1.17%. Mizoram showed a contrasting pattern, although GIA increased by 10 thousand ha, from 19 to 29 thousand ha, representing 52.63% growth with a CAGR of 2.38%, NIA remained unchanged at 16 thousand ha, with no absolute or percentage increase and a CAGR of 0.00%.

Table 3 Changes in cropping intensity in North-East India, 2004-05 to 2022-23

State	2004-05 (%)	2022-23 (%)	Absolute change (Percentage points)	Change (%)	CAGR (%)
Arunachal Pradesh	126.24	137.57	11.33	8.97	0.48
Assam	141.52	147.01	5.49	3.88	0.21
Manipur	100.00	100.00	0.00	0.00	0.00
Meghalaya	121.00	120.44	-0.56	-0.46	-0.03
Mizoram	100.00	142.07	42.07	42.07	1.97
Nagaland	122.98	130.47	7.49	6.09	0.33
Sikkim	157.69	167.47	9.78	6.20	0.33
Tripura	100.36	190.20	89.84	89.52	3.62
North-East India	132.54	142.09	9.55	7.21	0.39

Note: Absolute change is expressed in percentage points

Source: Compiled from Handbook of Statistics on Indian States 2023-24, Reserve Bank of India

Changes in cropping intensity

The data in (Table 3) reveal that cropping intensity in North-East India increased from 132.54% in 2004-05 to 142.09% in 2022-23, representing an absolute change of 9.55 percentage points and a change of 7.21%. The CAGR (compound annual growth rate) of cropping intensity was 0.39%, indicating a gradual increase in the intensity of agricultural land use during the study period. However, considerable variation was observed among the states [6].

The highest increase in cropping intensity was recorded in Tripura, where it increased from 100.36% to 190.20%, representing an absolute change of 89.84 percentage points and a change of 89.52%. The state also recorded the highest CAGR of 3.62%. Mizoram ranked second, with cropping intensity increasing from 100.00% to 142.07%, representing an absolute change of 42.07 percentage points and a change of 42.07%, with a CAGR of 1.97%. Arunachal Pradesh recorded an absolute change of 11.33 percentage points, followed by Sikkim (9.78 percentage points), Nagaland (7.49 percentage points) and Assam (5.49 percentage points). Their corresponding CAGRs were 0.48%, 0.33%, 0.33% and 0.21%, respectively. In contrast, Manipur showed no change in cropping intensity, remaining at 100.00% in both years, with a CAGR of 0.00%. Meghalaya was the only state to record a decline, from 121.00% to 120.44%, resulting in an absolute change of -0.56 percentage points, a change of -0.46% and a CAGR of -0.03%. The

findings indicate that cropping intensity increased in North-East India during the study period, but the extent of agricultural intensification varied substantially across the states, with Tripura and Mizoram showing the most pronounced increases.

Changes in gross and net irrigation ratios

Data depicted in (Table 4) shows considerable inter-state variation in Gross Irrigation Ratio (GIR) and Net Irrigation Ratio (NIR) between 2004-05 and 2022-23. Assam recorded the most substantial improvement in both indicators. Its GIR increased from 4.39% to 15.15%, representing an absolute change of 10.76 percentage points and a change of 245.10%, with a CAGR of 7.12%. NIR increased from 5.08% to 17.01%, representing an absolute change of 11.93 percentage points and a change of 234.84%, with a CAGR of 6.94%. Meghalaya also recorded notable increases, with GIR rising from 27.92% to 35.15%, representing an absolute change of 7.23 percentage points and a change of 25.89%, with a CAGR of 1.29%. Its NIR increased from 26.48% to 38.32%, representing an absolute change of 11.84 percentage points and a change of 44.71%, with a CAGR of 2.07%. Sikkim registered a modest increase in GIR, from 8.94% to 9.35%, representing an absolute change of 0.41 percentage points and a change of 4.59%, with a CAGR of 0.25%, while its NIR increased from 7.69% to 15.66%, representing an absolute change of 7.97 percentage points and a change of 103.64%, with a CAGR of 4.03%.

Table 4 Changes in gross and net irrigation ratios in North-East India, 2004-05 to 2022-23

State	GIR 2004-05 (%)	GIR 2022-23 (%)	Absolute change (Percentage points)	Change (%)	CAGR (%)	NIR 2004-05 (%)	NIR 2022-23 (%)	Absolute change (Percentage points)	Change (%)	CAGR (%)
Arunachal Pradesh	19.22	18.66	-0.56	-2.91	-0.16	24.26	25.30	1.04	4.29	0.23
Assam	4.39	15.15	10.76	245.10	7.12	5.08	17.01	11.93	234.84	6.94
Manipur	22.69	14.92	-7.77	-34.24	-2.30	22.69	14.92	-7.77	-34.24	-2.30
Meghalaya	27.92	35.15	7.23	25.89	1.29	26.48	38.32	11.84	44.71	2.07
Mizoram	19.59	14.08	-5.51	-28.13	-1.82	16.49	11.03	-5.46	-33.11	-2.21
Nagaland	27.37	25.90	-1.47	-5.37	-0.31	21.36	32.69	11.33	53.04	2.39
Sikkim	8.94	9.35	0.41	4.59	0.25	7.69	15.66	7.97	103.64	4.03
Tripura	38.43	24.12	-14.31	-37.24	-2.55	26.07	35.29	9.22	35.37	1.70

Source: Compiled and calculated by the authors from Handbook of Statistics on Indian States 2023-24, Reserve Bank of India

The remaining states displayed mixed trends. Arunachal Pradesh recorded a slight decline in GIR from 19.22% to 18.66%, representing an absolute change of -0.56 percentage points and a change of -2.91%, while NIR increased from 24.26% to 25.30%, representing an absolute change of 1.04 percentage points and a change of 4.29%. Nagaland recorded a decline in GIR but a substantial increase in NIR. Its GIR declined from 27.37% to 25.90%, representing an absolute change of -1.47 percentage points and a change of -5.37%, whereas NIR increased from 21.36% to 32.69%, representing an absolute change of 11.33 percentage points and a change of 53.04%, with a CAGR of 2.39%. In contrast, Mizoram experienced declines in both indicators. Its GIR declined from 19.59% to 14.08%, representing an absolute change of -5.51 percentage points and a change of -28.13%, while NIR decreased from 16.49% to 11.03%, representing an absolute change of -5.46 percentage points and a change of -33.11%, with a CAGR of -2.21%. Manipur also experienced a decline in both indicators, with GIR and NIR falling from 22.69% to 14.92%, representing an absolute change of -7.77 percentage points and a change of -34.24%, with a CAGR of -2.30% for both indicators. These contrasting movements indicate that

changes in irrigation coverage relative to gross and net sown areas were not uniform across the region.

Tripura exhibited a particularly contrasting pattern. Its GIR declined from 38.43% to 24.12%, representing an absolute change of -14.31 percentage points and a change of -37.24%, with a CAGR of -2.55%, whereas NIR increased from 26.07% to 35.29%, representing an absolute change of 9.22 percentage points and a change of 35.37%, with a CAGR of 1.70%. Thus, changes in gross and net irrigation coverage could follow markedly different trajectories within the same state. The findings indicate that the relative coverage of irrigation changed unevenly across North-East India during the study period, with gross and net irrigation coverage sometimes following different trajectories within the same state.

Relationship between irrigation development and agricultural intensification

The correlation results in (Table 5) show predominantly positive associations between irrigation development and cropping intensity across the North-Eastern states. The strongest positive association between gross irrigated area (GIA) and cropping intensity was observed in Mizoram ($r =$

0.902), followed by Tripura ($r = 0.775$), Arunachal Pradesh ($r = 0.744$) and Nagaland ($r = 0.701$). Meghalaya also recorded a moderately strong positive association ($r = 0.602$). Assam showed a comparatively weak positive association ($r = 0.339$), while Sikkim was the only state to exhibit a negative association between GIA and cropping intensity ($r = -0.252$).

The relationship between net irrigated area (NIA) and cropping intensity was strongest in Nagaland ($r = 0.853$), followed by Tripura ($r = 0.791$), Arunachal Pradesh ($r = 0.686$), Mizoram ($r = 0.582$) and Meghalaya ($r = 0.550$). Assam showed a weak positive association ($r = 0.356$), while Sikkim recorded a moderate positive association ($r = 0.381$). Manipur's coefficient could not be estimated because cropping intensity remained unchanged throughout the study period. The

predominantly positive correlation coefficients suggest that higher levels of irrigated area were generally associated with higher cropping intensity. The relationship was particularly strong in Mizoram for gross irrigated area (GIA) and in Nagaland for net irrigated area (NIA). However, the variation across states, including the negative GIA association in Sikkim, indicates that irrigation expansion alone does not uniformly translate into greater agricultural intensification. Other factors such as cropping systems, land characteristics, agricultural practices and the availability of complementary inputs may also influence the intensity of land use. These results therefore indicate an association between irrigation development and agricultural intensification rather than establishing a direct causal relationship [5].

Table 5 Relationship between irrigation development and cropping intensity in North-East India, 2004-05 to 2022-23

State	GIA and cropping intensity (r)	NIA and cropping intensity (r)
Arunachal Pradesh	0.744	0.686
Assam	0.339	0.356
Manipur	Not defined	Not defined
Meghalaya	0.602	0.550
Mizoram	0.902	0.582
Nagaland	0.701	0.853
Sikkim	-0.252	0.381
Tripura	0.775	0.791

Note: Pearson's correlation coefficient (r) is based on 19 annual observations for each state. The correlation coefficient for Manipur is not defined because cropping intensity remained constant at 100% throughout the study period, resulting in zero variance in the dependent variable

Source: Handbook of Statistics on Indian States 2023-24, Reserve Bank of India

CONCLUSION

The study shows that irrigation development and agricultural intensification in North-East India increased during 2004-05 to 2022-23, but with considerable inter-state variation. Gross and net irrigated areas expanded substantially at the regional level, while cropping intensity increased from 132.54% to 142.09%. However, changes in irrigation ratios were uneven, indicating that expansion of irrigated area did not uniformly translate into higher irrigation coverage relative to cultivated land. The correlation analysis revealed predominantly positive associations between irrigated area and cropping intensity, although the strength and direction of the

relationship varied across states. The strongest associations were observed for Mizoram in the case of GIA and Nagaland in the case of NIA, while Sikkim showed a negative association between GIA and cropping intensity. These findings suggest that irrigation development is associated with agricultural intensification, but the relationship is shaped by state-specific geographical, land-use and agricultural conditions. Thus, irrigation planning in North-East India should adopt state-specific approaches suited to the region's diverse agro-ecological and terrain conditions. The findings indicate association rather than causation and provide a basis for further research using more detailed farm-level and econometric approaches.

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