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Irrigation Efficiency and Cropping Intensity: A Spatial Perspective from Munger Division of Bihar

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Abstract: *Agricultural intensification has become an important strategy for enhancing productivity and ensuring food security in densely populated agrarian regions such as Bihar, where the scope for expansion of cultivable land is limited. This study examines the spatial relationship between irrigation efficiency and cropping intensity in the Munger Division of Bihar, comprising Munger, Begusarai, Khagaria, Lakhisarai, Sheikhpura, and Jamui districts. The analysis is based on secondary data for the agricultural year 2022–23 obtained from government sources. Cropping intensity is calculated as the ratio of gross cropped area to net sown area, while irrigation efficiency is measured as the proportion of gross irrigated area to gross cropped area. The study adopts descriptive, comparative and statistical methods, including spatial analysis and Karl Pearson's coefficient of correlation. The results reveal significant inter district disparities in agricultural intensification. Begusarai records the highest cropping intensity, whereas Sheikhpura shows the highest irrigation efficiency. The overall irrigation efficiency of the division is 71.63 percent and the average cropping intensity is 144.33 percent. Statistical analysis indicates a strong negative correlation (r = −0.74) between cropping intensity and irrigation efficiency. This suggests that higher cropping intensity is not necessarily associated with higher irrigation efficiency across districts. The findings highlight the influence of groundwater dependence, physiographic conditions, cropping patterns, and land use pressure on agricultural intensification. The study emphasizes the need for region specific irrigation planning, efficient water management, and integrated agricultural strategies for sustainable agricultural development in Munger Division.*

Key Words: *Cropping Intensity, Irrigation Efficiency, Agricultural Intensification, Spatial Analysis, Crop diversification.*

1. INTRODUCTION

Agriculture continues to occupy a central position in the Indian economy, particularly in agriculturally dominated states such as Bihar where a significant proportion of the population depends directly or indirectly on farming for livelihood, employment and food security. Despite structural transformation in the national economy, agriculture remains the principal source of income in rural regions and plays a decisive role in sustaining rural socio-economic stability. Regions characterised by high population pressure and limited scope for expansion of cultivable land, improving the efficiency of land utilization becomes essential for ensuring agricultural sustainability and enhancing farm productivity. In this context, cropping intensity has emerged as an important indicator of agricultural development, reflecting the extent to which agricultural land is cultivated more than once within an agricultural year. Cropping intensity represents the degree of agricultural intensification and is closely linked with irrigation availability, technological advancement, input use, and adaptive strategies of farmer. Higher cropping intensity generally indicates better utilization of land resources, wider adoption of improved agricultural practices and increased agricultural output. In densely populated agrarian regions such as Bihar, where landholdings are small and fragmented, increasing cropping intensity serves as an effective strategy for enhancing farm income and ensuring food security. However, the achievement of multiple cropping systems largely depends upon the availability of assured irrigation facilities, making irrigation one of the most significant determinants of agricultural intensity.

In monsoon dependent regions, irrigation plays a transformative role by reducing uncertainties associated with rainfall variability and enabling cultivation during rabi and kharif both seasons. Assured irrigation supports crop diversification, adoption of high yielding varieties and stabilization of agricultural production. Nevertheless, the relationship between irrigation efficiency and cropping intensity is neither uniform nor linear. It is influenced by a combination of physical, socio-economic and institutional factors such as soil fertility, physiography, groundwater availability, cropping patterns, access to markets and economic capacity of farmers. In several regions, intensive cultivation may occur even with moderate irrigation coverage due to efficient water management or intensive groundwater utilization, whereas extensive irrigation infrastructure may not necessarily result in higher cropping intensity. Bihar presents a notable example of spatial disparities in irrigation development and agricultural intensification. Although the state is endowed with fertile alluvial soils and favourable agroclimatic conditions, regional variations in irrigation infrastructure, flood prone environments and topographical diversity contribute to uneven agricultural development. Within this broader framework, Munger Division provides an appropriate geographical setting for examining the spatial relationship between irrigation efficiency and cropping intensity. The division encompasses districts with diverse physiographic characteristics ranging from fertile alluvial plains to upland and undulating terrains, resulting in significant variation in irrigation sources, land-use patterns, and agricultural practices. Therefore, a spatial analysis of irrigation efficiency and cropping intensity in Munger Division offers important insights into the dynamics of agricultural intensification in Bihar. Such an analysis is important for improving irrigation planning, promoting efficient water resource utilization and formulating region specific agricultural strategies aimed at enhancing productivity, sustainability, and rural economic resilience.

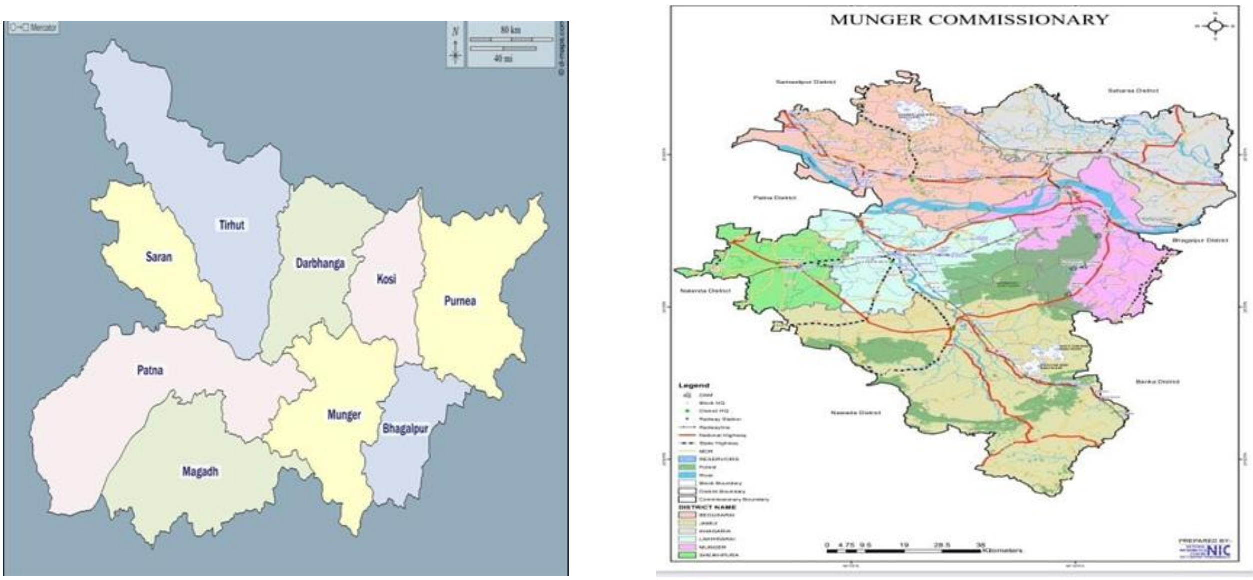
2.REVIEW OF LITERATURE

The relationship between irrigation facilities and agricultural intensification has been widely discussed in agricultural and regional geography, particularly in the context of developing agrarian economies such as India. Early geographical studies emphasized the role of irrigation as a fundamental determinant of agricultural productivity and land use intensity. Singh and Dhillon (2004) highlighted that cropping intensity reflects the degree of agricultural development and is closely associated with irrigation availability, technological adoption, and land pressure in densely populated regions. Dhawan (1988), his work on irrigation and agricultural development, argued that assured irrigation reduces climatic uncertainties, enables multiple cropping, and stabilizes agricultural output. Bhalla and Singh (2009) observed that agricultural intensification in post Green Revolution India has been significantly influenced by irrigation expansion, improved inputs, and institutional support, although regional disparities continue to persist due to uneven resource distribution. Subsequent studies have emphasized that the relationship between irrigation and cropping intensity is complex and mediated by several physical and socio-economic factors. Chand and Kumar (2004) pointed out that irrigation infrastructure alone does not guarantee higher productivity or cropping intensity, as factors such as soil fertility, farm size, market access, and economic capacity of farmer significantly influence agricultural outcomes. Research conducted in India has further shown that intensive groundwater exploitation often compensates for inadequate surface irrigation, leading to higher cropping intensity even in areas with moderate irrigation efficiency. Recent geographical studies increasingly adopt spatial and statistical approaches to analyse irrigation intensity relationships at regional scales. These studies emphasize that agricultural intensification is not merely a function of irrigation coverage but is shaped by integrated interactions between physical environment, irrigation management, and socio- economic conditions. The present study builds upon this body of literature by examining the spatial relationship between irrigation efficiency and cropping intensity in the Munger Division of Bihar, contributing to regional level understanding of agricultural intensification, where groundwater dependence, land pressure, and physiographic diversity significantly influence agricultural land-use patterns.

3.STUDY AREA:

The Munger Division located in the south-central part of the Bihar state, is comprising six districts Munger, Begusarai, Lakhisarai, Khagaria, Sheikhpura, and Jamui. It lies between 24°20′N to 25°30′N latitudes and 85°15′E to 87°15′E longitudes, covers an area of 972938 hectare. Munger division is served by the Ganga River in the north and the Chotanagpur Plateau in the south, creating a diverse physiographic landscape that includes fertile alluvial plains and undulating uplands. Climate of the division is tropical monsoonal, characterized by hot summers, humid monsoon season, and cool winters, with an average annual rainfall of about 1100 mm, which supports intensive agriculture. The Ganga, Kiul, Harohar, Burhi Gandak, Balan, Bagmati, Kosi and Kamla are the major rivers, providing irrigation and contributing to the agricultural prosperity of the division. Agriculture is the primary economic activity across the division. Major crops include rice, wheat, maize, pulses and oilseeds. The availability and sources of irrigation vary considerably across districts, ranging from canal irrigation and ponds to tubewells and other minor irrigation sources. These variations provide the spatial context for analysing differences in cropping intensity and irrigation efficiency. According to the Census of India 2011, the total population of Munger Division is 9402851 persons. The population is predominantly rural. Urban population is mainly concentrated in district headquarters. Munger division shows moderate population density with 966 persons per km^2 compared to other parts of Bihar.

LOCATION MAP: MUNGER DIVISION



4.OBJECTIVES: The present study has been undertaken with the following objectives:

(i) To examine the spatial variation in cropping intensity among the districts of Munger Division and to understand the pattern of agricultural land-use intensity.
(ii) To analyse the distribution of irrigation sources such as canals, ponds, tubewells and other minor irrigation systems across the districts of the division.
(iii) To assess the level of irrigation efficiency at both divisional and district levels in order to understand the effectiveness of irrigation utilization in agriculture.
(iv) To examine the relationship between irrigation efficiency and cropping intensity through statistical analysis using Karl Pearson's coefficient of correlation.
(v) To identify inter district disparities in agricultural intensification and irrigation development within Munger Division.
(vi) To provide a geographical perspective for agricultural planning, highlighting the need for efficient water management and region-specific irrigation strategies for sustainable agricultural development in the Munger Division.

5.DATABASE AND METHODOLOGY

The present study is based on secondary data collected from reliable government sources including the Directorate of Economics and Statistics, Government of Bihar, Agricultural Statistics at a Glance published by the Ministry of Agriculture and Farmers Welfare, Economic Survey of Bihar (2021–23), District Statistical Handbooks of Munger Division, Census of India 2011 and reports of the Minor Irrigation Department. The database includes district wise information on total geographical area, net sown area, gross cropped area, gross irrigated area, and source wise irrigation distribution for the agricultural year 2022–23. Cropping intensity has been calculated as the ratio of gross cropped area to net sown area multiplied by one hundred, while irrigation efficiency has been measured as the proportion of gross irrigated area to gross cropped area. The study adopts a descriptive, comparative and statistical methodology, combining

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spatial analysis with Karl Pearson's coefficient of correlation to examine the relationship between irrigation efficiency and cropping intensity across districts. District level comparison has been used to identify spatial disparities in agricultural intensification and irrigation development, while geographical interpretation has been made in relation to physiography, groundwater dependence, cropping pattern and landuse pressure, acknowledging that irrigation efficiency alone does not fully explain variations in cropping intensity within the Munger Division.

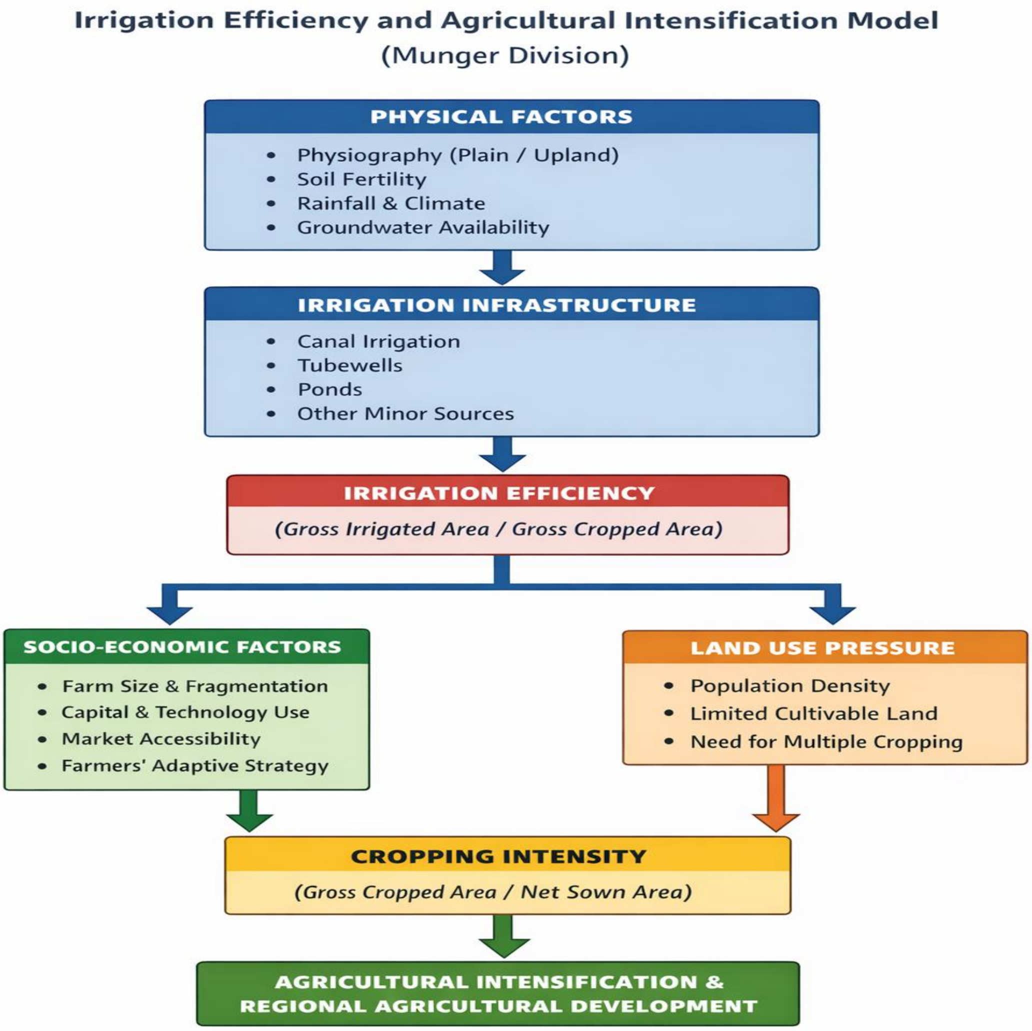

Table No. 1

Munger Division: Cropped Area and Cropping Intensity -2023

District	Total Geographical Area (in hac.)	Net Sown Area (in hac.)	Gross Cropped Area (in hac.)	Cropping Intensity (in percent)
Munger	139793	41700	47043	112.82
Khagaria	149342	80956	113807	140.56
Begusarai	187828	123450	215058	174.15
Lakhisarai	128602	60119	74111	123.27
Sheikhpura	62084	45511	55947	122.43
Jamui	305289	38359	56972	148.50
Total	**972,938**	**390,095**	**562,938**	**144.33**

Source: Directorate of Economics and Statistics, Government of Bihar- 2023

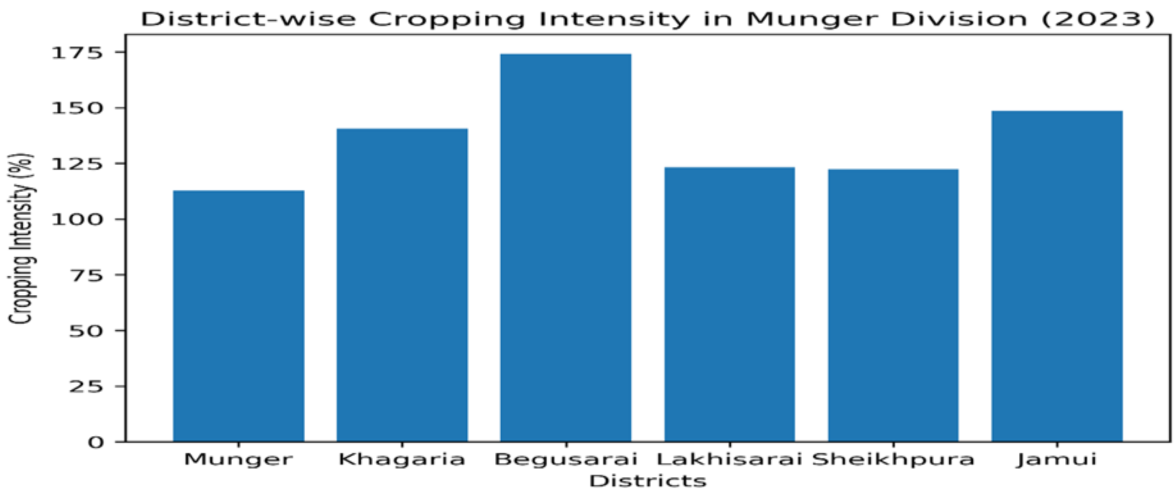

Table No. 1 shows the spatial variation in total Geographical area, Net sown area, Gross cropped area, and Cropping Intensity in Munger Division in 2023. Munger Division covers a total geographical area of 972,938 hectares, out of which 390,095 hectares are Net sown. The Gross cropped area amounts to 562,938 hectares, resulting in an overall cropping intensity of 144.33 percent. At district level Begusarai exhibits the highest cropping intensity of 174.15%, supported by a large Net sown area (123,450 hac.) and the highest Gross cropped area (215,058 hac.). This high intensity is the result of better irrigation facilities, fertile alluvial soils, and wider adoption of multiple cropping practices. Khagaria records the second highest cropping intensity of 140.56%, with a substantial expansion from net sown area (80,956 hac.) to gross cropped area (113,807 hac). Jamui, is the largest district in terms of total geographical area (305,289 hac.), has a relatively low net sown area (38,359 hac). However, its cropping intensity is 148.50 percent, which indicates repeated cultivation on limited agricultural land. Lakhisarai and Sheikhpura show moderate cropping intensities of 123.27 percent and 122.43 percent, respectively. These districts demonstrate limited multiple cropping, possibly due to constraints such as irrigation inadequacy, soil limitations, or fragmented landholdings. The district of Munger itself records the lowest cropping intensity of 112.82%, despite having a reasonable net sown area (41,700 hac.). This indicates relatively less intensive land use, which may be attributed to urban influence, soil degradation, or lower irrigation coverage.

Table No. 2

Munger Division: Means of Irrigation and Irrigation Efficiency -2023

Districts	Total Geog. Area (in hac.)	Gross Cropped Area (in hac.)	Irrigated land (in hac.)				Gross Irrigated Area (in hac.)	Irrigation Efficiency (in percent)
			Canal	Ponds	Tubewell	Other Sources		
Munger	139793	47043	24540	150	15670	260	40620	86.39
Khagaria	149342	113807	-	-	82120	70	82200	72.24
Begusarai	187828	215058	-	1070	139880	350	141290	65.70
Lakhisarai	128602	74111	12810	-	40720	170	53700	72.48
Sheikhpura	62084	55947	2650	10870	37720	150	51390	91.86
Jamui	305289	56972	2410	2620	28880	-	33910	59.53
Total	**972,938**	**562,938**	**42410**	**14710**	**344990**	**1000**	**403110**	**71.63**

Source: Directorate of Economics and Statistics, Government of Bihar-2023

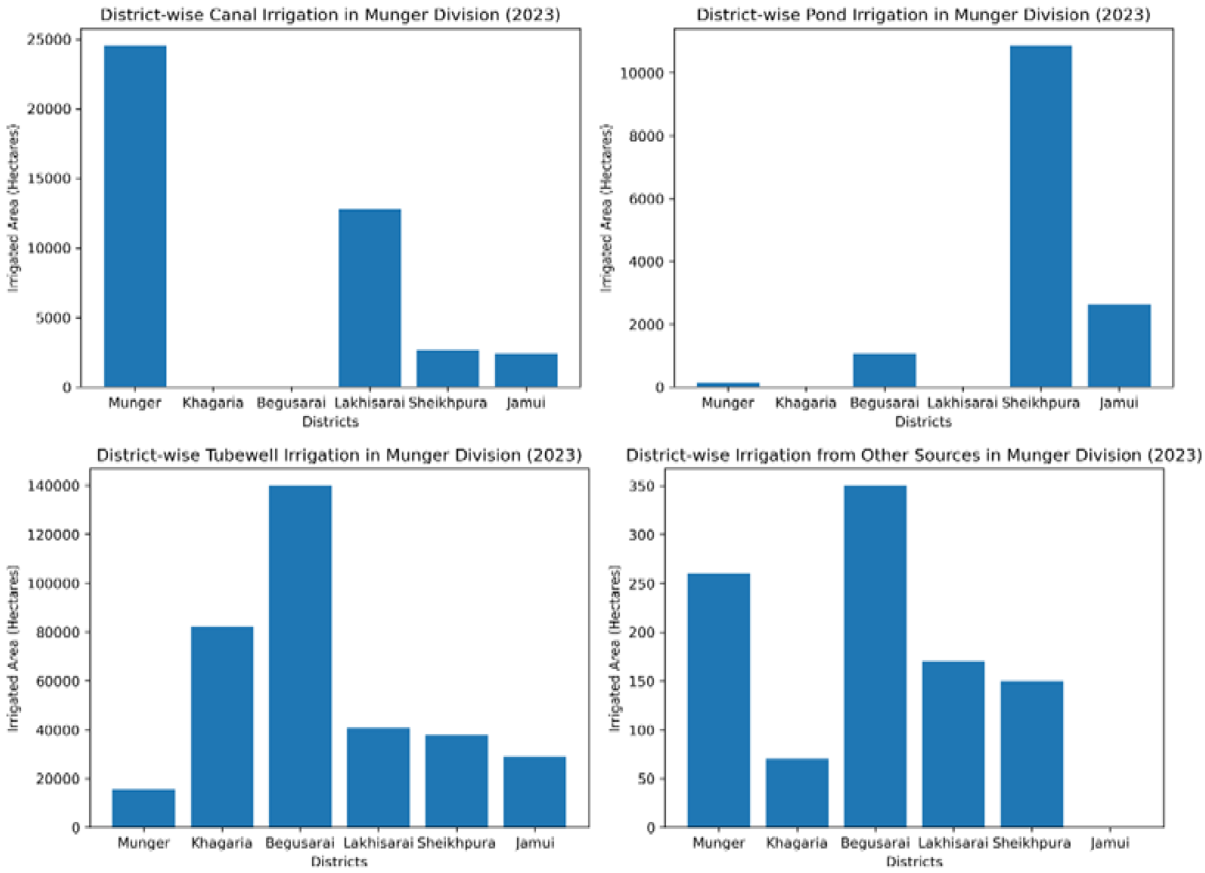

Table No. 2 highlights the district wise distribution of irrigation sources, gross irrigated area, and irrigation efficiency in the Munger Division in 2023. In Munger Division the total geographical area is 972,938 hectares, with a gross cropped area of 562,938 hectares. Out of this, 403,110 hectares are irrigated, resulting in an overall irrigation efficiency of 71.63 percent. This indicates that nearly three fourths of the cultivated land is supported by irrigation facilities. At district level, Munger district shows a relatively high irrigation efficiency of 86.39 percent, with 40,620 hectares out of 47,043 hectares of gross cropped area. Canal irrigation 24,540 hac. plays a dominant role, supported by tubewells 15,670 hac. indicating better surface groundwater integration compared to other districts. Khagaria is almost depends on tubewell irrigation, accounting for 82,120 hectares, while canal and pond irrigation are negligible. Its irrigation efficiency stands at 72.24 percent, suggesting reasonable irrigation coverage but high dependence on groundwater resources. Begusarai, despite having the largest gross cropped area of 215,058 hac. in the division, records a comparatively lower irrigation efficiency (65.70 percent**)**. Irrigation is largely based on tubewell 139,880 hac., with only marginal contribution from ponds and other sources. This indicates spatial imbalance between cropping intensity and irrigation availability. Lakhisarai exhibits a moderate irrigation efficiency of 72.48 percent, supported by both canals 12,810 hac. and tubewells 40,720 hac. The absence of pond irrigation suggests limited surface water storage and greater reliance on controlled irrigation systems. In Munger division Sheikhpura stands out with the highest irrigation efficiency of 91.86 percent. A balanced mix of pond irrigation 10,870 ha**c.** and tubewells 37,720 ha**c.** ensures extensive irrigation coverage 51,390 hac. over a comparatively smaller gross cropped area 55,947 hac. Jamui records the lowest irrigation efficiency of 59.53 percent despite its vast geographical area 305,289 hac. In Jamui irrigation is limited mainly to tubewells 28,880 hac. and small contributions from canals and ponds, reflecting physiographic constraints, undulating terrain, and limited irrigation infrastructure

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Table No. - 3

Correlation between Cropping Intensity and Irrigation Efficiency in Munger Division -2023

District	Cropping Intensity (CI)	Irrigation Efficiency (IE)	x = (CI−CĪ)	y = (IE−IĒ)	Xy	x^2	y^2
Munger	112.82	86.39	−24.14	+11.69	−282.40	582.74	136.69
Khagaria	140.56	72.24	+3.60	−2.46	−8.86	12.96	6.05
Begusarai	174.15	65.70	+37.19	−9.00	−334.71	1383.07	81.00
Lakhisarai	123.27	72.48	−13.69	−2.22	+30.40	187.49	4.93
Sheikhpura	122.43	91.86	−14.53	+17.16	−249.55	211.13	294.47
Jamui	148.50	59.53	+11.54	−15.17	−175.05	133.15	230.13
Total (Σ)	**821.73**	**448.20**	**0.00**	**0.00**	**−1019.17**	**2510.54**	**753.27**

Source:On the basis of table no.1 and table no.

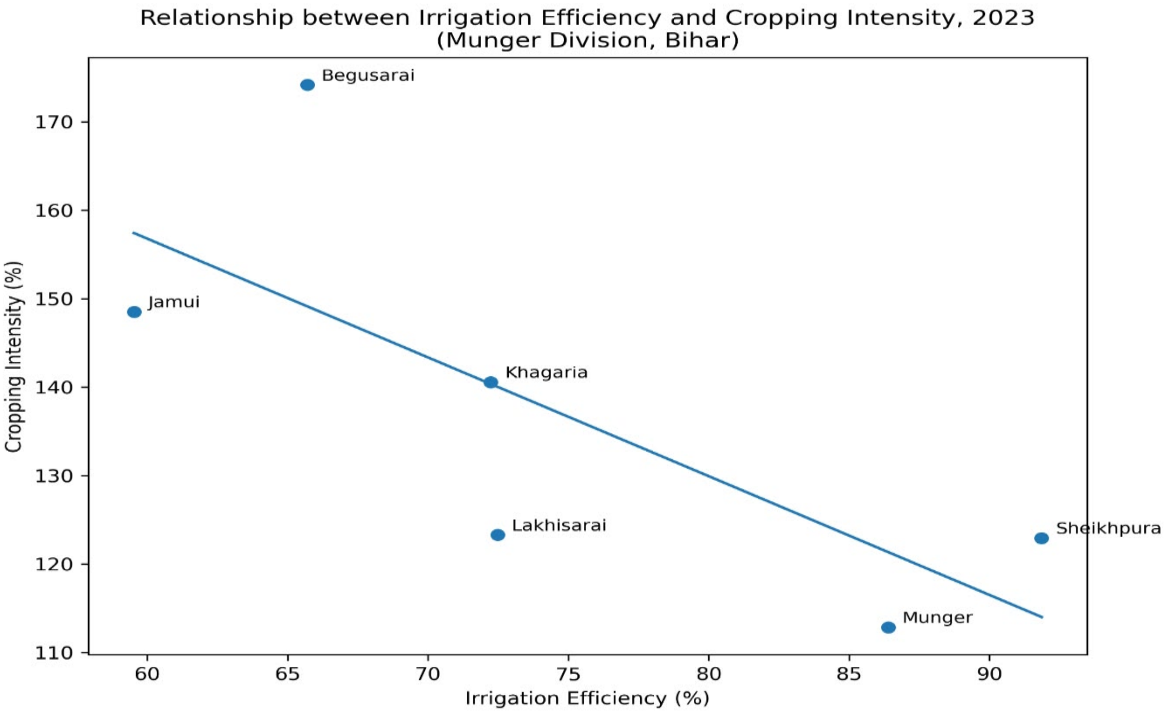

Table 3 and figure both presents the relationship between cropping intensity (CI) and irrigation efficiency (IE) across the districts of Munger Division for the year 2023. The table includes deviations of each variable from their respective mean values, along with the products of deviations and squared deviations required for correlation analysis. The mean cropping intensity is 136.96 percent, while the mean irrigation efficiency is 74.70 percent. Districts like Begusarai and Jamui show positive deviations in cropping intensity but negative deviations in irrigation efficiency, indicating that higher cropping intensity in these districts is not supported by proportionately higher irrigation efficiency. Conversely, Sheikhpura and Munger exhibit negative deviations in cropping intensity but positive deviations in irrigation efficiency, suggesting more efficient irrigation utilization despite relatively lower cropping intensity. The product of deviations (xy) is negative for most districts, resulting in a total value of −1019.17, which indicates an inverse association between the two variables. The higher values of squared deviations in cropping intensity ($\Sigma x^2 = 2510.54$) compared to irrigation efficiency ($\Sigma y^2 = 753.27$) suggest greater inter district variation in cropping intensity than in irrigation efficiency in Munger division. The overall statistical result derived from this table yields a Karl Pearson's coefficient of correlation ($r = -0.74$), indicating a strong negative correlation between cropping intensity and irrigation efficiency in the Munger Division. This implies that districts with higher cropping intensity generally tend to have lower irrigation efficiency.

From a geographical perspective, the result suggests that agricultural intensification in the region is influenced not only by irrigation availability but also by other factors such as soil fertility, rainfall dependence, cropping pattern, and pressure on limited cultivable land. The dominance of tubewell irrigation in several districts further indicates that multiple cropping may be achieved through intensive groundwater use rather than efficient irrigation coverage.

Factors Determine the Degree of Cropping intensity Other than Irrigation Efficiency in Munger Division: The analysis of cropping intensity in the Munger Division reveals that irrigation efficiency alone does not explain inter district variations in agricultural intensification. The spatial pattern of cropping intensity is shaped by a combination of physical, socio-economic, and institutional factors operating differently across districts such as Begusarai, Khagaria, Munger, Lakhisarai, Sheikhpura, and Jamui.

Physiography and Relief Conditions: Physiographic diversity is one of the most significant determinants of cropping intensity in the Munger Division. The northern districts such as Begusarai and Khagaria lie within the fertile new alluvial plains of the Ganga basin, characterized by homogeneous topography and deep alluvial soils. These conditions facilitate repeated cultivation and easy field operations, resulting in relatively higher cropping intensity. In contrast, Jamui district, located towards the southern margin of Chotanagpur Plateau, is marked by undulating terrain and upland characteristics. Despite limited net sown area, farmers tend to cultivate available land more intensively, but physiographic constraints restrict further expansion of multiple cropping.

Population Pressure and Land Use Intensity: High population density in the plains districts generates pressure on limited cultivable land, compelling farmers to increase cropping frequency. Begusarai, which records the highest cropping intensity in the division, reflects strong land use pressure where farmers maximize output through multiple cropping rather than expansion of agricultural land. This phenomenon demonstrates that cropping intensity in the division is partly a response to demographic pressure and livelihood dependence on agriculture. **Cropping Pattern and Agricultural Practices:** Cropping intensity in Munger Division is strongly influenced by prevailing cropping patterns. Districts with dominance of short duration crops and well established with rice–wheat rotations exhibit higher cropping intensity. In Begusarai and Khagaria, intensive cereal cultivation allows quick turnover between agricultural seasons. Conversely, areas with relatively higher proportion of pulses, oilseeds, or single season cultivation as observed in parts of Munger and Lakhisarai, tend to show moderate cropping intensity. **Groundwater Utilization and Private Irrigation Practices:** The study indicates that higher cropping intensity in certain districts is achieved through intensive groundwater extraction rather than efficient irrigation coverage. Begusarai and Khagaria rely heavily on tubewell irrigation, enabling farmers to cultivate multiple crops even when irrigation efficiency is comparatively lower.

Socio-Economic and Climatic Determinants of Cropping Intensity: In the Munger Division, cropping intensity is not only determined by irrigation availability but is also strongly influenced by socio-economic conditions and climatic factors. The predominance of small and fragmented landholdings across the division compels farmers to utilize land more intensively in order to sustain household income and livelihood security. Multiple cropping therefore becomes an economic necessity. Market accessibility also plays an important role in shaping cropping decisions. Proximity to urban centres and better transport connectivity encourage farmers to adopt market-oriented cropping systems and cultivate successive crops to maximize economic returns. The moderate rainfall and favourable temperature conditions, supports kharif cultivation and provides residual soil moisture for rabi crops in the study area. This climatic support allows farmers to maintain multiple cropping even where irrigation efficiency is moderate. Thus, cropping intensity in the Munger Division reflects the combined influence of socio-economic motivation, technological advancement, market opportunities, and climatic suitability alongside irrigation factors.

6.SUGGESSITIONS

Promotion of Efficient Water Management Practices: Efficient water management is essential in study area where irrigation resources are limited and cropping intensity is increasing. The adoption of micro irrigation techniques such as drip and sprinkler systems can significantly reduce water losses through seepage and evaporation. These techniques ensure uniform distribution of water and improve water use efficiency at the field level. In districts showing high cropping intensity but moderate irrigation efficiency, such practices can enhance productivity without increasing water consumption. Government subsidies and technical assistance can play an important role in encouraging farmers to adopt these systems.

Balanced Development of Surface and Groundwater Irrigation: The study indicates a high dependency on tubewell irrigation in study area, which may lead to long term groundwater depletion. Therefore, balanced utilization of both surface and groundwater resources is necessary for sustainable irrigation development. Strengthening canal irrigation systems, renovation of traditional ponds and promotion of rainwater harvesting can reduce pressure on groundwater extraction. Surface water irrigation also helps recharge groundwater aquifers and ensures long term water availability. Integrated water resource management should be adopted. Such balance will improve irrigation reliability and agricultural sustainability.

Improvement in Irrigation Infrastructure Maintenance: Many irrigation systems suffer from reduced efficiency due to poor maintenance, siltation, and leakage in canals and distribution channels. Regular de siltation and repair of canals and minor irrigation structures can significantly improve water conveyance efficiency. Proper maintenance ensures timely and equitable distribution of irrigation water among farmers. Strengthening institutional monitoring of irrigation infrastructure is equally important. Community participation in maintenance activities can further improve system performance. Improved infrastructure efficiency will directly enhance irrigation efficiency and support multiple cropping systems.

Promotion of Crop Diversification: Crop diversification can reduce excessive pressure on irrigation resources while improving farm income stability. District like Jamui facing water constraints, farmers should be encouraged to shift partially from water intensive crops to pulses, oilseeds, and horticultural crops. Diversified cropping systems improve soil health and reduce risks associated with climate variability. They also promote efficient use of available irrigation water across seasons. Market support and procurement policies can encourage farmers to adopt diversified cropping patterns. This approach will help maintain cropping intensity without overexploitation of water resources.

Strengthening Institutional Support and Farmer Awareness: Awareness and technical knowledge of Farmers plays an important role in improving irrigation efficiency and agricultural productivity. Extension services should provide training on scientific irrigation scheduling, efficient input use, and modern agronomic practices. Demonstration programs and farmer field schools can help disseminate best practices at the grassroots level. Institutional support from agricultural departments and local agencies can improve adoption rates of improved technologies. Awareness programs should also emphasize water conservation and sustainable farming methods. Enhanced farmer capacity will lead to better utilization of irrigation resources.

Encouragement of Climate Resilient Agricultural Practices: Agriculture in Bihar is highly influenced by monsoon variability and climate uncertainty, making climate resilient practices increasingly important. Adoption of drought tolerant and short duration crop varieties can reduce dependence on irrigation during uncertain rainfall periods. Conservation agriculture practices such as mulching and minimum tillage help retain soil moisture. Crop insurance and climate advisory services can further support farmers in managing risks. These practices help maintain cropping intensity without excessive water use. Climate-resilient agriculture contributes to long-term sustainability and stability of farm production.

Strengthening Data Based Agricultural Monitoring: Effective agricultural planning requires reliable and regularly updated data on irrigation coverage, groundwater levels, and cropping patterns. The use of GIS and remote sensing techniques can help monitor spatial variations in agricultural intensity and water utilization. Periodic assessment allows identification of emerging water stress areas and inefficient irrigation practices. Data-driven decision-making can improve resource allocation and policy implementation. Integration of spatial data with district-level agricultural statistics enhances planning accuracy. Such monitoring is essential for achieving sustainable and efficient agricultural development in the Munger Division.

7.CONCLUSION:

The study reveals significant spatial variations in cropping intensity and irrigation efficiency in the districts of Munger Division. The analysis indicates that higher cropping intensity is not necessarily associated with higher irrigation efficiency. Agricultural intensification in the division is influenced not only by irrigation availability but also by factors such as groundwater dependence, physiography, cropping patterns, and land-use pressure. Districts with higher cropping intensity often rely on intensive groundwater use rather than efficient irrigation coverage. The findings highlight the complex relationship between irrigation development and agricultural land-use intensity. From a planning perspective, the study emphasizes the need for balanced utilization of surface and groundwater resources. Efficient water management and maintenance of irrigation infrastructure are essential for sustainable agriculture. District specific agricultural and irrigation strategies should be adopted to reduce inter district disparities. Crop diversification and improved irrigation practices can enhance long term sustainability.

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