

Impact of Climate Variability on Cropping Patterns in Etawah District, Uttar Pradesh, India: A Geographical Analysis

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Abstract

Climate variability has become an important influence on agricultural decision-making in the Indo-Gangetic Plain, particularly in districts where farming depends on the interaction of monsoon rainfall, irrigation availability, temperature conditions and seasonal crop calendars. This study examines the impact of climate variability on cropping patterns in Etawah District of Uttar Pradesh, India. The research is based entirely on secondary data and adopts a descriptive, analytical and comparative geographical approach. Climatic evidence is drawn from the Uttar Pradesh State Action Plan on Climate Change, the District Agricultural Contingency Plan and published rainfall studies, while information on land use, irrigation and cropping patterns is derived from official statistical sources and relevant research available up to 31 December 2024.

The analysis indicates substantial rainfall variability, declining long-term rainfall tendencies and gradually rising temperature, particularly minimum temperature. These conditions influence sowing dates, crop selection, water requirements and the relative stability of kharif and rabi cultivation. Wheat, rice, millets, oilseeds, pulses and potato remain important components of the district agricultural system, while extensive irrigation has moderated some adverse effects of rainfall variability and supported high cropping intensity. Nevertheless, delayed monsoon onset, prolonged dry spells, insufficient groundwater recharge, heat stress, unseasonal rainfall, cold waves and frost create crop-specific risks. The study concludes that future cropping-pattern adjustment in Etawah should emphasise crop diversification, efficient irrigation, short-duration and climate-resilient varieties, weather-based crop planning and reduced vulnerability to water-intensive agricultural practices.

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Introduction

Agricultural cropping patterns represent the combined outcome of physical environment, technological capability, market demand, institutional support and farmers' decisions. Climate occupies a particularly important position within this relationship because rainfall, temperature, humidity and soil moisture directly affect crop suitability, sowing periods, irrigation requirements and yield stability. In monsoon-dominated agricultural systems such as India, the amount of annual rainfall alone is insufficient to explain agricultural performance. The timing, distribution and intensity of rainfall are often equally important. Delayed rainfall, prolonged dry spells or excessive precipitation during critical crop stages may significantly affect cultivation even when annual rainfall totals appear relatively normal.

Climate variability refers to fluctuations in climatic conditions around their long-term averages over monthly, seasonal, annual or longer periods. In agriculture, such variability may occur through delayed monsoon onset, premature withdrawal of rainfall, drought, intra-seasonal dry spells, unusually heavy rainfall, temperature anomalies, heat waves, cold waves and frost. These conditions influence both crop productivity and agricultural decision-making. Farmers may respond by modifying sowing dates, adopting short-duration varieties, changing crop combinations or increasing dependence on irrigation. Consequently, variations in climate may gradually reshape cropping patterns even when the total cultivated area remains comparatively stable.

Indian agriculture has historically adapted to climatic uncertainty through mixed cropping, multiple cropping, irrigation and changes in crop calendars. However, the increasing frequency and intensity of weather-related stress have made climate adaptation more significant. Mall et al. (2006) observed that changes in temperature, precipitation and water availability may substantially influence Indian food-grain production. Auffhammer et al. (2012) demonstrated that both drought and extreme rainfall adversely affect rice productivity in India. BIRTHAL et al. (2014) similarly found that higher temperature can negatively influence the yield of important crops such as wheat, rice, pulses and pigeon pea.

Etawah District provides an appropriate geographical setting for examining these relationships. Located in southwestern Uttar Pradesh, the district forms part of an intensively cultivated agricultural region characterised by alluvial plains, ravine-affected areas and extensive irrigation. The district supports both kharif and rabi agriculture, while canals, tube wells and groundwater reduce complete dependence on seasonal rainfall. According to the District Agricultural Contingency Plan, normal annual rainfall is approximately 752.4 mm, of which a substantial proportion is received during the southwest monsoon. The same agricultural profile reported approximately 147.6 thousand hectares of net sown area, 242.4 thousand hectares of gross cropped area and a cropping intensity of about 164.2 per cent.

Despite relatively developed irrigation, agriculture in Etawah remains exposed to climate variability. The Uttar Pradesh State Action Plan on Climate Change 2.0 provides district-level climatic analysis for the period 1980–2019 and indicates rising temperatures and declining rainfall tendencies in Etawah. Minimum temperature shows a comparatively stronger upward trend, while annual and southwest monsoon rainfall show negative long-term tendencies. Such changes are important because they affect evapotranspiration, soil moisture, crop duration and irrigation demand. Rainfall uncertainty may also influence groundwater recharge and indirectly affect irrigated rabi agriculture.

District-specific rainfall research also demonstrates substantial variability. Yadav et al. (2021) identified fluctuations between normal, surplus and drought conditions in Etawah and highlighted the occurrence of moisture stress at agriculturally critical stages. Rainfall deficiency during the early crop season can delay sowing and transplanting, whereas rainfall shortages near crop maturity may affect grain development. Unseasonal rainfall during the rabi season can additionally increase crop losses and disease incidence. These variations demonstrate that the agricultural significance of rainfall lies not only in annual quantity but also in seasonal distribution.

The principal research problem is therefore to understand how climate variability interacts with irrigation and other agricultural factors to influence cropping patterns in Etawah. Existing studies have examined rainfall variability, individual crops, agricultural intensity and adaptation measures, but relatively fewer studies integrate long-term climate trends with changes in crop choice and seasonal agricultural structure at the district level. The present study addresses this gap through a geographical synthesis of climate, cropping pattern and irrigation. It does not assume that every change in crop area is caused by climate, because prices, technology, government policy and markets also influence farmers' decisions.

The study aims to examine the nature of climate variability in Etawah District, analyse the existing agricultural and cropping structure, evaluate the effects of rainfall and temperature variability on kharif and rabi agriculture, assess the buffering role of irrigation and identify suitable climate-resilient crop strategies. It accordingly asks how climatic conditions have varied in Etawah, which crops are most exposed to weather variability, how irrigation modifies climatic impacts and what changes in crop management may improve resilience. These questions are examined within the broader framework of climate adaptation and agricultural geography.

The central argument of the paper is that climate variability does not produce a simple or uniform replacement of one crop by another. Its influence is mediated through irrigation availability, seasonal water supply, crop duration, production costs, market opportunities and farmers' capacity to respond to weather information. Etawah therefore represents an agricultural system in which climatic stress is partly absorbed by irrigation and multiple cropping.

Nevertheless, increasing rainfall uncertainty and temperature stress strengthen the need for more diversified and climate-responsive agricultural planning.

Study Area

Etawah District is situated in southwestern Uttar Pradesh and forms part of the wider Gangetic plain transition towards the Yamuna–Chambal region. The district headquarters lies near 26.48° N latitude and 79.06° E longitude, while the geographical area is approximately 2,311 square kilometres. The landscape contains productive alluvial plains as well as dissected ravine tracts associated with the Yamuna and Chambal river systems. Differences in terrain influence soil depth, irrigation accessibility and agricultural intensity. Relatively level areas support intensive cultivation, while ravine-affected landscapes present greater constraints.

Agriculturally, Etawah falls within an important cereal-producing region of Uttar Pradesh. Deep loamy, fine-textured and silty soils occur in different parts of the district and support a mixture of food grains, oilseeds, pulses and horticultural crops. Wheat is particularly important in the rabi season, while rice, millets and other crops form part of the kharif system. Potato, mustard, pulses and garlic also contribute to agricultural diversification. Crop selection varies according to irrigation access, soil quality and market conditions.

The district receives most of its annual rainfall during the southwest monsoon. The agricultural contingency profile reports normal annual rainfall of approximately 752.4 mm distributed over about 67 rainy days, with nearly 669.1 mm occurring during June–September. Rainfall during the remaining months is comparatively limited. This strong seasonal concentration makes the timing and reliability of the monsoon particularly important for agricultural operations. Even irrigated agriculture remains indirectly dependent on monsoon rainfall through groundwater recharge and reservoir or canal supplies.

Irrigation significantly modifies the physical constraints imposed by climate. Canals and tube wells enable farmers to maintain rabi cultivation and, in suitable locations, water-demanding kharif crops. The relatively high level of irrigation has contributed to multiple cropping and high cropping intensity. However, greater irrigation dependence may also create pressure on groundwater during prolonged dry periods. Climate variability and irrigation must therefore be analysed together rather than as independent influences.

Literature Review

Climate–agriculture relationships in India have been widely examined because agricultural production continues to depend heavily on weather conditions. Mall et al. (2006) reviewed the possible effects of climate change on Indian agriculture and highlighted the significance of rising temperatures, changing rainfall and altered water availability. They emphasised that agricultural impacts vary between regions according to crop type, irrigation and agro-climatic conditions.

Their work demonstrates the need for geographically differentiated adaptation. It is particularly relevant for districts such as Etawah where both irrigated and rainfall-sensitive crops coexist.

Auffhammer et al. (2012) examined the relationship between monsoon conditions and rice yields in India. They demonstrated that drought as well as extreme rainfall can reduce rice productivity, although the magnitude of impact varies geographically. Rice is particularly sensitive during crop establishment and other critical growth stages. This is important for Etawah because rice forms an important component of kharif agriculture. Greater uncertainty in monsoon timing can therefore modify both cultivation practices and the relative attractiveness of rice.

Birthal et al. (2014) investigated climate and yield relationships for major Indian crops and found that increases in maximum temperature adversely affected several crops. Wheat, rice, chickpea and pigeon pea showed varying degrees of sensitivity. Their findings suggest that climate variability should be considered not merely as a rainfall problem. Increasing temperature can influence crop duration, evapotranspiration and water requirements even where irrigation is available. The implications are especially relevant to wheat-dominated rabi agriculture in northern India.

Crop diversification has increasingly been recognised as an important adaptation strategy. Birthal and Hazrana (2019) found that rainfall deficit and heat stress can reduce agricultural productivity, while greater crop diversification can improve resilience to climatic shocks. Diversification allows farmers to distribute climatic risk across crops with different water requirements, sowing periods and growth characteristics. However, diversification is effective only when supported by appropriate markets, irrigation and agricultural infrastructure. It should therefore be viewed as part of a broader adaptation strategy rather than an isolated solution.

Research on Etawah itself provides important local evidence. Yadav et al. (2021) analysed rainfall variability in the district and identified considerable fluctuations between normal, surplus and drought periods. Their study highlighted the possibility of moisture stress both during the beginning of the agricultural season and during later crop-development stages. Such conditions may affect sowing dates, crop establishment and yield formation. The study therefore supports the interpretation of rainfall variability as an important source of agricultural risk.

The Etawah District Agricultural Contingency Plan further demonstrates the relationship between weather variability and crop management. It recommends specific crop and variety adjustments under delayed monsoon conditions, mid-season drought and terminal drought. Under severe delay in monsoon rainfall, farmers may need to replace longer-duration crops with shorter-duration alternatives such as mung bean, fodder maize or cowpea. Direct-seeded rice is also recommended where inadequate rainfall delays canal water and makes conventional transplantation difficult. These recommendations provide institutional evidence that crop choice in Etawah is responsive to weather and water availability.

Commercial and horticultural diversification is another component of the district agricultural system. Srivastava et al. (2023) examined garlic-growing farms in Etawah and documented high cropping intensity among their selected sample farmers. Although those findings cannot be generalised to the whole district, they illustrate the potential role of high-value crops in an irrigated agricultural landscape. Garlic, potato and vegetables can enhance farm income but may also increase dependence on irrigation, storage and markets. Climate-resilient diversification therefore requires economic as well as environmental assessment.

Overall, previous studies establish strong connections among rainfall variability, temperature, irrigation, crop productivity and diversification. However, district-level research often focuses on individual components rather than examining the cropping system as an integrated geographical structure. The present study brings these dimensions together and evaluates how climate variability interacts with irrigation and cropping intensity in Etawah. This provides a more comprehensive basis for identifying future adaptation priorities.

Research Methodology

The study adopts a descriptive, analytical and comparative research design based exclusively on secondary data. No questionnaire survey, farmer interview or experimental field investigation has been conducted. All evidence used in the paper is derived from government publications, institutional documents and academic studies available up to 31 December 2024. This temporal cutoff is applied consistently to the literature and statistical evidence. Later publications are not used in the analysis.

Climatic information is principally drawn from the Uttar Pradesh State Action Plan on Climate Change 2.0, which provides district-level temperature and rainfall trend analysis for 1980–2019. The Etawah District Agricultural Contingency Plan is used to identify normal rainfall, land utilisation, irrigation, major crops and climate-contingency recommendations. Published rainfall research by Yadav et al. (2021) is used to supplement the official climatic evidence. Together these sources provide a basis for assessing rainfall variability and temperature tendencies.

Agricultural land-use and irrigation statistics are derived from the Statistical Diary of Uttar Pradesh and district agricultural records. For 2022–23, the Statistical Diary reports approximately 266 thousand hectares of gross sown area and 154 thousand hectares of net sown area in Etawah. Gross irrigated area was approximately 214 thousand hectares, while net irrigated area was about 140 thousand hectares. These figures indicate a highly irrigated agricultural system. They are used to assess the capacity of irrigation to buffer seasonal rainfall variability.

Cropping intensity is calculated as the ratio of gross cropped area to net sown area multiplied by 100. On the basis of the 2022–23 figures, Etawah recorded an approximate cropping intensity of 172.7 per cent. This indicator demonstrates the extent of multiple cropping but is not interpreted

as an independent measure of climate adaptation. Cropping intensity is affected by irrigation, technology, crop prices, market access and farm-management decisions. Climate is therefore considered one influence among several.

Crop structure is examined using the district agricultural profile and related evidence. The contingency plan reported wheat, rice, millets, oilseeds, pulses and potato as major crops. The study compares their relative climatic requirements and seasonal exposure rather than claiming a statistically estimated causal relationship between individual weather variables and crop-area change. The analysis therefore represents an evidence-based geographical interpretation. A fully causal assessment would require a consistent long-term annual dataset of crop area, rainfall, temperature, irrigation and socioeconomic variables.

Analysis and Discussion

Climate Variability in Etawah District

Climate variability in Etawah is strongly associated with the seasonal concentration of rainfall. The district agricultural profile reports normal annual rainfall of approximately 752.4 mm, of which about 669.1 mm occurs during June–September. Rainfall outside the monsoon season is substantially lower. Consequently, agricultural operations during the kharif season remain highly sensitive to monsoon timing. Delays of even a few weeks can alter sowing conditions and reduce the remaining crop-growth period.

The long-term climatic evidence also indicates gradual warming. The Uttar Pradesh State Action Plan on Climate Change reports an average annual maximum temperature of approximately 32.54°C and an average minimum temperature of about 18.98°C for Etawah during 1980–2019. Both maximum and minimum temperatures displayed positive trends, with minimum temperature increasing more rapidly. This change can influence crop respiration, evapotranspiration and irrigation demand. Rising night-time temperatures may also affect crop development even when daytime temperature change is modest.

The same climate assessment indicates a declining long-term rainfall tendency for Etawah. Its analytical dataset reports lower average annual rainfall than the normal rainfall value in the agricultural contingency plan because the two sources employ different datasets, periods and definitions. These values should therefore not be mechanically compared. Their shared implication, however, is that rainfall availability is variable and that the district has experienced a negative long-term rainfall tendency. This increases the importance of irrigation and water conservation.

Rainfall variability is particularly important when it occurs during critical agricultural stages. Yadav et al. (2021) documented both drought and surplus rainfall conditions in Etawah. Deficient rainfall at the beginning of the season may delay land preparation, sowing and

transplantation. Moisture stress during flowering or grain development may reduce productivity, while excessive rainfall can cause waterlogging and disease. Agricultural risk therefore depends on rainfall distribution as much as total seasonal rainfall.

Existing Cropping Pattern

Etawah's cropping pattern remains strongly dominated by cereals, particularly wheat and rice. According to the district agricultural profile, wheat occupied approximately 93.9 thousand hectares and rice about 48.8 thousand hectares in the reported baseline period. Millets occupied approximately 36.6 thousand hectares, while oilseeds, pulses and potato formed additional components of the cropping system. The coexistence of these crops gives the district a moderately diversified agricultural structure. Nevertheless, wheat and rice together account for a particularly large share of cultivated area.

Wheat dominance reflects the significance of irrigation and favourable winter cultivation conditions. The crop forms the foundation of rabi agriculture and benefits considerably from canal and tube-well irrigation. Rice, in contrast, is more directly affected by monsoon behaviour during the kharif season. Millets provide comparatively greater resilience under moisture stress and remain important in areas where water availability is more uncertain. Pulses and oilseeds also broaden the crop portfolio and may require less water than conventional cereal combinations.

Potato and other commercial crops contribute an additional dimension to the cropping pattern. Their cultivation is supported by irrigation and market opportunities but may be highly sensitive to temperature extremes and storage conditions. Garlic cultivation documented in selected Etawah farms similarly shows the presence of high-value diversification. However, such crops cannot automatically be considered climate-resilient. Their suitability depends on irrigation reliability, farm investment, cold storage and market access.

Irrigation and Climatic Risk

Irrigation has played a crucial role in reducing the immediate effect of rainfall variability on cropping patterns in Etawah. According to 2022–23 agricultural statistics, approximately 214 thousand hectares of gross sown area were irrigated out of a gross sown area of around 266 thousand hectares. Net irrigated area was approximately 140 thousand hectares compared with 154 thousand hectares of net sown area. These figures indicate that the overwhelming majority of cultivated land has access to irrigation. This helps explain the persistence of intensive double cropping.

The approximate cropping intensity of 172.7 per cent also demonstrates the importance of irrigation. Multiple cropping would be considerably more difficult if farmers depended exclusively on monsoon rainfall. Irrigation supports wheat and other rabi crops and allows supplementary watering of kharif crops during rainfall gaps. It therefore acts as an important

climatic buffer. However, the effectiveness of irrigation depends on the reliability and sustainability of its water sources.

Groundwater-based irrigation may itself become vulnerable under prolonged rainfall deficiency. Low monsoon rainfall reduces natural recharge while simultaneously increasing pumping requirements. The cost of irrigation may therefore rise during dry periods. Canal supplies may also become uncertain when upstream water availability is low. Climate adaptation through irrigation consequently requires improvements in water-use efficiency rather than unlimited expansion of water extraction.

Kharif Crops and Monsoon Variability

Kharif agriculture experiences the most direct consequences of monsoon variability. Rice requires relatively dependable water during field preparation, transplantation and early crop establishment. Delayed rainfall may therefore postpone transplantation and reduce the available crop-growth period. Where canal water is also delayed, conventional rice cultivation becomes increasingly risky. Direct-seeded rice provides one possible adaptation because it can reduce water and labour requirements under suitable conditions.

The district contingency plan recommends changes in crop selection under severe delays in rainfall. With a substantial delay in monsoon onset, maize may be replaced by mung bean or other shorter-duration alternatives. Under even longer delays, fodder maize, cowpea or other low-duration crops may become more appropriate. These recommendations demonstrate that climate variability can influence cropping patterns through seasonal substitution. The decisive factor is whether sufficient growing time remains for the originally intended crop.

Millets offer particular relevance under such conditions. Pearl millet and related crops possess greater tolerance of moisture stress than transplanted rice. Maintaining or expanding suitable millet cultivation in relatively dry parts of Etawah may therefore strengthen agricultural resilience. Such diversification could also reduce irrigation demand. Nevertheless, adoption will depend on market returns, consumption demand and procurement conditions in addition to climate suitability.

Rabi Crops and Rising Temperature

Rabi agriculture is less directly dependent on monsoon rainfall because of irrigation, but it remains vulnerable to temperature variability. Wheat requires relatively cool conditions during much of its growth cycle and can experience productivity loss when temperatures rise rapidly during grain filling. The long-term increase in temperature identified for Etawah therefore has potential implications for wheat management. These implications should not be interpreted as evidence that wheat area has necessarily declined. Wheat remains the dominant rabi crop.

Adaptation in wheat cultivation may involve timely sowing, shorter-duration cultivars, heat-tolerant varieties and improved irrigation scheduling. Earlier sowing can, where agronomically appropriate, help crops avoid severe terminal heat later in the season. Efficient water application may also reduce heat-related moisture stress. Crop breeding and extension services are therefore important components of adaptation. Climate resilience requires adjustment in crop management as well as changes in crop choice.

Potato and winter vegetables face different climatic risks. Cold waves and frost can damage sensitive crops, while unusually warm winters may also influence growth and quality. Unseasonal winter rainfall can create waterlogging and increase disease incidence. Consequently, climate variability affects high-value crops through both temperature and precipitation extremes. Diversification towards commercial crops must therefore be accompanied by risk-management infrastructure.

Extreme Weather and Cropping Stability

Extreme weather can have disproportionate impacts even when long-term climatic averages change slowly. Heavy rainfall may cause short-duration flooding or waterlogging, particularly in poorly drained fields. The agricultural contingency framework consequently recommends improved drainage and field management under excessive rainfall conditions. Such measures are particularly important for crops that cannot tolerate prolonged standing water. Local landform and soil characteristics influence the severity of these impacts.

Drought conditions create a contrasting set of problems. Moisture deficiency can restrict crop establishment, reduce fodder availability and increase irrigation demand. Under severe drought, farmers may shift towards short-duration or drought-tolerant crops. Such adjustments alter seasonal cropping patterns even without permanently changing land use. The capacity to make timely changes depends on seed availability, weather forecasts and agricultural extension.

Heat waves can raise evapotranspiration and increase the frequency of irrigation required by crops. Cold waves and frost create risks for potato, vegetables and other sensitive rabi crops. These different hazards demonstrate why climate resilience cannot be achieved through dependence on a single crop. A diversified crop portfolio distributes climatic risk across crops with different growth periods and physiological requirements. This principle is increasingly important under conditions of greater climatic uncertainty.

Crop Diversification and Adaptation

Crop diversification provides one of the most promising strategies for improving agricultural resilience in Etawah. Greater inclusion of pulses, oilseeds, millets and suitable high-value crops can reduce excessive dependence on wheat–rice combinations. Pulses often require less irrigation and can improve soil fertility through biological nitrogen fixation. Millets are generally

better suited to moisture-stressed environments. Oilseeds can provide additional income opportunities while diversifying seasonal risk.

Diversification should nevertheless be location-specific. Replacing cereals indiscriminately with horticultural crops may increase exposure to temperature variation, market volatility and storage losses. High-value crops frequently require reliable irrigation, greater capital investment and post-harvest facilities. The climatic advantages of diversification therefore need to be considered together with economic feasibility. A resilient system is one that balances climatic suitability, water availability and farmer income.

The future cropping system of Etawah would benefit from combining cereals with pulses, oilseeds, millets, fodder crops and carefully selected horticultural crops. Such a portfolio can spread climatic and market risks across different agricultural activities. It can also reduce excessive dependence on a limited number of water-intensive crops. Agricultural extension services should therefore promote diversification on the basis of local soils, irrigation conditions and farm size. A uniform district-wide crop substitution policy would be less appropriate.

Climate-Resilient Agricultural Strategies

Climate-responsive crop planning should begin with improved weather information. Farmers require timely forecasts regarding monsoon onset, rainfall gaps, heat waves, cold waves and extreme precipitation. Weather information becomes useful only when linked with practical crop recommendations. Contingency crop plans should therefore be communicated before critical sowing decisions rather than after climatic stress has already developed. Digital agricultural advisory services can strengthen this process.

Water management represents a second priority. Direct-seeded rice, improved irrigation scheduling, field levelling, water harvesting and efficient irrigation technologies can reduce unnecessary water use. Groundwater recharge should be strengthened through local conservation structures wherever suitable. Canal and groundwater management also need greater coordination. Climate resilience cannot depend indefinitely on increasing groundwater extraction.

Wheat production requires attention to heat tolerance and sowing management, while moisture-stressed areas should receive greater emphasis on millets, pulses and oilseeds. Short-duration varieties can help farmers adjust when monsoon rainfall is delayed. Crop insurance and contingency seed reserves can further reduce the economic costs of unexpected weather events. Farmer training is necessary to ensure that recommended technologies correspond with local farming conditions.

Commercial diversification towards potato, garlic and vegetables should be supported through cold storage, processing and market infrastructure. These crops can improve farm income but also involve greater financial risk. Climate adaptation should therefore be combined with price-

risk management and post-harvest support. The objective should not simply be to maximise crop diversity, but to establish a productive and economically sustainable climate-resilient cropping system.

Major Findings

The study demonstrates that climate variability has become an important influence on agricultural decision-making in Etawah District. Rainfall is highly seasonal, and variations in monsoon onset and distribution directly affect kharif sowing and crop establishment. Long-term climatic evidence also indicates increasing temperature and declining rainfall tendencies. These changes increase the importance of supplementary irrigation and adaptive crop management.

Etawah nevertheless maintains a highly intensive agricultural system because irrigation substantially reduces dependence on direct rainfall. Wheat and rice remain the dominant crops, while millets, pulses, oilseeds and potato contribute to diversification. The approximate cropping intensity of 172.7 per cent in 2022–23 reflects extensive multiple cropping. However, high irrigation coverage does not completely remove climate vulnerability because groundwater recharge and canal availability remain linked to rainfall.

The influence of climate variability is most visible through delayed sowing, increased irrigation demand, crop substitution and changes in crop-management practices. The district contingency framework explicitly recommends alternative crops where monsoon rainfall is severely delayed. This provides direct institutional evidence of the relationship between weather conditions and cropping decisions. The effect is therefore adaptive and dynamic rather than a simple long-term replacement of crops.

Kharif agriculture is comparatively more vulnerable to rainfall variability, whereas rabi agriculture is more strongly buffered by irrigation. Rising temperature, however, creates an increasingly important risk for wheat and other winter crops. Crop diversification can reduce climatic risk, but its effectiveness depends on irrigation, markets, storage and extension services. Climate resilience therefore requires integrated agricultural planning rather than a single technological intervention.

Conclusion

Climate variability is increasingly influencing the agricultural geography of Etawah District through changes in rainfall distribution, temperature conditions, irrigation requirements and seasonal agricultural risk. The district continues to support an intensive cropping system dominated by wheat and rice, while millets, oilseeds, pulses, potato and other crops provide additional diversity. Extensive irrigation has enabled farmers to maintain high cropping intensity despite substantial rainfall variability. This demonstrates the important stabilising role of agricultural infrastructure.

The most significant climatic challenges arise from delayed monsoon onset, irregular rainfall, dry spells, rising temperature, unseasonal precipitation, heat waves, cold waves and frost. These conditions affect crop choice, sowing periods and water demand in different ways. Rice and other kharif crops remain particularly sensitive to monsoon conditions, whereas wheat and rabi crops depend strongly on irrigation. Increasing temperature introduces additional stress even where adequate irrigation is available.

The evidence does not support the conclusion that climate variability alone has caused a wholesale transformation of Etawah's cropping pattern. Agricultural change results from the combined effects of climate, irrigation, technology, markets, government policy and farmer behaviour. Climate variability primarily acts by changing the relative risk and resource requirements associated with different crops. Farmers respond through altered sowing dates, supplementary irrigation, short-duration varieties, crop substitution and diversification.

Future agricultural planning should therefore strengthen climate-resilient cropping systems rather than focus only on individual crops. Greater inclusion of millets, pulses and oilseeds in suitable environments can reduce water demand and distribute climatic risk. Efficient irrigation, groundwater recharge, direct-seeded rice, heat-tolerant wheat varieties and improved weather advisory services should also receive greater attention. High-value diversification should be supported where adequate irrigation, storage and markets are available.

The present study is limited by the absence of a fully harmonised annual district-level dataset combining climate variables, crop area, irrigation and socioeconomic indicators over a sufficiently long period. The analysis consequently establishes evidence-based geographical relationships rather than statistically identified causal coefficients. Future research should combine district or block-level crop-area data with IMD climatic datasets, satellite-based crop mapping and GIS techniques. Such analysis could identify spatial zones where climate variability has produced the strongest changes in crop suitability and water requirements.

Overall, Etawah represents an agricultural system that has demonstrated considerable capacity to adapt to climatic variability through irrigation and intensive cultivation. Its future resilience, however, will depend increasingly on efficient water management, flexible crop planning and scientifically guided diversification. Climate-resilient agriculture should therefore be understood not as abandoning established crops, but as creating a more flexible agricultural system capable of responding to changing climatic conditions while maintaining productivity, income and environmental sustainability.

References

- Auffhammer, M., Ramanathan, V., & Vincent, J. R. (2012). Climate change, the monsoon, and rice yield in India. *Climatic Change*, 111(2), 411–424. <https://doi.org/10.1007/s10584-011-0208-4>.

- Birthal, P. S., & Hazrana, J. (2019). Crop diversification and resilience of agriculture to climatic shocks: Evidence from India. *Agricultural Systems*, 173, 345–354. <https://doi.org/10.1016/j.agsy.2019.03.005>.
- Birthal, P. S., Khan, M. T., Negi, D. S., & Agarwal, S. (2014). Impact of climate change on yields of major food crops in India: Implications for food security. *Agricultural Economics Research Review*, 27(2), 145–155.
- Directorate of Census Operations, Uttar Pradesh. (2016). *District Census Handbook, Etawah: Census of India 2011*. Office of the Registrar General & Census Commissioner, India.
- Economics and Statistics Division, Planning Department, Government of Uttar Pradesh. (2024). *Statistical Diary, Uttar Pradesh 2024*. Government of Uttar Pradesh.
- Government of Uttar Pradesh, Department of Environment, Forest and Climate Change. (2024). *Uttar Pradesh State Action Plan on Climate Change 2.0, 2021–2030*. Government of Uttar Pradesh.
- ICAR–Central Research Institute for Dryland Agriculture. (2014). *Agriculture Contingency Plan for District: Etawah, Uttar Pradesh*. Indian Council of Agricultural Research.
- Mall, R. K., Singh, R., Gupta, A., Srinivasan, G., & Rathore, L. S. (2006). Impact of climate change on Indian agriculture: A review. *Climatic Change*, 78(2–4), 445–478. <https://doi.org/10.1007/s10584-005-9042-x>.
- Pattanayak, A., Srinivasan, M., & Kavi Kumar, K. S. (2023). Crop diversity and resilience to droughts: Evidence from Indian agriculture. *Journal of Emerging Market Finance*.
- Srivastava, A., Singh, K. K., & Ahmad, R. (2023). Study of cropping pattern and cropping intensity of garlic in Etawah District of Uttar Pradesh. *International Journal of Statistics and Applied Mathematics*, 8(4S), 111–113.
- Yadav, A., Singh, H. C., Alam, A., Kashyap, P. S., Kumar, A., & Yadav, J. P. (2021). Estimate of the variation rainfall with respect to normal, surplus and drought months in Etawah District of U.P. *International Journal of Current Microbiology and Applied Sciences*, 10(3), 1026–1036. <https://doi.org/10.20546/ijcmas.2021.1003.130>.
- Yadav, S. K., & Kumar, A. (2023). Crop diversification for climate resilient agriculture: Opportunity and challenges. *Indian Farming*, 73(2), 12–14.