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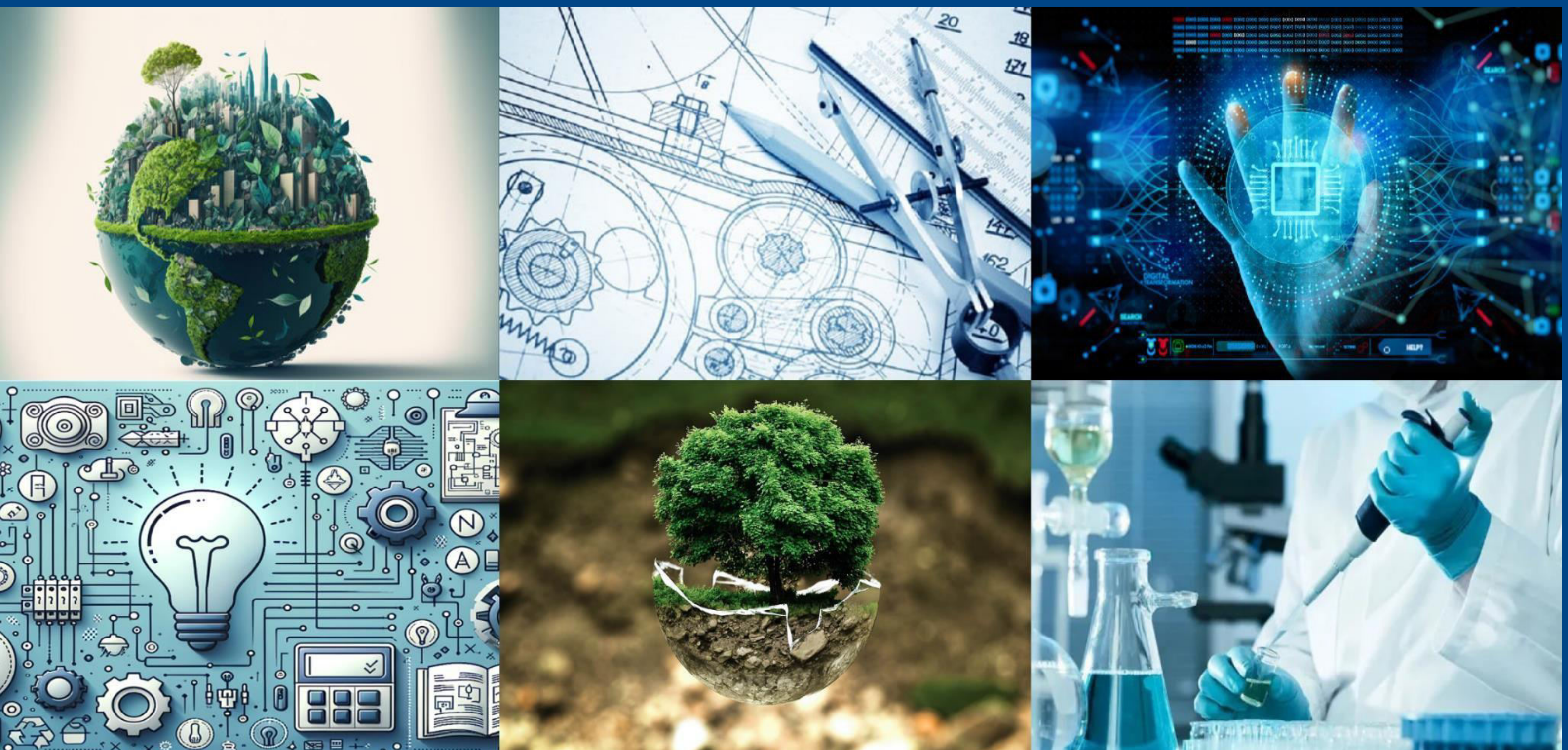

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Spatio-Temporal Analysis of Factors Responsible for Changing Cropping Pattern in Mahendergarh District, Haryana

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ABSTRACT: The cropping pattern in Mahendergarh District, Haryana has witnessed substantial transformation during 1991 to 2021, marked by a shift from traditional subsistence crops such as bajra and pulses towards commercial crops including wheat, mustard and cotton. This paper conducts a spatio-temporal analysis of the major factors driving these changes in the semi-arid region of southern Haryana. The study systematically examines the role of natural, economic, social and governmental factors using temporal data for the period 1991-2021 and spatial variations at block level.

Natural factors including erratic rainfall averaging 500 mm with high variability, sandy loam soils with low water retention capacity, and declining groundwater table from 15 meters in 1991 to 35 meters in 2021 have traditionally limited crop choices while expansion of irrigation enabled greater diversification. Economic factors such as higher profitability of cash crops backed by Minimum Support Price, mechanization and improved market access have accelerated the shift, with wheat increasing from 15% to 22% and mustard from 10% to 18% of gross cropped area. Social factors like population growth, land fragmentation (51% marginal holdings) and urbanization have promoted intensive farming practices. Government policies, particularly the Jawahar Lal Nehru Canal, Pradhan Mantri Krishi Sinchayee Yojana and input subsidies, have significantly contributed by raising irrigation coverage from 25% to 65% of net sown area and increasing cropping intensity from 135.6% to 152.8%.

The analysis reveals notable block-wise variations, with northern plains exhibiting faster commercialization compared to southern hilly areas. Although these changes have improved agricultural productivity and farmer incomes, they have also intensified challenges of groundwater depletion and soil degradation. The paper offers policy recommendations for promoting sustainable cropping systems, water-efficient technologies and balanced diversification to ensure long-term agricultural resilience in Mahendergarh District.

KEYWORDS: Changing cropping pattern, Spatio-temporal analysis, Mahendergarh District, Natural factors, Economic factors, Government policies, Crop diversification, Irrigation development, Sustainable agriculture, Haryana.

I. INTRODUCTION

Cropping patterns in semi-arid regions of Haryana have undergone notable transformation over the past three decades. These regions, characterized by low and erratic rainfall, sandy loam soils, and limited water resources, traditionally relied on drought-resistant crops such as bajra and pulses to ensure food security. However, with the expansion of irrigation infrastructure, technological advancements, and changing market dynamics, there has been a gradual shift towards more commercial and high-value crops like wheat, mustard, and cotton. This transition reflects the dynamic interplay between environmental constraints and socio-economic opportunities, resulting in increased cropping intensity and agricultural productivity, while also raising concerns about resource sustainability.

Mahendergarh District, located in the southern part of Haryana, holds particular significance in this context. Situated in a semi-arid agro-climatic zone bordering the Aravalli hills, the district represents the typical challenges and potential of dryland agriculture in the state. Agriculture remains the backbone of the district's economy, supporting a large rural population and contributing substantially to local livelihoods. The district's unique geographical setting, with undulating plains in the north and rocky terrains in the south, creates distinct spatial variations in cropping practices. Understanding

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the changing cropping patterns in Mahendergarh is therefore crucial not only for the district but also for framing broader strategies for sustainable agriculture in similar semi-arid regions of Haryana and beyond.

The rationale for studying the factors responsible for these changes stems from the need to explain the drivers behind the observed shift from traditional subsistence crops (bajra and pulses) to commercial crops (wheat, mustard, and cotton). While natural conditions have historically shaped agricultural possibilities, economic incentives, social transformations, and government interventions have accelerated the pace of change. Analyzing these factors through a spatio-temporal lens helps identify block-wise variations, assess their relative influence, and highlight both positive outcomes (such as higher yields and incomes) and emerging challenges (such as groundwater depletion and soil degradation). Such an analysis provides valuable insights for evidence-based policy making aimed at balancing productivity with long-term sustainability.

The present study covers the period from 1991 to 2021, which encompasses the post-Green Revolution phase, implementation of major agricultural schemes, and significant climatic and socio-economic developments in the region. This time frame allows for a comprehensive examination of temporal trends and spatial patterns in cropping systems.

Mahendergarh District lies in the southern part of Haryana, spanning an area of approximately 1,899 square kilometers. The district is characterized by semi-arid climate with average annual rainfall of around 500 mm, predominantly received during the monsoon season. It features varied physiography including northern plains, central lowlands, and southern hilly tracts of the Aravalli range. Agriculture dominates land use, with a major portion under net sown area. The district is administratively divided into several blocks, each exhibiting distinct cropping responses to changing conditions.

This paper examines the spatio-temporal dimensions of changing cropping patterns with special focus on the underlying factors. The subsequent sections detail the study area, methodology, observed changes in cropping patterns, analysis of key factors, impacts, and policy suggestions.

II. STUDY AREA

Mahendergarh District is located in the southern part of Haryana, forming part of the semi-arid agro-climatic zone of the state. It lies between 27° 47' to 28° 26' North latitude and 75° 56' to 76° 51' East longitude. The district is bounded by Rewari and Jhajjar districts in the north, Bhiwani in the west, Sikar and Jhunjhunu districts of Rajasthan in the south and southwest, and shares its eastern boundary with Rewari. It covers a total geographical area of approximately 1,899 square kilometers (190,580 hectares).

The physiography of the district is diverse, characterized by northern undulating plains, central fertile lowlands, and southern rocky tracts of the Aravalli hills. The northern and central parts consist of gently sloping plains suitable for intensive cultivation, while the southern region features rugged hilly terrain with shallow soils. This variation significantly influences land use and cropping practices across the district.

The climate of Mahendergarh is typically semi-arid with extreme temperature variations. Summers are hot with maximum temperatures reaching up to 45°C in May-June, while winters record minimum temperatures as low as 3°C in December-January. Annual rainfall averages around 500 mm, with 75-80% received during the monsoon season (July to September). Rainfall is highly erratic with a coefficient of variation of about 30%, often leading to droughts. These climatic conditions traditionally favor drought-resistant crops.

Soils in the district are predominantly sandy loam and loamy sand, covering about 85% of the area. These soils have low organic carbon content (around 0.5%) and limited water retention capacity, making them susceptible to wind erosion. The soils are generally fertile but require regular nutrient supplementation for sustained productivity.

Drainage is primarily through seasonal streams such as the Dohan and Krishnawati rivers, which originate from the Aravalli hills and flow northward. These streams remain active only during the monsoon period and contribute significantly to groundwater recharge.

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Irrigation plays a crucial role in the district's agriculture. The share of irrigated area has increased substantially over time, supported by the Jawahar Lal Nehru (JLN) Canal and a large number of tube wells. Groundwater remains the dominant source, though its over-extraction has led to a declining water table.

Demographically, the district had a population of approximately 0.92 million as per the latest available records, with a high rural proportion and heavy dependence on agriculture. The workforce is predominantly engaged in farming and allied activities. Average landholding size has declined due to population pressure, with a large percentage of marginal and small farmers.

III. SPATIO-TEMPORAL CHANGES IN CROPPING PATTERN (1991–2021)

The cropping pattern in Mahendergarh District has undergone a profound transformation between 1991 and 2021. Traditionally dominated by drought-resistant subsistence crops suited to the semi-arid environment, the district's agriculture has gradually shifted towards more commercial and market-oriented crops. This change reflects the combined influence of expanding irrigation, technological interventions, economic incentives, and changing farmer preferences. The period under study marks a transition from predominantly rain-fed farming to a more intensive and diversified system, though significant spatial variations continue to exist across different blocks of the district.

In 1990-91, bajra (pearl millet) was the dominant crop, occupying nearly 48% of the gross cropped area (approximately 1,007 thousand hectares out of 2,099 thousand hectares). Pulses and gram together accounted for around 12%, while wheat and mustard had relatively smaller shares. By 2020-21, the share of bajra declined substantially to about 25% (590 thousand hectares), while wheat increased from 15% (315 thousand hectares) to 22% (520 thousand hectares) and mustard rose from 10% (210 thousand hectares) to 18% (425 thousand hectares). Cotton emerged as a notable commercial crop, reaching 5% (118 thousand hectares) of the gross cropped area. Pulses witnessed a decline to 8% (189 thousand hectares). This shift indicates a clear movement from traditional food crops to high-value cash crops.

The gross cropped area expanded over the three decades due to an increase in cropping intensity. Productivity levels also improved considerably. Wheat yields rose from around 2,500 kg/ha in 1990-91 to approximately 4,000 kg/ha in 2020-21. Mustard productivity increased from 1,200 kg/ha to 1,800 kg/ha during the same period. Bajra showed moderate improvement in irrigated pockets, though its overall dominance reduced. These gains were largely supported by the adoption of high-yielding varieties, increased fertilizer use, and better irrigation facilities.

Cropping intensity, which reflects the intensity of land use, recorded a significant rise from 135.6% in 1990-91 to 152.8% in 2020-21. This increase demonstrates that farmers are now able to grow more than one crop on the same piece of land in a year in many areas. Crop diversification has also progressed, with a movement away from mono-cropping of bajra towards wheat-mustard and other crop combinations, particularly in areas with assured irrigation.

Table 1
Temporal Changes in Area under Major Crops in Mahendergarh District (1991–2021)

Crop	1990-91 Area ('000 ha)	1990-91 (% of GCA)	2020-21 Area ('000 ha)	2020-21 (% of GCA)	Change in % Share
Bajra	1007	48	590	25	-23
Wheat	315	15	520	22	+7
Mustard	210	10	425	18	+8
Pulses	252	12	189	8	-4
Cotton	Negligible	Negligible	118	5	+5
Others	315	15	520	22	+7

Block-wise Variations

Significant spatial differences exist across the district. Northern and central blocks (Narnaul, Ateli) have shown faster adoption of wheat and mustard due to better access to the Jawahar Lal Nehru Canal and higher tube well density. These blocks now exhibit higher cropping intensity and greater crop diversification. In contrast, southern and western blocks

(Nangal Chaudhary, Kanina) continue to rely more on bajra and pulses because of hilly terrain, shallow soils, and limited irrigation facilities. This north-south divide in cropping patterns clearly highlights the influence of physiographic and irrigation availability on agricultural practices.

Overall, the spatio-temporal changes observed during 1991–2021 indicate a progressive commercialization of agriculture in Mahendergarh District. While this has contributed to higher productivity and income, it has also increased pressure on natural resources, particularly groundwater. The following section analyses the major factors responsible for these observed changes.

Analysis of Factors Responsible for Changing Cropping Pattern

The transformation in cropping pattern of Mahendergarh District from 1991 to 2021 is the result of complex interactions among natural, economic, social, and institutional factors. This section provides a detailed spatio-temporal analysis of these factors and their influence on the shift from traditional subsistence crops (bajra and pulses) to commercial crops (wheat, mustard, and cotton).

Natural Factors

Natural factors form the foundational base that shapes agricultural possibilities in the semi-arid environment of Mahendergarh District. Climate variability, soil characteristics, water resources, and topography/geomorphology have significantly influenced cropping decisions over the study period.

The district experiences a semi-arid climate with average annual rainfall of around 500 mm, of which 75-80% is received during the monsoon season (July-September). High variability in rainfall (coefficient of variation ~30%) and frequent droughts have traditionally favoured drought-resistant crops like bajra. However, the expansion of irrigation has enabled cultivation of wheat and mustard even in low rainfall years. Temperature extremes (up to 45°C in summer and down to 3°C in winter) further limit crop choices.

Soils are predominantly sandy loam and loamy sand (85% of the area) with low organic carbon (0.5%) and poor water retention capacity. These soils are prone to wind erosion but respond well to fertilizers and irrigation, supporting the shift towards high-yielding varieties of wheat and mustard.

Water resources, particularly groundwater, have been the most critical factor. In 1990-91, only 25% of the net sown area was irrigated. By 2020-21, irrigation coverage increased to 65%, largely through tube wells and the Jawahar Lal Nehru Canal. However, this has led to over-extraction (150% of recharge), causing the water table to decline from 15 meters in 1991 to 35 meters in 2021, with 70% of blocks classified as overexploited.

Topography plays a decisive role in spatial variations. Northern undulating plains support intensive farming and higher cropping intensity, while southern Aravalli hills with rocky terrain and shallow soils remain largely rain-fed, sustaining bajra and pulses.

Economic Factors

Economic considerations have been the strongest driver of change in cropping patterns. Profitability, Minimum Support Price (MSP), market access, mechanization, and modern inputs have encouraged farmers to move towards commercial crops.

Mustard and wheat offer significantly higher returns compared to bajra. MSP for mustard (Rs. 5,650/quintal) and wheat, coupled with assured procurement, has made these crops more attractive. Cotton has also gained due to market demand. Mechanization (tractors increasing from 2,000 to 8,500) and rising fertilizer use (from 20 kg/ha to 150 kg/ha) have reduced labor costs and increased yields, making commercial crops more viable even for small farmers.

Improved market connectivity through regulated markets in Narnaul and Kanina has further strengthened the shift towards cash crops.

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Social Factors

Social changes have reinforced the move towards intensive and commercial farming. Population growth from 0.68 million in 1991 to 0.92 million in 2021 has led to land fragmentation, with 51% of holdings now marginal (<1 hectare). Smaller landholdings have pushed farmers towards high-value crops that give better returns per unit area.

Urbanization near Narnaul and exposure to markets have changed dietary preferences and consumption patterns, reducing demand for bajra and increasing preference for wheat. Educational advancement through Krishi Vigyan Kendras has promoted adoption of modern practices, HYV seeds, and micro-irrigation among farmers.

Government Policies and Institutional Factors

Government policies have played a transformative role. The Jawahar Lal Nehru Canal and expansion of tube wells, along with Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), increased irrigation coverage dramatically. Subsidies on fertilizers, HYV seeds, and micro-irrigation systems, along with Soil Health Cards and crop insurance schemes, have reduced risk and encouraged diversification. Technological support through extension services has accelerated adoption of new varieties and practices.

Interlinkages and Spatio-Temporal Synthesis

Natural constraints provided the initial framework, but economic incentives and government policies acted as catalysts for change, while social factors determined the pace of adoption. Northern blocks, with better irrigation and market access, witnessed faster commercialization. Southern blocks remained relatively slower due to physiographic limitations. The combined effect of these factors has resulted in increased cropping intensity and diversification, though at the cost of groundwater sustainability.

Table 2
Temporal Changes in Key Natural and Economic Indicators (1991–2021)

Indicator	1990-91	2020-21	Change
Irrigation Coverage (% of NSA)	25%	65%	+40%
Groundwater Depth (meters)	15	35	-20 meters
Cropping Intensity	135.6%	152.8%	+17.2%
Fertilizer Use (kg/ha)	20	150	+130 kg/ha
Tractor Numbers	2,000	8,500	+6,500

Table 3
Block-wise Impact of Major Factors on Cropping Shifts (Summary Matrix)

Block	Natural Factors	Economic Factors	Social Factors	Policy Factors	Overall Shift
Narnaul & Ateli	Moderate	High	High	High	Fast Commercialization
Kanina	Moderate	Medium	Medium	Medium	Moderate Shift
Nangal Chaudhary	High Constraint	Low	Low	Low	Slow Change
Others	Moderate	Medium	Medium	Medium	Mixed Pattern

Impacts of Changing Cropping Pattern

The changing cropping pattern in Mahendergarh District from 1991 to 2021 has produced both positive and negative impacts on agricultural productivity, farmer income, rural livelihoods, and the environment. While the shift towards commercial crops has enhanced economic returns and intensified land use, it has also generated serious sustainability challenges, particularly related to groundwater depletion and soil health.

Positive Impacts on Productivity and Income

The transition from traditional bajra-dominated systems to wheat-mustard-cotton systems has significantly boosted agricultural productivity. Wheat yields increased from approximately 2,500 kg/ha in 1990-91 to 4,000 kg/ha in 2020-21.

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Mustard productivity rose from 1,200 kg/ha to 1,800 kg/ha during the same period. Overall cropping intensity improved from 135.6% to 152.8%, resulting in higher output per unit of land.

These productivity gains have translated into substantial improvement in farmer incomes. Cash crops like mustard and wheat, supported by Minimum Support Price and better market access, have yielded significantly higher returns (mustard approximately Rs. 40,000/ha and wheat Rs. 50,000/ha) compared to traditional bajra (Rs. 15,000/ha). As a result, average farm income is estimated to have increased by around 40% during the study period. This has improved the economic condition of many farming households and supported better access to education, healthcare, and housing.

Impact on Livelihoods

The commercialization of agriculture has provided new livelihood opportunities through increased demand for labor in harvesting, marketing, and processing of commercial crops. It has also encouraged allied activities such as dairy farming (due to availability of crop residues) and vegetable cultivation in irrigated pockets. However, marginal and small farmers (51% of total holdings) have faced challenges due to higher input costs of seeds, fertilizers, and irrigation, making them more vulnerable to price fluctuations and crop failure.

Environmental Impacts

The most serious impact of the changing cropping pattern has been on natural resources. The sharp rise in irrigated area from 25% to 65% of net sown area has led to over-exploitation of groundwater. The water table has declined from 15 meters in 1991 to 35 meters in 2021, with 70% of blocks now categorized as overexploited. This threatens the long-term sustainability of agriculture in the district.

Soil health has also been adversely affected. Intensive cultivation and higher use of chemical fertilizers have resulted in declining organic carbon content and emerging salinity in some areas (affecting about 10% of farmland). Wind erosion continues to be a problem in the sandy loam soils, particularly in the western and southern parts of the district.

Biodiversity has declined as traditional crop varieties and mixed cropping systems have been replaced by monoculture of commercial crops. The reduction in pulses and bajra area has also affected soil nitrogen levels and dietary diversity in rural households.

Overall Assessment

The changing cropping pattern has delivered short-term economic benefits through higher productivity and incomes but has created long-term environmental risks. The district now faces the dual challenge of maintaining productivity gains while ensuring sustainable use of natural resources. Without appropriate interventions, the gains achieved over the last three decades may become unsustainable in the coming years. This analysis of impacts provides the basis for the findings, discussion, and policy suggestions presented in the subsequent sections.

Major Findings

The spatio-temporal analysis of cropping patterns in Mahendergarh District between 1991 and 2021 brings forth several significant findings. First, there has been a clear and consistent shift from traditional subsistence-oriented crops to commercial crops. The share of bajra in the gross cropped area declined sharply from approximately 48% in 1990-91 to 25% in 2020-21. In contrast, wheat increased from 15% to 22% and mustard from 10% to 18% during the same period. Cotton emerged as an important commercial crop, occupying about 5% of the gross cropped area by 2020-21. Pulses registered a moderate decline from 12% to 8%.

Second, cropping intensity recorded a notable rise from 135.6% in 1990-91 to 152.8% in 2020-21, reflecting more intensive use of cultivable land. Productivity of major crops also improved substantially. Wheat yields increased from around 2,500 kg/ha to 4,000 kg/ha, while mustard productivity rose from 1,200 kg/ha to 1,800 kg/ha. These changes have contributed to higher overall agricultural output.

Third, distinct spatial variations exist across the district. Northern and central blocks such as Narnaul and Ateli witnessed faster commercialization, higher cropping intensity, and greater diversification due to better irrigation facilities and market access. Southern and western blocks like Nangal Chaudhary and Kanina continued to show relatively slower transition and higher dependence on rainfed crops like bajra and pulses because of hilly terrain and limited irrigation.

Fourth, irrigation expansion emerged as the most dominant factor, followed by economic incentives (MSP, profitability, and mechanization) and government policies. Natural factors (climate and soil) largely acted as constraints, while social factors such as population growth and land fragmentation accelerated the pace of change.

Finally, while the changes have brought positive economic outcomes, they have also created environmental challenges, particularly groundwater depletion and soil degradation.

IV. DISCUSSION

The findings of the present study clearly indicate that Mahendergarh District has followed the broader trajectory of agricultural commercialization observed in semi-arid regions of Haryana. The shift from bajra-based traditional farming to wheat-mustard dominated systems is economically rational in the short term, as it has significantly enhanced productivity and farmer incomes. The increase in cropping intensity and adoption of high-yielding varieties have helped the district achieve higher agricultural output despite limited rainfall.

However, this transformation has not been uniform across space and has come at a considerable environmental cost. The heavy dependence on groundwater for irrigation has led to a sharp decline in the water table, turning most blocks into overexploited zones. The north-south divide in cropping patterns further highlights how access to irrigation and market infrastructure determines the nature and speed of agricultural change. Northern blocks have benefited more from the process, while southern blocks continue to face structural disadvantages.

The study also reveals that while government policies have successfully promoted intensification, they have been less effective in ensuring long-term sustainability. The current pattern of cropping, if continued without corrective measures, may threaten the very resource base on which agriculture in the district depends.

Policy Suggestions

In order to sustain the productivity gains and address emerging challenges, the following policy recommendations are suggested:

Water Resource Management

Urgent steps are needed to promote efficient water use. Large-scale adoption of drip and sprinkler irrigation under PMKSY should be encouraged through higher subsidies. Rainwater harvesting and artificial recharge structures must be developed on a priority basis in overexploited blocks. Crop water budgeting and incentives for low-water-demand crops should be introduced, especially in southern blocks.

Crop Diversification

A balanced diversification strategy should be adopted. Special incentives, including assured procurement and higher MSP, should be provided for pulses, oilseeds, and traditional drought-resistant crops. Promotion of integrated farming systems combining crops, horticulture, dairy, and agroforestry is recommended to reduce risk and improve soil health.

Support to Small and Marginal Farmers

Special focus must be given to marginal and small farmers who constitute 51% of total holdings. Formation and strengthening of Farmer Producer Organizations (FPOs) and cooperatives can help them achieve economies of scale in input procurement and marketing. Targeted credit, insurance, and training programmes should be designed for this vulnerable section.

Soil Health and Environmental Sustainability

Universal implementation of Soil Health Cards should be followed by practical support for organic manure, green manuring, and balanced fertilizer application. Conservation practices such as crop rotation, mulching, contour bunding, and agroforestry need to be promoted on a wider scale, particularly in erosion-prone areas.

Institutional and Technological Strengthening

Extension services should be strengthened with the use of mobile technology and GIS-based advisories for weather forecasting and market information. Regular monitoring of groundwater and cropping patterns using remote sensing should be institutionalised for better planning.

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Effective implementation of these suggestions, with active involvement of local communities and panchayati raj institutions, can help Mahendergarh District achieve a more sustainable, resilient, and inclusive agricultural system in the coming years.

V. CONCLUSION

The present study on "Spatio-Temporal Analysis of Factors Responsible for Changing Cropping Pattern in Mahendergarh District, Haryana" clearly demonstrates that the district has experienced a significant transformation in its agricultural landscape between 1991 and 2021. The traditional dominance of drought-resistant subsistence crops like bajra and pulses has gradually given way to commercial crops such as wheat, mustard, and cotton. This shift has been accompanied by a rise in cropping intensity from 135.6% to 152.8% and notable improvements in productivity and farmer incomes.

The analysis reveals that the changing cropping pattern is the outcome of complex interactions among multiple factors. Natural constraints of semi-arid climate, sandy soils, and limited rainfall provided the initial framework, while expansion of irrigation infrastructure emerged as the most powerful driver of change. Economic factors including higher profitability, Minimum Support Price, and market access, along with government policies such as the Jawahar Lal Nehru Canal and PMKSY, accelerated the process. Social factors like population growth, land fragmentation, and education further influenced the pace and direction of this transformation. Distinct block-wise variations highlight that northern blocks (Narnaul and Ateli) have undergone faster commercialization, whereas southern blocks (Nangal Chaudhary and Kanina) continue to show slower transition due to physiographic limitations.

While the changing cropping pattern has delivered positive outcomes in terms of enhanced productivity and economic returns, it has also created serious sustainability challenges. The most critical concern is the sharp decline in the groundwater table and emerging issues of soil degradation. These findings underscore the urgent need to balance short-term economic gains with long-term ecological stability.

In conclusion, the study emphasizes that future agricultural development in Mahendergarh District must adopt a more sustainable and spatially sensitive approach. Promoting efficient water management, crop diversification, soil conservation, and inclusive support for small and marginal farmers will be crucial for ensuring the resilience and long-term viability of agriculture in this semi-arid region. The insights from this research can serve as a valuable reference for policymakers, agricultural planners, and researchers working towards sustainable agricultural transformation in similar agro-climatic zones of Haryana and India.

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