1. INTERLINKAGES BETWEEN AGRICULTURE, WATER AND FOOD SECURITY IN A CHANGING CLIMATE

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POSITION PAPERS

Bridging the Nutrition Gap through Agriculture: Aligning Crop Production with Dietary Needs in Bihar
Kalpna Kumari

Rethinking Agricultural Water Efficiency: A Regional Approach to Water Productivity of India's Dominant Crop
Nishtha Jain

Analyzing the Impact of Urbanization and Labor Market Dynamics on Water Scarcity in Bengaluru, India
Kushi Naidu

Locust Outbreaks and Climate Variability: Addressing Food Insecurity in Rewari District, Haryana, India
Bhoomika Thakur

Beyond Antibiotics: *In Silico* Discovery and Enzymatic Insights for *H. pylori* Eradication
Samruddhi Mane

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Bridging the Nutrition Gap through Nutrition Sensitive Agriculture: Aligning Crop Production with Dietary Needs in Bihar

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Executive Summary

India faces a dual burden of undernutrition and diet-related non-communicable diseases, despite being a food-surplus nation. Bihar, a state with considerable agricultural potential, exhibits some of the worst nutritional indicators in the country. This position paper draws upon original research to investigate how agricultural production in Bihar aligns with the nutritional requirements of its population. Using data from five representative districts (Araria, Arwal, Banka, Kaimur, and West Champaran), the study maps nutrient availability from 26 crops over ten years and compares it to age- and gender-specific dietary needs. The analysis revealed widespread nutrient shortfalls, especially in protein, fat, iron, calcium, and B-complex vitamins. Only carbohydrates and Vitamin C showed adequate or surplus levels in a few districts.

The findings demonstrate a systemic misalignment between what is grown and what is needed for adequate nutrition. The paper advocates for a shift from calorie-centric to nutrition-sensitive agriculture in Bihar. Recommended strategies include crop diversification, adoption of biofortified varieties, integrated farming systems, improved soil nutrient management, and restructured food policies. Implementing these interventions can help bridge the nutritional gap and contribute to national goals under POSHAN Abhiyaan and SDG 2 (Zero Hunger). This position paper argues that current governance mechanisms are inadequate to address the specific wastewater challenges faced by India's small towns. It recommends urgent investment in decentralised wastewater treatment units (DWWTs), the establishment of town-level river health governance bodies, and the institutionalisation of water quality modelling in local planning frameworks.

Context & Problem Statement

India's agricultural system, shaped by the Green Revolution, prioritizes caloric sufficiency over nutritional adequacy. This imbalance has contributed to persistent malnutrition, particularly in states like Bihar. Bihar, despite being agriculturally rich, exhibits alarming nutritional statistics: 42.9% of children under five are stunted, and over 64% of women of reproductive age are anaemic (NFHS-5, 2019-21).

The state's agricultural policy and practice continue to favor cereal-dominant production, especially rice and wheat. These crops provide calories but lack essential micronutrients such as iron, calcium, and Vitamin A. Moreover, the limited cultivation of pulses, fruits, vegetables, and oilseeds, along with poor utilization of livestock, aggravates the nutritional crisis.

Climate vulnerabilities, small and fragmented landholdings, and poor market access further constrain agricultural diversification. Public distribution policies, focusing on cereals, reinforce unhealthy dietary patterns.

This position paper responds to a critical gap: the lack of district-level assessment of the nutritional contribution of agriculture

agriculture in Bihar. It presents empirical evidence on nutrient gaps and recommends actionable pathways to align crop production with population dietary needs.

Literature Review

The dominant focus of Indian agriculture on staple crops has come at the cost of dietary diversity. Studies highlight the unintended nutritional consequences of the Green Revolution (NIAS, 2013). Biofortification and crop diversification are increasingly recognized as essential tools to improve food system outcomes.

Swaminathan and Bhavani (2013) emphasized the three pillars of food security: availability, access, and absorption. Despite food availability, nutrient absorption remains low in Bihar due to poor dietary quality and health infrastructure. Shirsath et al. (2021) demonstrate that optimized crop planning can ensure caloric sufficiency but not necessarily micronutrient adequacy.

The role of livestock in improving protein and micronutrient intake is well established (Singh et al., 2020). Yet, policy frameworks rarely integrate animal-source foods into nutrition planning. Climate-resilient agricultural practices and biofortified crops offer promise in addressing hidden hunger, but adoption remains low.

Das (2021) proposed redesigning the Public Distribution System (PDS) to include nutrient-rich foods, and Kapoor et al. (2022) highlighted the nutritional value of underutilized crops and wild edibles. Despite growing recognition of nutrition-sensitive agriculture, there is little localized evidence from Bihar, which this paper aims to address.

Research Focus and Methodology

The study aimed to evaluate how well the nutritional output of Bihar's agriculture meets the dietary needs of its population. The specific objectives were:

- To map the nutritional values of 26 major crops grown in five districts of Bihar.
- To identify gaps between nutrient availability and population dietary requirements.
- To recommend strategies to realign agricultural practices with nutritional goals.

The study selected five districts (Araria, Arwal, Banka, Kaimur, West Champaran) based on agro-ecological and socio-economic diversity. Crop production data (2013–2023) were sourced from the Ministry of Agriculture. Nutrient content was derived from USDA and ICMR databases.

Nutrient availability was calculated by multiplying crop yields by nutrient composition. Population-based dietary demand was estimated using Recommended Dietary Allowances (RDAs) from ICMR, disaggregated by age and gender. The nutrient gap was calculated by comparing supply and demand annually.

The results were analyzed using Excel-based models and visualized through comparative graphs. This approach allowed for a spatial and temporal analysis of nutrient deficits and surpluses.

Key Findings and Observations

The study revealed that while some districts meet caloric needs, critical gaps exist across all macro- and micronutrients.

Carbohydrates: Arwal and West Champaran showed surpluses due to cereal-centric farming, while Banka faced deficits.

Proteins and Fats: All districts showed protein and fat deficits. Pulse and oilseed production remains insufficient.

Micronutrients: Severe shortfalls were found in iron, zinc, calcium, and magnesium. Even districts with better crop yields lacked micronutrient diversity.

Vitamins: Vitamin A and B-complex deficiencies were pervasive. Only Vitamin C showed adequacy in some districts due to horticultural crops.

District-level insights:

Araria and Banka: Faced the most critical nutrient deficits due to poor diversification and agroecological limitations.

Kaimur and West Champaran: Performed better but still fell short in micronutrients.

Interpretation: The dominance of rice-wheat systems, limited adoption of biofortified crops, poor soil health, and weak market incentives contribute to Bihar's nutritional deficits. Nutrient gaps are not just a production issue but a systemic outcome of policy, practice, and socio-economic constraints.

Policy and Practice Implications

To bridge Bihar's nutritional gap, the following strategies are recommended:

Crop Diversification: Integrate millets, pulses, vegetables, and oilseeds into the cropping system. These are rich in essential nutrients and climate-resilient.

Biofortified Varieties: Promote iron-rich millets, zinc -rich rice, and Vitamin A-enriched sweet potatoes. Extension services should support farmer adoption.

Integrated Farming Systems: Combine crop, livestock, and horticulture to enhance nutrient diversity and farm income.

Soil Health Management: Implement site-specific nutrient management and organic inputs to restore micronutrient-rich soils.

Nutrition-Sensitive Extension: Train farmers on the link between agriculture and health. Women's groups can lead kitchen gardens and household nutrition programs.

Reform Public Procurement: Redesign PDS to include pulses, millets, and fortified cereals. Support institutional demand in schools and hospitals.

District-Level Planning: Use GIS and nutritional mapping tools for agro-nutritional zoning. Create district dashboards to guide crop planning.

Conclusion

This paper presents evidence of a fundamental mismatch between food production and nutritional needs in Bihar. The overemphasis on cereals, ecological vulnerabilities, limited crop diversity, and policy biases contribute to systemic nutrient gaps.

A transition to Nutrition-Sensitive Agriculture (NSA) is both necessary and feasible. By integrating diversified cropping, soil health practices, biofortified seeds, and data-driven planning, Bihar can move toward nutritional security. The recommended interventions align with national goals under PM POSHAN Scheme and SDGs.

The research underscores the importance of localized data and participatory planning. Future research should expand to include livestock, fishery contributions, and food loss metrics to build a comprehensive agro-nutritional or NSA strategy for Bihar State.

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Rethinking agricultural water efficiency: a regional approach to water productivity of India's dominant crops

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Executive Summary

India's agriculture, which supports nearly half of the country's population, is increasingly burdened by unsustainable water use, particularly in the cultivation of water-intensive crops such as rice, wheat, and sugarcane. These three crops, while central to national food security and export earnings, account for a disproportionate share of the country's irrigation water, contributing to ecological stress in groundwater-dependent regions. Despite long-standing policy incentives such as minimum support prices (MSP) and free electricity, the environmental trade-offs of these cropping patterns are becoming more severe in the face of climate change, declining water tables, and regional water imbalances. This position paper builds on a multi-scalar assessment of water productivity (WP) in Indian agriculture, with a focus on the temporal and spatial efficiency of water use across major crop-producing states. Using a combination of empirical trends from secondary datasets and simulation modeling through FAO's CROPWAT tool, the study examines physical and economic water productivity (PWP and EWP) across key states and blue and green water productivity (BWP and GWP) across selected districts, identifying stark variations and misalignments between water use and crop returns. Key findings reveal that states like Punjab and Maharashtra maintain high productivity levels through intensive irrigation, yet face growing groundwater depletion. Meanwhile, eastern and central Indian states often demonstrate lower productivity not due to lack of water, but because of policy neglect and infrastructural gaps. The study emphasizes the importance of regional realignment of crop production, targeted irrigation reform, and export policy recalibration to reduce India's virtual water losses.

This paper argues for a paradigm shift from yield-maximizing to water-efficient cropping systems, integrated with sustainable irrigation technologies and region-specific policy interventions. Addressing the spatial and economic inefficiencies of current practices is essential to building climate-resilient and water-secure agricultural futures in India.

Context & Problem Statement

India's agricultural sector is at a critical juncture, facing a dual burden: meeting the food demands of a growing population while conserving its increasingly scarce water resources. Agriculture consumes approximately 90% of India's total freshwater withdrawals (World Bank, 2021), a figure driven largely by the cultivation of a few dominant crops i.e., rice, wheat, and sugarcane. These crops are not only central to the country's food security and export economy but are also responsible for some of the most unsustainable patterns of water use in the country.

This imbalance is most pronounced in ecologically vulnerable regions. In Punjab, for instance, groundwater levels are rapidly declining due to entrenched rice-wheat cultivation, incentivized by MSPs and free electricity for irrigation.

Similarly, in Maharashtra, sugarcane cultivated over just 4% of the state's farmland uses more than 60% of the available irrigation water, often through inefficient flood irrigation methods. These trends reflect a systemic misalignment between cropping patterns and regional water availability, exacerbated by outdated subsidy structures and policy inertia.

At the same time, policy frameworks continue to favor high-input, high-output systems with little consideration for ecological cost. The substantial export of water-intensive crops, particularly rice, has led to a surge in virtual water trade, India is effectively exporting its limited freshwater resources embedded within agricultural goods. As groundwater stress intensifies, this silent loss threatens long-term national water security. Despite the mounting risks, much of the existing water productivity analysis in India remains confined to national or state-level aggregates. Such analyses obscure micro-level variations in water use efficiency and fail to capture the nuanced interplays between climate, irrigation practices, and crop choice. There is also insufficient understanding of how physical and economic water productivity varies across regions and how it intersects with environmental degradation.

Crucially, climate variability and changing rainfall patterns are increasing irrigation demands and shifting agro-climatic zones. This calls for urgent evidence-based strategies that go beyond general water-use metrics to include crop-specific, regionally grounded assessments of water productivity and sustainability.

The core problem this research addresses, therefore, is the lack of integrated, granular insights into how and where India's water is being used to grow its major crops and how effectively. Without such knowledge, efforts to improve irrigation efficiency, promote sustainable cropping, or redesign export policy remain incomplete. By bridging this gap, the study aims to support informed, regionally differentiated strategies that align agricultural production with ecological realities and long-term water resilience.

Literature Review

The sustainability of water use in agriculture has been a subject of growing academic and policy interest, particularly in countries like India where irrigation demands are exceptionally high. Two key analytical frameworks have emerged in this context: water productivity (WP), which measures crop yield per unit of water used (kg/m³), and water footprint (WF), which quantifies the total volume of water consumed, including blue (irrigation), green (rain-fed), and grey (pollution-assimilating) components through the crop's life cycle (Hoekstra et al., 2011). Molden et al. (2007) and Zwart & Bastiaanssen (2004) emphasized WP as a critical indicator of agricultural water use efficiency, arguing that improvements in WP can help reduce pressure on water resources without compromising yields. In India, Sharma et al. (2018) demonstrated considerable variability in WP across crops and regions, with rice showing particularly low physical water productivity, especially in groundwater-dependent zones. Jain et al. (2021) further highlighted that while wheat displays relatively better WP, it often relies on unsustainable extraction practices in the Indo-Gangetic Plians.

WF studies have added important dimensions to this conversation. Studies by Mekonnen & Hoekstra (2016) and Aldaya et al. (2010) documented how virtual water trade i.e., the export of water-intensive crops contribute to "invisible" freshwater losses from water-stressed regions. In the Indian context, Punjab and Haryana, despite being water-deficient, remain key exporters of rice and wheat, leading to the paradox of food security gains at the cost of long-term water insecurity (Gulati & Mohan, 2018). Technological interventions such as micro-irrigation (e.g., drip, sprinkler systems), alternate wetting and drying (AWD) in rice, and resource-conserving practices like zero tillage have been proposed to enhance WP (Bhatt et al., 2023; Vatta et al., 2018). However, as Perry et al. (2009) and Lankford (2025) caution, such interventions may not translate into real water savings at the basin scale due to rebound effects and increased cropping intensity.

Recent literature has also stressed the importance of integrating economic dimensions into water analysis. Cai et al. (2017) and Lee et al. (2024) propose economic water productivity (EWP) as a more policy-relevant indicator, accounting for monetary returns per unit of water. Yet, few studies have rigorously

compared EWP across crops and regions or evaluated trade-offs between physical efficiency and economic gain.

This study builds on these strands by offering a multi-scalar WP analysis that combines temporal trends, spatial disparities, and simulated irrigation requirements for selected crops in key regions of India. It also responds to a research gap by focusing on district-level disparities and the underexplored role of virtual water trade in agricultural planning.

Research Focus and Methodology

This research aims to analyse the spatial and temporal dynamics of water productivity in India's agriculture, with a focus on wheat, rice, and sugarcane i.e., the most water-intensive and policy-influential crops. By understanding how water is used across diverse agro-ecological and administrative scales, the study provides evidence for sustainable planning, irrigation policy, and crop diversification strategies. The study was guided by **four primary objectives:**

1. To analyze long-term trends (2000–2020) in physical and economic water productivity of rice, wheat, and sugarcane across major producing states.
2. To assess spatial disparities in water productivity for these crops across diverse agro-climatic regions.
3. To compare water productivity of wheat, rice, and sugarcane with other high-water-demand crops such as maize and cotton.
4. To simulate crop water requirements and estimate WP indicators at the district level using CROPWAT 8.0 for select regions.

Study crops and regions- Three major crops: wheat, rice, and sugarcane were selected due to their significant contribution to India's irrigated area, food grain production, and virtual water exports. Maize and cotton were included as comparative crops to assess the potential of crop substitution.
Nine states: Uttar Pradesh, Punjab, Madhya Pradesh, Bihar, Maharashtra, Andhra Pradesh, Karnataka, West Bengal, and Gujarat were chosen for state-level analysis based on their contribution to crop production. For micro-level analysis, four districts were selected: Ludhiana and Amritsar in Punjab (for wheat), and Pune and Ahmednagar in Maharashtra (for sugarcane).

The analysis used a combination of secondary and modeled data:

- Water productivity data: Sourced from the India Water Productivity Atlas (IWMI-ICAR), which integrates remote sensing and field datasets.
- Climate and soil data: Extracted from FAO's CLIMWAT 2.0 for CROPWAT simulations.
- Yield and production data: Obtained from the Directorate of Economics and Statistics (DES), FAO, and APEDA.

A two-tiered methodology was used:

1. **Temporal-spatial analysis:** State-level physical (kg/m³) and economic (USD/m³) water productivity were evaluated over two decades (2000-2020) using WP Atlas data to identify spatial disparities and temporal trends.
2. **Simulation modeling:** The FAO CROPWAT 8.0 tool was used to estimate district-specific crop water requirements (CWR), evapotranspiration (ETc), and irrigation needs. These outputs were combined with crop yield data to compute:

$$PWP = Yield/Etc$$

$$GWP = Work/Effective\ Rainfall$$

$$BWP = Yield/Irrigation\ Requirement$$

This mixed-method approach offers both empirical breadth and micro level precison, making it possible to triangulate results and formulate actionable recommendations tailored to regional conditions.

Key Findings & Argument

The findings from this multi-scalar study highlight stark temporal and spatial variability in water productivity across India's key agricultural crops and regions. These patterns are shaped not just by agro-climatic conditions but also by historical policy choices, irrigation infrastructure, and market incentives.

1. Temporal trends: Unequal gains in water productivity

Over the two-decade analysis period (2000-2020), the physical water productivity (PWP) of wheat, rice, and sugarcane exhibited moderate to high fluctuations across states. Punjab consistently recorded the highest PWP for wheat, often exceeding 1.5 kg/m³ driven by assured procurement and advanced irrigation infrastructure. However, this came at the cost of unsustainable groundwater extraction, highlighting a classic case of high productivity with low ecological sustainability.

Uttar Pradesh, though India's largest wheat producer, showed only moderate PWP (0.7-1.1 kg/m³), reflecting continued reliance on outdated irrigation practices. Bihar and Madhya Pradesh, despite improvements, lagged due to fragmented landholdings, climatic risks, and poor irrigation infrastructure. These disparities reinforce the need for targeted irrigation support and precision water management in the eastern Indo-Gangetic plains.

Sugarcane followed a similarly uneven trajectory. Andhra Pradesh and Karnataka achieved relatively higher PWP (0.5-0.6 kg/m³), attributed to partial adoption of micro-irrigation systems and policy support through programs like PMKSY and APMIP. Maharashtra's productivity data was inconsistent due to reporting gaps, though field evidence suggests excessive water use through flood irrigation. Uttar Pradesh's sugarcane belt maintained moderate WP levels, but rising cultivation in less irrigated eastern districts threatens to drag efficiency down further.

For rice, Punjab again stood out with high PWP (up to 0.8 kg/m³), but its agro-climatic unsuitability and heavy groundwater dependence make this an unsustainable model. West Bengal and Andhra Pradesh showed stable performance, with room to improve through better irrigation scheduling and water-saving technologies like direct seeded rice (DSR).

2. Spatial disparities and misalignments

Spatial analysis across nine major crop-producing states revealed a deeper structural misalignment between crop selection and regional water availability. High water-consuming crops are concentrated in states facing critical groundwater stress like Punjab, Maharashtra, and parts of Uttar Pradesh. Meanwhile, ecologically suitable eastern and northeastern states remain underutilized for irrigated agriculture despite better rainfall and aquifer recharge potential.

This spatial disconnect stems largely from distorted policy incentives especially MSPs, subsidized electricity, and procurement assurances that have led to persistent monocultures of water-intensive crops in fragile zones. Such patterns are not only economically inefficient but also ecologically dangerous, given the declining water tables and deteriorating soil health in these areas.

3. Comparative water productivity with alternative crops

When benchmarked against maize and cotton, wheat and sugarcane demonstrated relatively high physical productivity but poor economic returns per unit water. Cotton, although water-intensive, showed better economic water productivity (EWP) due to its high market value. Maize emerged as a promising alternative in regions with moderate irrigation capacity, offering better WP without heavy groundwater dependence.

These comparisons reveal the potential of crop diversification, not necessarily abandoning current staples, however gradually transitioning toward a more balanced cropping mix that includes maize, oilseeds, millets, and pulses in suitable regions.

4. District-level simulation insights

Using CROPWAT 8.0, district-level simulations were conducted for wheat in Ludhiana and Amritsar (Punjab) and for sugarcane in Pune and Ahmednagar (Maharashtra). These case studies revealed important micro-level insights:

Wheat in Punjab: High PWP values (~1.8 kg/m³) were achieved but were reliant on intensive irrigation and minimal rainfall contribution. Blue water productivity (BWP) was comparatively lower, indicating dependence on pumped groundwater.

Sugarcane in Maharashtra: Despite relatively high yields, irrigation demand was extremely high (~1400 mm), and sugarcane is a perennial crop, requiring water throughout the year. Effective rainfall makes minimal contribution, especially in Ahmednagar, due to erratic monsoon patterns.

These findings suggest that improving WP is not just about increasing yield but optimizing the mix of rainfall use and irrigation. The high share of blue water use also highlights the urgent need to promote techniques such as drip irrigation and mulching to enhance green water utilization and reduce groundwater extraction.

5. Economic trade-offs and virtual water losses

Economic water productivity remained consistently lower than physical productivity across all crops and states, highlighting a critical gap between input efficiency and monetary return. This divergence often stems from stagnant market prices, high input costs, and post-harvest losses.

Moreover, the analysis pointed to significant virtual water losses through agricultural exports. For instance, rice exports from Punjab equate to the externalization of over 3,000 m^3 of water per tonne of grain. Without region-specific trade regulations or virtual water audits, such practices pose long-term risks to national water security.

Policy and Practice Implications

A recurring theme was the neglect of regional equity in resource allocation. States like Bihar and Madhya Pradesh, which have potential for sustainable intensification, remain underfunded in irrigation support and policy incentives. Meanwhile, ecologically overburdened regions continue to receive disproportionate benefits under centrally driven procurement and subsidy regimes.

This imbalance calls for policy decentralization, empowering states to promote cropping patterns aligned with their resource endowments. Equity in water allocation especially in terms of financial and technological access is essential for achieving national food security without compromising environmental resilience.

Conclusion

This position paper has argued for a fundamental rethinking of how water is managed in India's agriculture, particularly in relation to the production and trade of water-intensive crops like rice, wheat, and sugarcane. By assessing water productivity (both physical and economic) across temporal and spatial scales, and by simulating crop water requirements at the district level, the research highlights critical inefficiencies in current cropping patterns, irrigation practices, and policy frameworks.

A key insight is that high productivity in itself does not guarantee sustainability. In states like Punjab and Maharashtra, productivity gains are being achieved at the cost of depleting groundwater, while many eastern and central states with relatively better water endowments remain underutilized. Furthermore, India's significant export of high water-footprint crops contributes to the hidden loss of freshwater resources through virtual water trade. The central position of this paper is clear: India's agricultural water governance must become both ecologically sensitive and economically rational. Only then can the country move toward a future where food systems are not just productive but also resilient, equitable, and water-secure.

Future research could extend this work by incorporating grey water components, analysing carbon-water trade-offs, or integrating basin-level hydrological modelling. Such efforts would further enrich policy dialogue and help build adaptive capacity in a climate-stressed, water-scarce world.

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Analysing the Impact of Urbanization and Labour Market Dynamics on Water Scarcity in Bengaluru, India

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Executive Summary

The study aims to explore the intricate relationship between urbanization, changes in labour market dynamics, and water scarcity, with focus on the depletion of groundwater that often goes unnoticed in urban settlements. Today, more than half of world's population resides in urban clusters, facing serious socio-economic and environmental implications. Unplanned and unregulated urbanization has led to range of urban issues including to traffic congestion, surge of informal settlements, poor resource quality, overcrowding, insufficient infrastructure among others.

In this context, the study assesses the impact of urbanization on the water scarcity situation in Bengaluru in the past decade, i.e., 2013 - 2023. The study disaggregates urbanization into landscape urbanization (land use change indicators), demographic urbanization changes in labour market (captured through change in employment in key sectors), and economic urbanization. To assess this relationship, the study undertakes a multivariate regression analysis to regress the urbanization indicators on groundwater levels of Bengaluru; the results indicate towards a negative relationship, i.e., changes in land use and land cover, high population density and economic growth without adequate water infrastructure exerts strain on not only groundwater levels but also impacts the aquifer recharge capacity. Furthermore, the study also evaluates the role of Bangalore Water Supply & Sewerage Board (BWSSB) under indicators of environmental (unaccounted water) and financial sustainability (non-revenue water) respectively. The analysis highlights the governance gaps through mismatch between roles/functions and the scale of water regulation in the city. Finally, as one of India's leading economic hubs, this study on Bengaluru acts as the guiding pillar in proposing sustainable urban planning practices for several metropolitan cities on a similar growth trajectory.

Context & Problem Statement

Bengaluru mainly consists of two major water sources – the Cauvery River and groundwater. Before large-scale urbanization, the city mainly relied on the Cauvery River to meet its water needs. The efficient use and transportation of this water was attributed to the massive system of interconnected lakes the city adorned. A study on Bengaluru's lakes revealed that rejuvenation of lakes alone has the potential to meet close to 50% of drinking water demand (Ahmed & Ramamoorthy, 2024). With Britishers settling in Bengaluru post 1800s, the demand for water significantly increased that caused unprecedented pressure upon the existing water system. As the alterations made by Britishers on the water system increased, the dependence and usage of these lakes drastically reduced. As a result, the lakes began to shrink. To add to this misery, urbanization paved path to build concrete constructions on these lake beds. Bengaluru mainly consists of two major water sources – the Cauvery River and groundwater. Before large-scale urbanization, the city mainly relied on the Cauvery River to meet its water needs. The efficient use and transportation of this water was attributed to the massive system of interconnected lakes the city adorned. A study on Bengaluru's lakes revealed that rejuvenation of lakes alone has the potential to meet close to 50% of drinking water demand (Ahmed & Ramamoorthy, 2024).

With Britishers settling in Bengaluru post 1800s, the demand for water significantly increased that caused unprecedented pressure upon the existing water system. As the alterations made by Britishers on the water system increased, the dependence and usage of these lakes drastically reduced. As a result, the lakes began to shrink. To add to this misery, urbanization paved path to build concrete constructions on these lake beds. Around 43 lakes have been concretized into infrastructure such as, hospitals, commercial parks, stadium to name a few (Bengaluru's 43 Lost Lakes and What Stands on Them Today, 2024). Furthermore, discharge of harmful chemical effluents into lakes have caused deterioration in the quality, rendering large volumes of water unusable. Thus, with decreasing number of water bodies due to infrastructure expansion, the city reflects a strong misalignment between urban growth and environmental sustainability a major concern this thesis aims to address.

At the core of this study, the research problem is to understand how unregulated urbanization and shifts in labour market dynamics has escalated the water crisis in Bengaluru. Given the growth in urban population in the city, resulting in human encroachment into the green tapestry and causing ecological imbalance, it becomes imperative to understand how such changes in land use and land cover alter the city's hydrological system contributing to chronic water stress. Additionally, despite mandatory policy interventions stated by the water utility in Bengaluru, effective on-ground implementations have not been observed, calling for an assessment of the efficiency of water governance in Bengaluru.

Literature Review

This chapter presents a thematic review of the literature, with a focus on Bengaluru, India. The chapter is broadly sub-divided into urbanization trends (global and Bengaluru's urbanization trends), insights on water scarcity (emphasizing on its environmental impacts), the importance of economics in urban water supply and the role of economic instruments in encouraging efficient water governance.

Urbanization is defined as "The transformation of unoccupied or sparsely occupied land into densely populated cities" (Urbanization, n.d.). In 2019, The United Nations forecasted that more than half of the world's population, i.e. around 6 billion people will live in urban areas by 2041 (Kuddus et al., 2020). With such rapid rates of urbanization resulting in high population density settled in confined 'urban' boundaries, the allocation and use of resources ranging from housing, healthcare, education, employment opportunities should all be meticulously planned (Ritchie et al., 2024). Among the metropolitan cities in India, Bengaluru has stood out as a prime example of rapid urbanization. The surge in urbanization has led to large environmental degradation, one of the most prominent impacts in Bengaluru was seen on its water resources.

The literature on establishing a relationship between urbanization and water scarcity is well documented. According to IPCC's report, urbanization combined with climate change impacts 7 is likely to have a negative impact on urban development, and lead to several societal concerns ranging from water security, degradation of water quality, rising pollution level to food shortages (Tayebi et al., 2022). Forecasted estimates also reveal that the world will face a 40 percent gap between water supply and demand (Tayebi et al., 2022), calling for an imperative need to articulate sustainable water management policies.

In situations of water scarcity, it becomes imperative to not just find sources of freshwater supply, but also use and value water adequately to ensure sustainable urban progress. As Adam Smith asserts, valuing water appropriately reflects the true utility, also referred to as 'value-in-use' of a commodity in economic literature (Batten, 2007). In the entire gamut of water governance discussions, where the decisions are mainly influenced by geography, population rise, and often political considerations, ironically, the economic factor that directly depicts scarcity (Convery, 2013) price, is frequently ignored. Despite this, several developing countries' will/capacity to develop pricing instruments grounded in economic theories remains limited, leading to institutional failure or governance collapse. Lack of identification of water as an economic good, remains one of the critical reasons behind poor urban water management. Instruments such as tiered water pricing helps cost recovery because of efficient

commodity pricing. In this context, tiered water pricing encourages behavioural shifts in water consumption by rewarding a lower water tax with every decrease in water consumption, thus inculcating social welfare along with cost recovery. Another economic theory "Marginal cost pricing" equates the price to the marginal cost incurred with additional production of output; this also includes the increase in price necessary to cut excessive consumption (Turvey, 1964). In their study, Hanke & Davis (1973), assessed the role of marginal cost pricing in efficient resource allocation. They further state that, with expansion in commodity demand, extraction from supply resource increase; however, prices often fail to account for the cost to future consumers of forgone resource or service. This results in failure of the primary function of price, i.e., to balance price and cost at the margin, further encouraging excessive consumption as a result of under-pricing the commodity.

Research Methodology

This chapter presents an overview of the data and methodology employed in this study to assess the impact of urbanization on water scarcity in Bengaluru between 2013-2023. In this period, the built-up area of Bengaluru is increase by a massive 1055% (Kaggere, 2024); thus, the time frame serves an appropriate period to capture the impact of sudden rise in urbanization on the city's water resources.

Furthermore, the study employs a mixed method approach to address both the research questions:

1. How does the rise in urbanization rate and change in labour market dynamics impact the water availability and usage in the city?

2. To what extent do water management and urban planning policies play a role in mitigating or exacerbating water scarcity problems?

To address the first research question, the study uses secondary data from government sources, further segregating the data into five divisions of Bengaluru – Yelahanka, North, East, South, Anekal. Using this data, the study builds two multivariate regression models; model 1 analyses the impact of demographic (captured through increase in employment over the years) and landscape urbanization (captured through land-use change categorised by residential and commercial establishments) on water scarcity and model 2 analyses the impact of economic urbanization (captured through increase in employment in key industrial sectors) on water scarcity. The models are as shown below:

Model 1:

$$GW\ Level_{it} = \beta 0 + \beta 1 Lag_Rainfall_{it} + \beta 2 Residential_{it} + \beta 3(Commercial_{it} \times Employment_{it}) + \beta 4 Commercial_{it} + \beta 5 Employment_{it} + \beta 6 Temperature_{it} + \epsilon_{it}$$

Model 2:

$$GW\ Level_{it} = \beta 0 + \beta 1 Textiles_{it} + \beta 2 Chemicals_{it} + \beta 3 Engineering_{it} + \beta 4 Others_{it} + \epsilon_{it}$$

The choice of GW (groundwater) level as the dependent variable is grounded in literature suggesting that any alterations in land use & land cover is likely to impact the groundwater reserves more intensely than surface water. In his study, Patra et al., (2018) finds that increase in impervious surfaces as a consequence of urbanization leads to reduced evapotranspiration in urban clusters, thus having direct impacts on 'groundwater'. Additionally, it has been observed that, core city has not been facing severe water shortages since they have piped Cauvery water supply service facilitated by the water utility; whereas, the periphery is facing severe shortage as rely mainly on groundwater sources. Hence, it is established that the water crisis in Bengaluru is fundamentally a 'groundwater crisis'. Moreover, to address the second research question, the study employs the IAD Framework to identify the key water management authority concerned with water collection and distribution in the city. Further, the role of the water utility is assessed in regulating such a water crisis under key parameters of environmental and financial sustainability.Overall, this study adopts an interdisciplinary approach to understand the combined effect of the interaction between urbanization changes and water governance on water scarcity.

Results and Discussions

This section will present the results and analysis based on the methodology outlined in the previous section. In its centrality, the study aims to empirically establish a relationship between urbanization variables and groundwater level. To support this narrative with empirical evidence, the following section presents the regression results, followed by some discussion.

Model 1: Impact of demographic & landscape urbanization on groundwater (2013-2023)

$$GW\ Level_{it} = \beta_0 + \beta_1 Lag_Rainfall_{it} + \beta_2 Residential_{it} + \beta_3 (Commercial_{it} \times Employment_{it}) + \beta_4 Commercial_{it} + \beta_5 Employment_{it} + \beta_6 Temperature_{it} + \epsilon_{it}$$

Table 1: Multiple linear regression results for the impact of urbanization on groundwater level (2013-2023)

	Estimate	Std. Error	t value	Pr(>t)
(Intercept)	1.111e+02	32.65	3.402	0.0013 ***
Lag Rainfall	-1.156e+01	4.204	-2.749	0.008 ***
Commercial	-1.024e+00	0.589	-1.738	0.08 *
Employment	-3.701e-05	0.000015	-2.457	0.01 **
Residential	-3.220e-02	0.0558	-0.577	0.566
Temperature	-2.650e+00	1.323	-2.003	0.05 *
Comm*Emp	4.988e-06	0.00000199	2.508	0.01 **

Source: Author's Compilation

Signif. codes: *** p < 0.01, ** p < 0.05, * p < 0.1

Residual standard error: 6.301 on 47 degrees of freedom

Multiple R-squared: 0.4344, p-value: 0.0001

Relationship between groundwater and the independent variables are presented below,

Commercial Sites

The estimate presents a significant negative relationship between commercial sites and groundwater level. The estimate is statistically significant at 10%. In areas where commercial growth outpaces residential settlements, piped water supply infrastructure spread at a slow pace, leaving no choice for these commercial zones but to rely on underground aquifer systems.

Labour Influx

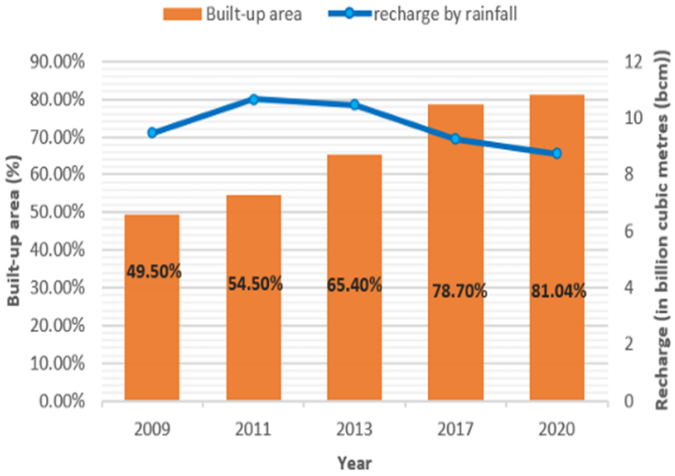
The regression estimate indicates a negative relationship between labour influx (proxied by employment data) and groundwater level. The estimate is statistically significant at 5%. As demand for labour rises in a specific city, they bring along residential, commercial and other service-related demand, leading to infrastructure expansion. This infrastructure expansion leads to various kinds of land use changes, altering the city's natural water infrastructure and recharge mechanism.

Rainfall

The estimate of rainfall indicates a negative impact on groundwater, as seen in the regression results. The estimate stands highly statistically significant at 1%. This result may seem counterintuitive, since conventional functioning of rainfall is understood to have a positive impact on groundwater recharge. The reasoning behind the negative relationship is three-fold, reduced rainfall potential to recharge groundwater could be due to – soil sealing (urbanization), changes in hydrological patterns as a result of climate change, and gaps in governance.

To validate the literature empirically, a graph indicating the increase in built-up area in Bengaluru along with the level of groundwater recharge is presented below.

Figure 8: Annual trend of recharge by rainfall and built-up area during 2009, 2011, 2013, 2017, and 2020



Source: Author's Compilation

As can be seen in the graph above, with increase in built-up area in Bengaluru, the potential of rainfall to recharge groundwater has significantly reduced (Patra et al., 2018).

Model 2: Impact of economic urbanization on groundwater level (2013-2023)

$$GW\ Level_{it} = \beta 0 + \beta 1 Textiles_{it} + \beta 2 Chemicals_{it} + \beta 3 Engineering_{it} + \beta 4 Others_{it} + \epsilon_{it}$$

Table 2: Multiple linear regression results for the impact water-intensive industries on groundwater level (2013-2023)

	Estimate	Std. Error	t value	Pr(>t)
(Intercept)	4.038e+01	1.593e+01	2.535	0.0444 **
Textiles	2.646e-04	1.342e-04	1.972	0.0961 *
Chemical	-1.327e-04	4.338e-05	-3.060	0.0222 **
Engineering	-5.157e-06	5.095e-05	-0.101	0.9227
Others	-3.315e-05	3.217e-05	-1.030	0.3427

Source: Author's Compilation

Signif. codes: ** p < 0.05, * p < 0.1

Residual standard error: 2.397 on 6 degrees of freedom

Multiple R-squared: 0.7813, p-value: 0.03497

Relationship between chemical industry and groundwater level: The estimate indicates a negative relationship between chemical industry and groundwater level. The estimate is statistically significant at 5%. This result aligns with conventional expectation of chemical industry's high exertion on groundwater, given its water-intensive nature. The production of chemical involves a series of sequential processes that require continuous water (Ellis et al., 2017). Bengaluru's intermittent piped water supply may cause hindrance in manufacturing processes (Vairavamoorthy et al., 2007). Hence, they tend to rely on tankers or private borewells, causing local aquifer stress.

As an additional exercise, the study forested the groundwater level for the time period 2024 – 2028, given the pattern of industrial water use remains the same. The graphical representation of the same is given below.

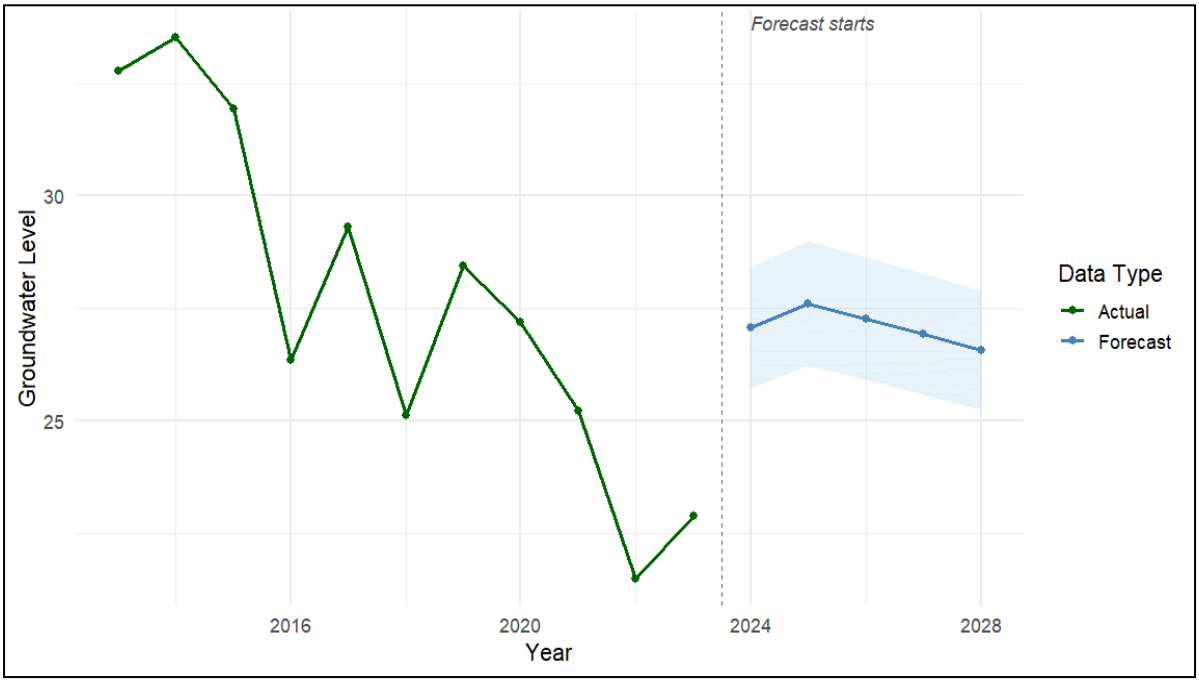


Figure 9: Groundwater Level Trend: Actual v/s Forecast (2010-2028)
Source: Author's Compilation (created using RStudio)

As seen in the graph above, groundwater level is expected to decline if both – the use of groundwater remains unaccounted of the environmental cost and management remains unregulated.

Qualitative Analysis

In the following sections, the analysis is undertaken on two critical dimensions of water management, i.e., environmental, and financial sustainability. The indicators assessed under each of these dimensions is discussed in detail below.

Environmental Sustainability: Unaccounted Water

Unaccounted water in Bengaluru, was found to be as high as 48% in 2012-23, much higher than the suggested benchmark by the American Water Works Association (AWWA), i.e., around 10%. To address this, BWSSB undertook a project to reduce UFW, funded by the Japan International Cooperation Agency (JICA) in 2013. In 2025, with these efforts, BWSSB slashed the amount of UFW by more than half of what persisted a decade ago (51%), bringing the UFW down to 24%. Moreover, with rising volumes of water being saved, large amount of BWSSB's revenue is being saved, using which the board aims to UFW further down to 15-16% in coming years and eventually to zero percent *(Bengaluru: Unaccounted for Water Project Is Finally Yielding Results, Claims BWSSB, 2017).*

Financial Sustainability: Non-Revenue Water

A subset of unaccounted water explored in the previous section is Non- Revenue Water (NRW), which comprises of water that is supplied but not billed. As per the Central Public Health and Environmental Engineering Organization (CPHEEO) standards, the allowable level of NRW should be under 15% (Sridhar, 2025). Bengaluru's NRW stood at around 52% in 2007, much higher than the permissible level.

In April 2025, BWSSB announced a 3% hike in the tariff structure as per the recommendation of the Karnataka State Administrative Reforms Commission (BWSSB Hikes Water Tariff by 1 Paise per Litre; Annual 3% Rise Planned, 2025).

This revision in tariff structure becomes significant for two reasons. First, when water is priced fairly, it helps bring behavioural shift in water usage among citizens, which is critical to a city facing chronic water stress. Second, the increase in BWWSB's revenue can be used in investment in advanced water technology, construction of sewage treatment plants to utilize wastewater potential, lake rejuvenation among others.

Policy Implications

This section builds on the key findings discussed in the previously to point out some policy recommendations.

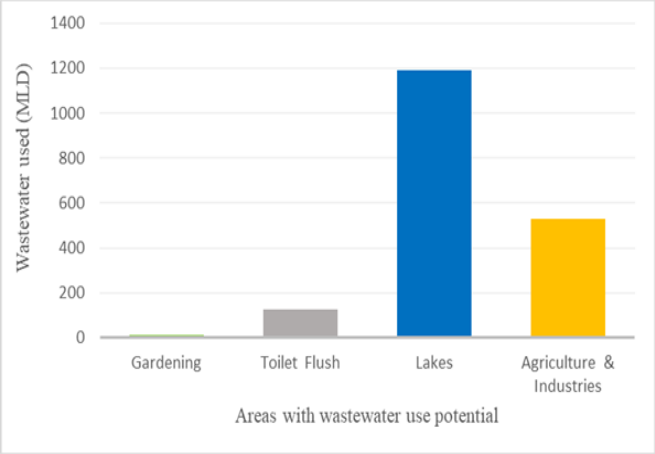


Figure 12: Distribution of wastewater use in different tertiary purposes (Source: Author's Compilation)

Wastewater Treatment: According to report by WELL Labs, Bengaluru generates approximately 2000 MLD of wastewater, of which only 30% is being reused (Ramesh, 2023). The usage of this 30% for several purposes is presented in the graph above. As it can be seen in the graph, large amount of wastewater is being released into lake. Release of treated wastewater into lakes not just renders volumes of water waste, but also pollutes these water bodies (Palur et al., 2024). While the city is making considerable attempt to encourage construction of decentralized sewage treatment plants, a lot of wastewater potential remains untapped.

Demand-Side Management: Citizens can take measures such as mandatory installation of Rainwater Harvesting in private properties, residential complexes, industrial zones, commercial establishments among others. Additionally, embracing use of grey water for gardening or flushing can reduce demand for water significantly. Installation of water-efficient technologies (water filters, low-flow taps) could slash wastage by a great amount.

Policy implementation from lessons around the globe: Singapore: The country has a robust water supply system referred to as Singapore's 'Four National Taps' (Tortajada, 2018). They consist of increasing local catchment area for rainwater collection, imported water through pipe infrastructure from Malaysia (water agreement that expires in 2061), NEWater – water recycled using high grade technology making it fit for industrial and agricultural uses. Additionally, along with wastewater treatment through centralized and decentralised sewage treatment plants, the country has set up two large-scale desalination plants that involves the process of salt segregation from saline water, making it suitable for consumption.

Denmark: One of the best practices include the 'producer pays' approach to wastewater discharge. This incentivizes industries to cut massively on their pollutants. Additionally, discharge beyond the stated threshold is heavily penalized in the country. Also, a NRW (drinking water) greater than 10% imposes a penalty fee on drinking water management board.

Conclusion

The exploration of urbanization and its association with water resources present a dynamic view of how spatial expansion, economic growth and change in labour market dynamics intersect with the natural ecosystem. The choice of Bengaluru as the study area is both timely and interpretatively valuable in the light of the severe water crisis that occurred in the summer of 2024. Being one of India's fastest-growing metropolitan cities, Bengaluru serves as a strong analytical example of the complex interaction between urban sprawl, economic growth, and environmental vulnerability.

There were two primary objectives of the study: to quantify the impact of urbanization, disaggregated as three broad types – landscape, demographic and economic – on groundwater levels in Bengaluru; and study the role of water utility in mitigating and exacerbating water stress. Three key findings for Bengaluru hold important implications for sustainable urban development and water regulation. First, water stress is not a by-product of urbanization, but an active manifestation through choices made in the process of urbanization. The empirical findings in this respect suggest that the expansion in built-up area, mainly commercial establishments and population increase (employment driven), as well as economic growth, exert unprecedented pressure on already overexploited aquifers.

This results when the scale and speed of urbanization is much faster than the what the infrastructure mechanism can support. Second, the scale of water utility must be sufficiently large to look after both operational as well as regulatory functions related to water governance.

The qualitative analysis of BWSSB (concerned with supply and distribution) from this study indicates that, while areas in the city periphery fall in the jurisdictional boundary of governance, the scope of water supply and monitoring of extraction from aquifers mainly remains confined to Bengaluru's core areas. This caused settlements in peri-urban areas to resort to illegal drilling of borewells due to limited formal water supply facility, emphasizing the need to expand governance capacity with increase in urban footprints.

In conclusion, the study underscores the need to internalize environmental costs in urban planning and reduce water vulnerability through strengthening regulatory framework to achieve economic resilience and ensure sustainable urban development.

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Locust Outbreaks and Climate Variability: Addressing Food Insecurity in Rewari District, Haryana, India

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Executive Summary

This research investigates the growing threat of desert locust (Schistocerca gregaria) outbreaks in the Indian subcontinent, with a focused case study on the Rewari district of Haryana. The study explores the relationship between changing climatic variables particularly rainfall, temperature, and wind speed and the frequency and intensity of locust swarms. Utilizing a mixed methods approach, the study combines long-term meteorological data (19792020), regression and correlation analyses, and qualitative field surveys across three vulnerable villages in Rewari block to assess the ecological and socioeconomic consequences of locust invasions. Findings reveal a significant shift toward erratic rainfall, persistent high summer temperatures, and intermittent wind spikes all of which create conducive conditions for locust breeding, maturation, and migration. The 2020 locust outbreak, exacerbated by unseasonal rainfall and favourable wind patterns, aligns with these observed climatic anomalies. Regression analysis shows a strong negative correlation between temperature and rainfall, with rising temperatures linked to decreasing precipitation, an alarming trend in the context of increasing locust activity.

The socioeconomic survey of 90 respondents highlights that over 80% of households experienced total crop damage, with significant loan burdens and income losses during the 2020 outbreak. The dual shock of COVID19 and locust invasion amplified rural distress, revealing gaps in government relief mechanisms and pest management preparedness. The research underscores the need for integrated locust management that aligns climate data with real-time surveillance, early warning systems, and community participation. Sustainable alternatives such as botanical pesticides, remote sensing, and locust utilization for food security are explored. The study advocates for policy reforms recognizing locust invasions as natural disasters and recommends developing adaptive strategies involving all stakeholders to mitigate future risks. This work contributes to climate resilient pest control and food security planning in arid and semiarid regions of India.

Context & Problem Statement

The research addresses the issue of food insecurity resulting from locust infestations, specifically in the Rewari district of Haryana, India. It investigates how climatic factors such as temperature, rainfall, and wind speed contribute to the occurrence and intensity of locust swarms, which in turn disrupt agricultural productivity and food supply. The study focuses on understanding the link between changing weather patterns and locust outbreaks, and the cascading effects these have on local livelihoods, socioeconomic stability, and food security in rural communities through interdisciplinary tools and regional cooperation is crucial for effective, climate resilient locust management amid increasing weather extremes.

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The study focuses on understanding the link between changing weather patterns and locust outbreaks, and the cascading effects these have on local livelihoods, socioeconomic stability, and food security in rural communities . This issue is significant because locust outbreaks pose a serious threat to food systems, particularly in agrarian economies like India, where a large portion of the population depends on farming for survival. Uncontrolled swarms can destroy vast tracts of crops within hours, leaving communities without food or income. In Rewari district, such invasions have exacerbated rural poverty, disrupted livelihoods, and highlighted the inadequacy of current pest control measures. Moreover, the study underscores the urgency of developing sustainable, climate resilient strategies that can both predict and mitigate the impact of such biological threats in the future.

From a social and economic perspective, the study is rooted in the lived experiences of rural communities that have suffered crop losses due to recent locust attacks. It captures the local challenges, including loss of income, food shortages, and pressures on health and education. Environmentally, it recognizes the role of climate change in altering ecosystems and creating favourable conditions for locust breeding and migration. Politically, the research evaluates the response of government schemes and administrative interventions aimed at managing locust outbreaks, while also suggesting improvements in policy design to better protect vulnerable populations and ensure food security in the face of ecological uncertainty. Despite extensive research on locust outbreaks, key gaps persist such as the lack of integrated climate Locust models, limited socioeconomic impact analysis, untested tech interventions, and weak cross border coordination. Addressing these through interdisciplinary tools and regional cooperation is crucial for effective, climate resilient locust management amid increasing weather extremes.

Literature Review

Locusts, especially the desert locust (Schistocerca gregaria), are among the most destructive migratory pests, capable of decimating crops across large areas. Northwestern Indian states like Rajasthan, Gujarat, and Haryana are particularly vulnerable due to changing climatic conditions (Sharma, 2014). Temperature, humidity, and rainfall are key factors in triggering outbreaks. Optimal breeding conditions include 32.235°C temperatures, 3545% humidity, and moist soils aided by rainfall, which also stimulates vegetation growth (Mitra et al., 2024). Events like Cyclone Mekunu (2018) and erratic monsoons have triggered largescale breeding and swarm movement (Mitra et al., 2024b; Singh et al., 2022). The socioeconomic consequences of locust attacks are severe ranging from crop and fodder loss to food insecurity, poverty, and educational setbacks, especially among children (Friedman, 2024). In extreme cases, invasions trigger migration, social unrest, and strain on government resources through emergency pesticide campaigns and compensation (Sokame et al., 2024).

Control measures include chemical spraying (e.g., chlorpyrifos, malathion), biological agents, and cultural deterrents like waving cloths or smoke (Mehta, 2020). However, excessive pesticide use harms ecosystems, affecting pollinators, natural predators, and human health (Aggarwal, 2020; Biotic Invasions, 2000). Neem oil, a safer botanical pesticide, has shown localized effectiveness (Hartbauer, 2020). Innovative solutions, like harvesting protein rich locusts as food or feed, offer dual benefits of pest control and food security (Hussain et al., 2023). India's 2020 response involved coordinated aerial spraying and government action along breeding hotspots (Government of India, 2020). Economic analysis reveals wheat yield losses up to 12%, underlining the need for disaster recognition and crop insurance schemes (Chatterjee, 2020; Khan et al., 2023).

Overview of the Methodology

This study adopts a mixed methods approach, combining both quantitative and qualitative research to gain a comprehensive understanding of the connection between climate change, locust outbreaks, and their impacts on agriculture and food security in Rewari district, Haryana. The approach is well-suited to explore both statistical trends and the lived experiences of affected communities.

Data Collection and Location

The research focuses on three randomly selected villages within the Rewari Block of Haryana. This selection allows for targeted analysis while keeping the scope manageable. For the quantitative aspect, historical climate data (covering the period from 1979 to 2020) is sourced from credible institutions like the India Meteorological Department (IMD) and FAO Desert Locust Watch. This data helps identify long-term patterns in temperature, rainfall, and wind speed that may be linked to locust swarm occurrences. Additionally, government records and field observations are used to assess agricultural losses caused by these invasions.

Primary Data and Sampling

To capture the on-ground impact of locust attacks, interview-based questionnaires were conducted with 90 respondents across the three villages. The participants were chosen to represent diverse backgrounds in terms of social, and economic status. The survey included both closed ended questions for quick analysis and open-ended ones to explore individual experiences, allowing a deeper understanding of how locust outbreaks have affected rural livelihoods, especially when combined with challenges like COVID19.

Research Objectives

1. To analyse the relationship between climate change and locust swarm occurrence in the Indian subcontinent

2. To assess the impact of locust infestations on agricultural productivity and food security.

3. To find sustainable ways to manage locusts by combining environmental, technological, and policy strategies.

Research Questions

1. How do climatic factors (temperature, rainfall, wind patterns) influence locust outbreaks?

2. What are the socioeconomic consequences of locust invasions on farmers and food supply chains?

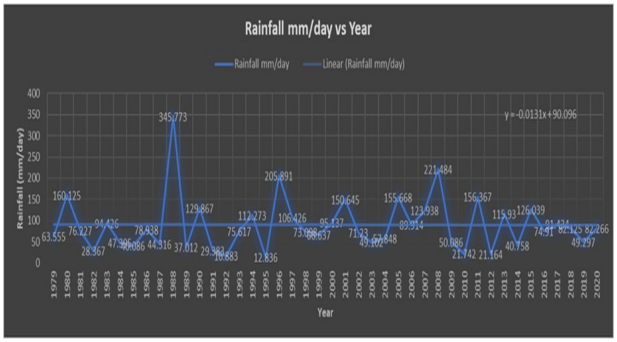
3. How effective are current locust management strategies?

Figure 1: Trend Analysis Graph of Rewari District (Reinafall vs Year)

Findings and recommendations

Trend analysis of the historical rainfall data (19792020) for Rewari, Haryana

Rainfall Trend Analysis: Rewari (19792020)



Key Observations :

Long-term Decline: The linear trend line equation: $y = -0.0131x + 90.096$

This indicates a gradual decline in average daily rainfall (mm/day) over time, pointing to a drying trend in the region.

Qualitative Component Data Analysis Tools and Justification

Data from primary surveys were organized and analysed using Microsoft Excel, leveraging tools such as PivotTables, charts, and regression models to explore relationships between variables. Statistical methods including trend analysis, correlation,

and nonparametric tests were applied to assess patterns and make projections. The use of Excel made it easier to visualize data and detect anomalies. This methodology is appropriate for the research as it balances data driven analysis with humancentric insights, ensuring that both climatic trends and community impacts are addressed comprehensively.

High Variability: Extreme peaks in certain years (e.g., 1988, 1996, 2006). Multiple years with low rainfall (e.g., 19841986, 19911994, 20152020). This pattern suggests inconsistent monsoon behaviour with occasional rainfall surges surrounded by dry years.

Recent Decade (20102020): Mostly below average rainfall. 2013 and 2014 had moderate spikes, but the years after show drought prone conditions.

Rainfall Locust Outbreak Relationship: Desert locust swarms (Schistocerca gregaria) are sensitive to rainfall patterns, especially in arid and semiarid zones. The Rewari rainfall trend contributes to locust risk in the following ways:

Declining Rainfall (Aridification):

- Creates semiarid landscapes, which are ideal for desert locust migration.
- Vegetation becomes patchy, making locusts more mobile and prone to swarm behaviour.

Sporadic Rainfall Spikes: Occasional heavy rains cause rapid greening and growth of grasses/weeds ideal for:

- Egg laying
- Nymph development

Years like 1988, 1996, and 2006, which saw rainfall spikes, may have triggered breeding grounds when followed by warm temperatures.

Rainfall After Drought:

- Long dry spells followed by sudden rain (common in the graph) stimulate egg hatching.
- This creates a "boombust" ecological cycle, perfect for swarm escalation if not checked.

Implications for Agriculture and Locust Management

- The drying trend weakens crop systems and reduces resilience to pests.
- Sudden rainfall increases surprise locust outbreaks, especially pre-monsoon or early monsoon.
- These rainfall anomalies in an increasingly dry climate make Rewari a climate sensitive hotspot for nontraditional locust invasions.

Inference:

The historical rainfall data of Rewari reveals a clear trend of declining and erratic rainfall. This evolving pattern:

- Supports desert-like conditions, ideal for locust transit and feeding.
- Promotes episodic vegetation booms, which act as breeding triggers.
- Enhances the ecological vulnerability of the region to locust swarms, especially when combined with rising temperatures and favourable winds.

Action Needed: Monitoring such rainfall trends is crucial for forecasting locust risks, and integrating this data into early warning systems can prevent agricultural damage in Haryana and beyond.

Temperature and Wind Speed vs Year graph for Rewari (19792020).

Temperature (°C) Trend:

Graph Line Colour: *Blue*

Trendline Equation*: y=−0.0251x+41.888y = 0.0251x + 41.888*

Observation:

- The temperature shows a slight negative slope, indicating a marginal downward trend.
- However, the trend is largely flat, and the temperature stays within the high range of ~3845°C, suggesting persistent heat, especially during pre-monsoon and summer seasons.
- A visible outlier dip around 1987 may be due to data error or climatic anomaly.

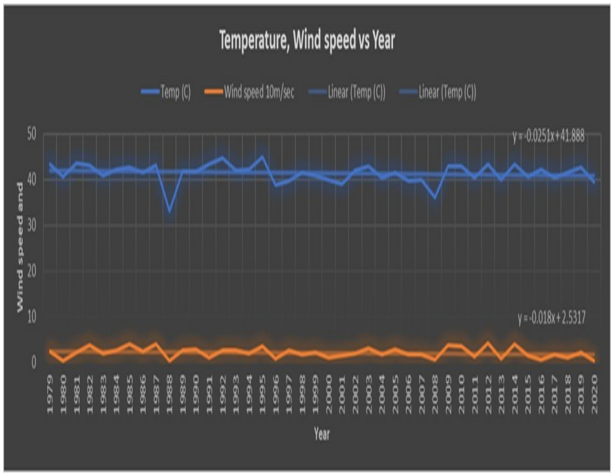


Figure: Trend Analysis Graph of Rewari District (Temperature and Wind Speed vs Year)

Wind Speed (10 m/sec) Trend:

- ***Graph Line Colour:*** *Orange*
- ***Trendline Equation:*** $y=-0.018x+2.5317$
- ***Observation:***

- *T*he wind speed shows a slight declining trend.

- Despite the downward slope, peaks in wind speed are visible in certain years (e.g., 1988, 2011, 2014), indicating intermittent strong wind events.

- Average wind speeds remain above 2 m/s, which can significantly influence locust movement and swarm dispersal.

Climatic Influence on Locust Activity

Role of Temperature:

Desert locusts flourish in hot, dry conditions, with optimal breeding and development occurring at temperatures between 3542°C. In regions like Rewari, consistently high pre-monsoon temperatures can prepare locusts for swarming, especially if followed by rainfall.

Role of Wind Speed:

Locust movement is highly dependent on wind. Strong and sustained winds enable long-distance travel, while sudden gusts can either disperse or introduce swarms. Although the overall wind trend is declining, occasional high wind years facilitate sudden migratory events into regions like Rewari.

Combined Climatic Interaction:

The combination of warm, dry weather, episodic strong winds, and prior rainfall creates ideal conditions for locust breeding, migration, and crop damage.

Conclusion:

Rewari's Suitability for Locust Activity Despite slight downward trends in temperature and wind speed, Rewari's climate remains favourable for locust activity due to persistent high temperatures, episodic wind bursts, and erratic rainfall, making it increasingly vulnerable under shifting pre-monsoon patterns.

Recommendations

Adopt early warning systems integrating real-time temperature and wind data with forecast models. Emphasize surveillance from April to June, when locusts are likely to arrive and conditions are conducive to their spread.

1. Correlation Analysis: Temperature, Wind Speed, and Rainfall (19792020)

Locust outbreaks, particularly those involving Schistocerca gregaria (desert locust), are profoundly influenced by climatic variables such as rainfall, temperature, and wind. Understanding the trends and

- Correlation Matrix Interpretation
- The correlation matrix contextualizes the relationships between temperature, wind speed, and rainfall in the Rewari region (19792020) and ties them into broader climatic and ecological implications.
- Inter-relationships among these variables is critical to assessing vulnerability and forecasting locust invasions. This analysis examines the long-term patterns of these climate indicators in Rewari, Haryana, and analyses their potential role in shaping locust activity in the region.

Correlation Matrix Interpretation

The correlation matrix contextualizes the relationships between temperature, wind speed, and rainfall in the Rewari region (19792020) and ties them into broader climatic and ecological implications.

From an agricultural standpoint, these trends pose a growing threat to food security and rural livelihoods. The findings underscore the urgent need for integrated climate risk assessments and robust locust early warning systems, particularly during the premonsoon period, to mitigate emerging threats in nontraditional invasion zones like Rewari.

Correlation Matrix: Temperature, rainfall and wind speed

	Temp (°C)	Wind Speed (10m/s)	Rainfall (mm/day)
Temp (°C)	1.000	0.667	**0.885**
Wind Speed (10m/s)	0.667	1.000	0.622
Rainfall (mm/day)	0.885	0.622	1.000

Interpretation:

- **Temp & Rainfall:** Strong negative correlation (0.885) - as temperature increases, rainfall tends to decrease.
- **Temp & Wind Speed:** Moderate positive correlation (0.667) - higher temperatures are associated with higher wind speeds.
- **Wind Speed & Rainfall:** Moderate negative correlation (0.622) - stronger winds tend to accompany lower rainfall

Temperature and Rainfall (r = 0.885)

There is a strong negative correlation between temperature and rainfall. This implies that as temperatures rise, rainfall tends to decline in the region.

- **Implication:** Warming conditions, potentially driven by climate change or urbanisation, are likely contributing to reduced precipitation levels. This could lead to drier soil conditions, water scarcity, and reduced crop yields in the agricultural district of Rewari.
- **Locust linkage:** Higher temperatures and lower rainfall can create favourable breeding grounds for desert locusts, especially when followed by sudden rain events that stimulate vegetation growth.

Temperature and Wind Speed (r = 0.667)

A moderate positive correlation is observed between temperature and wind speed. Temperature increases are generally associated with stronger wind speeds.

- **Implication:** Warmer air masses tend to rise, creating pressure differences that increase surface wind activity. These winds may aid the spread of pests and crop diseases, including facilitating locust migration from neighbouring regions.
- **Locust linkage:** Stronger winds, when combined with elevated temperatures, enhance the mobility and range of desert locust swarms, helping them reach inland regions like Rewari that are not traditionally affected.

Wind Speed and Rainfall (r = 0.622)

A moderate negative correlation exists between wind speed and rainfall. As wind speeds increase, rainfall tends to decrease.

- **Implication:** High wind speeds are commonly associated with dry atmospheric conditions or the movement of storm systems that do not deposit significant precipitation locally.
- **Locust linkage:** Lower rainfall accompanied by strong winds supports arid conditions conducive to locust breeding, while also enabling long distance swarm travel. This contributes to the risk of locust incursions into low rainfall zones like Rewari.

Over the past four decades, Rewari has experienced a gradual shift toward a warmer, drier, and windier climate. These evolving conditions marked by declining but sporadic rainfall, persistently high temperatures, and intermittent strong wind shave collectively increased the region's ecological suitability for desert locust invasions. Such climatic dynamics weaken the natural rainfall support system while amplifying the risk of locust outbreaks, particularly during years marked by anomalous weather patterns.

From an agricultural standpoint, these trends pose a growing threat to food security and rural livelihoods. The findings underscore the urgent need for integrated climate risk assessments and robust locust early warning systems, particularly during the premonsoon period, to mitigate emerging threats in nontraditional invasion zones like Rewari. Strengthening surveillance and response frameworks is essential to safeguard both the environment and the socioeconomic fabric of the region.

2. Findings of a Survey conducted in 3 villages of Rewari Block in Rewari district of Haryana.

Three villages, Aakera, Balaswar Ahir and Alwalpur, were chosen for a field survey to assess the impact of locust infestations on agricultural productivity and food security, to understand the socioeconomic consequences of locust invasions on farmers and food security and to understand the effectiveness of the current locust management strategies. The primary occupation of the villagers is agriculture, and a key source of their household incomes as well. Majorly, Wheat, Cotton, Mustard, Bajra, Jowar, Gram (Chana) and Maize are the crops which are currently cultivated in these three villages. These crops are severely affected due to locust attack. The landholding size ranges between 0.60 ha. to 2.1 ha. The recent locust attack happened in 2020 which was a Covid19 year, and farmers faced dual hardships as their livelihoods and socioeconomic conditions were severely impacted.

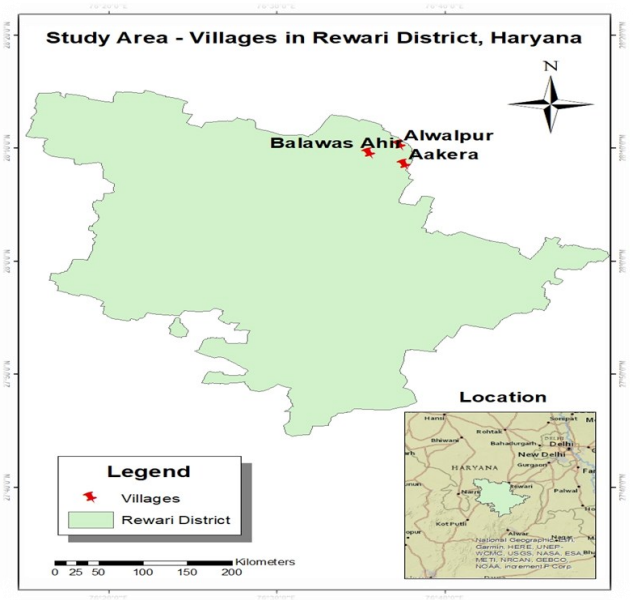


Figure 3: Map of three villages of Rewari District, Haryana where survey was conducted.

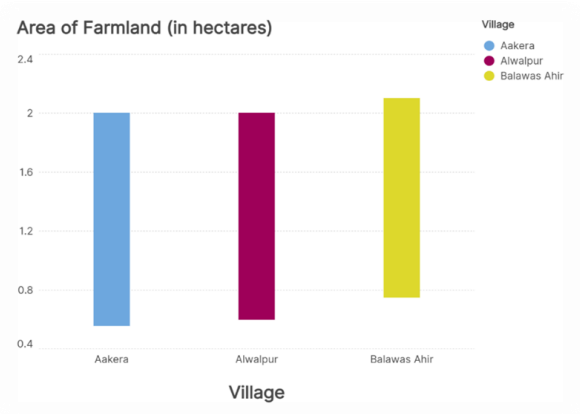


Figure 4: Land holding range of three village

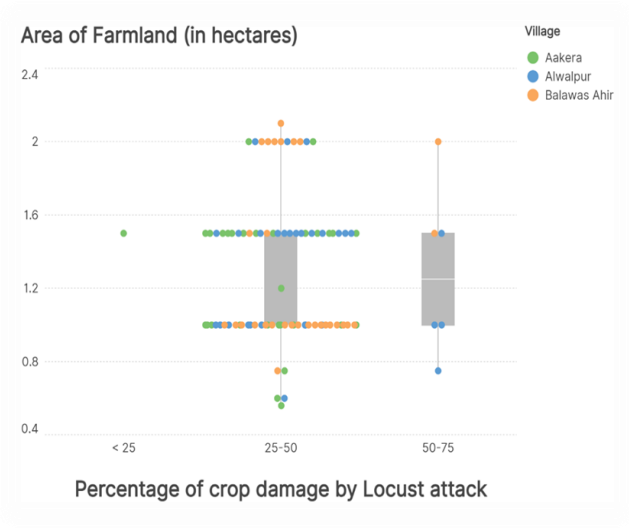


Figure 5: Boxplot of Land holding and % loss. Most of the damage (2550%) has occurred in all three villages. < 25 only in Aakera.

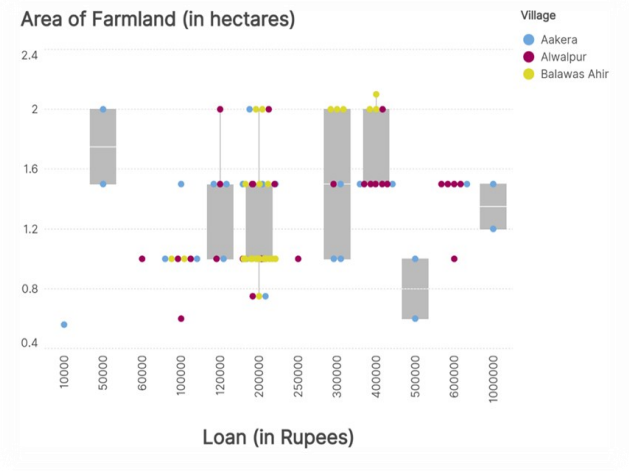


Figure 6: Boxplot of Land holding and Loan amount

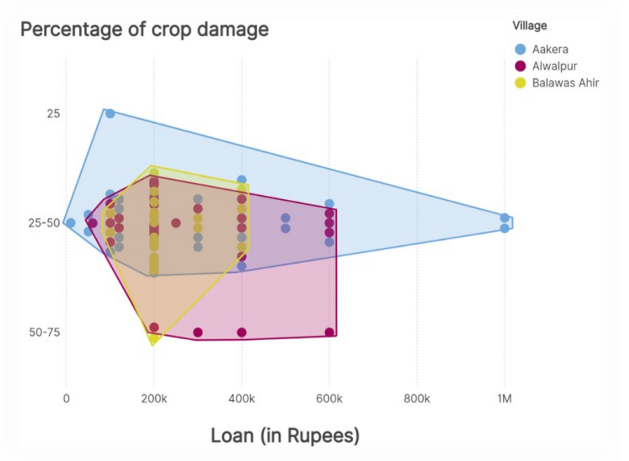


Figure 7: Percentage of Crop damage vs Loan money taken

Aakera village had the widest range of loan amount 10k to 1 million, and land holding as well. Alwarpur village loan range varied between 60k to 600k with land holding up to 2 ha., and in Balawas loan amount varied between 40k to 400k with land holding more than 2 ha. The relation between land holding and loan amount was found weakly related (R square= 0.04, $F(1, 85) = 4.216376$, $p < 0.05$)

The polygon method analysis depicts that Aakera village's crop damage was up to 50% but loan amount was maximum (1 million). Alwarpur suffered greater loss than Akera (up to 75% crop) but their loan amount was up to 600 K and Balawas Ahir village suffered like Alawarpur but their loan amount was up to 400k.

The survey findings indicate that a significant majority of respondents (80%) reported that the locust attack completely damaged their crops. Additionally, 8.9% of respondents experienced heavy crop loss, while an equal proportion (8.9%) stated that their household income was heavily affected. A smaller percentage, 1.1%, reported that their livelihood was severely affected, and another 1.1% fell below the poverty line due to the impact of the locust attack and COVID19 situation. These results highlight the widespread agricultural damage and the varying degrees of economic hardship experienced by affected households.

The analysis reveals that in Aakera village, farmers with land around 1.6 hectares experienced crop damage ranging from severe to complete loss and livelihood was heavily affected. In Alwalpur, although most farmers had similar land size (1.41.6 ha), the impact varied from falling below the poverty line to complete crop loss. Balawas Ahir farmers, with relatively smaller land areas (~1.2 ha), mostly faced complete crop damage and livelihood disruption, but fewer reported falling below the poverty line.

88.9% of households were severely affected and 11.1% were moderately affected by locust attacks. During the interactions with respondents, it was found that the traditional methods such as firecrackers, beating utensils and making loud noises were more effective than pesticide usage. It was economically also more effective as does not require monetary investment. Although Govt. aided in pesticide availability, but it was not appropriate.

Farmers had to take loans to deal with dual impact of Covid19 and locust attack. The survey also highlights the lack of disbursement of monetary compensation to the farmers for locust attack. The administrative machinery could not provide effective solutions and aid other than pesticide spraying at few locations. Farmers had to deal with the menace on their own. Effective government intervention is required to understand the damage caused and declare it as an agriculture emergency. Administrative guidance, early warning system, preparedness and a robust plan to deal with the situation is important.

Conclusion

In recent years, the fight against locust outbreaks has advanced through a mix of traditional knowledge and innovative solutions. Scientists and policymakers are increasingly relying on technologies such as remote sensing, GIS, and GPS to track and predict locust movements with greater precision. . Alongside these tools, there's growing interest in environmentally friendly approaches, such as using natural fungi like Metarhizium acridum to infect and reduce locust populations without harming other organisms (Riaz and Hakeem, 2024).

These strategies offer promising alternatives to chemical pesticides, which often come with serious ecological side effects. Moreover, researchers have studied how locusts damage crops and are working on sustainable control techniques to limit the scale of destruction. Together, these efforts represent a shift toward smarter, greener, and more coordinated management of one of agriculture's oldest threats.

A ray of hope is seen in the opportunity to use Locust as feed for fulfilling protein requirement of the population in order to combat food insecurity. Effective and timely administrative action by tracing locust migration paths by use of drones, spraying of pesticides and disbursement of monetary compensation can create a robust mechanism to deal with this menace. Predictive climate modelling to understand and trace the next occurrence of attack can help better preparedness. Climate change is the main cause of shift in temperature and precipitation pattern which affects the locust's migration across the world.

The shift from traditional dryland cultivation of crops towards cash crops has also led to severe damage of crops. This resulted in food insecurity, economic losses, socio economic consequences and causing livelihood damages. An integrated approach to find solutions by keeping all stakeholders like farmers, locals, government, international organisations, scientists and academicians in consensus can help tackle this issue of locust attack. The field of research is open to new solutions and management strategies.

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Beyond Antibiotics: In Silico Discovery and Enzymatic Insights for H. pylori Eradication

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Executive Summary

Helicobacter pylori is a spiral-shaped, gram-negative bacterium which grows in the mucus layer that coats the inside of the human stomach. It is a considerable burden to public health; infections acquired in childhood can lead to chronic diseases, including gastric ulcers and cancer. The transmission route of this bacterium is poorly understood, but it generally subsists in water (contaminated) and in poor sanitation conditions. There are no exclusive drugs to eradicate H. pylori, but the multidrug gold-standard treatment achieves eradication rates of over 90%. Healthcare is one objective of the United Nations' Sustainable Development Goals. Using biotechnological applications, pathogenic organisms and their protein structures can be studied and brought to use in the healthcare of humankind. The Gmhc (also referred to as HldE, D-beta-D-heptose 7-phosphate kinase) is a protein in the lipopolysaccharide (LPS) biosynthesis layer, primarily part of the Heptose synthesis (ADP-d-glycero-β-d-manno-heptose) pathway in H. pylori. The research focuses on blocking the function of this protein, which will truncate the LPS, resulting in control of the growth of H. pylori. The protein has been studied both in vitro and in silico. A certain new approach was taken by using antimicrobial peptides as the molecules to block the activity of gmhc, by docking these AMPs to the active site of the protein receptor. With the increasing antibiotic resistance, this new approach combats the former problem.

Context & Problem Statement

Helicobacter pylori is a gram-negative spiral bacterium that causes peptic ulcer disease and is associated with an increased risk of gastric cancer. It is the sixth most prevalent cancer in the world and the third leading cause of cancer death. (Rajendran and and Ponnuraj, 2024). In this study, gmhc (D-beta-D-heptose 7-phosphate kinase) HP0858, an enzyme involved in the biosynthesis of lipopolysaccharides that encourages bacterial adherence, self-aggregation. gmhc is a bifunctional enzyme; it acts as a kinase and adenyltransferase. It is a dimeric protein, part of the Heptose synthesis pathway of the core oligosaccharide in the lipopolysaccharide layer of Helicobacter pylori . This pathway has four proteins: gmhA, HldE, and gmhB. This pathway is present in almost all Gram-negative bacteria, as they require heptose sugars in the inner core of their LPS. H. pylori appears to use mainly its Cag type 4 secretion system (CagT4SS0 to also mediate the transfer of heptoses into human gastric epithelial cells and monocytes/macrophages, while Enterobacteriaceae (Shigella and Yersinia) may also enlist T3SS for a similar purpose. The impact of H. pylori resistance on patients' treatment failure is a major concern. Therefore, the development of novel or alternative therapies for H. pylori is urgent. Generally, Antimicrobial peptides (AMPs) are short peptides consisting of 10–60 amino acids with an overall positive charge (generally +2 to +9) and have a substantial proportion of hydrophobic residues (>30%) These characteristics of AMPs (amino acid sequences, net-positive charge, amphipathicity, and very small size) allow APMs to bind to and disrupt the membranes of microorganisms. When we block the activity of gmhc, the LPS layer formation gets disturbed. We have studied the in silico as well as in vitro properties of this protein for a better understanding. The exclusive work with antimicrobial peptides and their compatibility has

also been studied and checked against the gmhc, which acts as a receptor for these peptides. The selected peptides are naturally occurring and have the potential to block the gmhc enzymatic activity. This research can be carried forward by in vitro synthesis of these selected antimicrobial peptides and testing them against the H. pylori culture, to check the minimum inhibitory concentration. Even further to increase the binding affinity, mutations can be generated in gmhc. The advent of in silico methods of bioinformatics, molecular docking, and molecular dynamics simulation provides an extraordinary advancement in the field of drug discovery. These molecular approaches enhance our knowledge regarding biological pathways of protein-peptide, protein-protein, or protein-ligand complexes, which provide insights into the mechanisms of novel interactions. Molecular docking helps scientists to predict the best binding patterns and interactions between compound complexes.

Literature Review

Most strains of H. pylori produce virulence factors that have developed to influence host cell signalling pathways. Among the many distinctive traits of H. pylori, its remarkable ability to survive for decades in the challenging gastric environment due to the host's failure to eradicate the infection is particularly noteworthy. Unlike other viruses and bacteria, H. pylori has developed the capacity to thrive in the stomach's highly acidic environment by converting urea into ammonia through urease, which creates a neutral zone around the bacterium. Current evidence supports the idea that H. pylori has lived alongside humans for tens of thousands of years, with genetic research suggesting that humans have harboured H. pylori for at least 58,000 years (Chmiela et al., 2014). Currently, half of the world's population is infected with this infection. Most people do not show any symptoms. ("Helicobacter pylori (H. pylori) and Cancer - NCI," 2013; Chmiela et al., 2014; Linz et al., 2007; McArthur et al., 2005).

Lipopolysaccharide (LPS) is crucial for the virulence associated with H. pylori infection. LPS is a significant element of the outer membrane in Gram-negative bacteria, typically regarded as toxic and possessing strong immune-modulating and immune-stimulating effects.

Alexander Fleming identified lysozyme in 1922, which initiated the advancement of modern innate immunity. Since that time, antibiotics and antimicrobial peptides (AMPs) have been discovered. The sources of AMPs can be divided into mammals (human host defence peptides account for a large proportion), amphibians, microorganisms, and insects according to statistical data. The docking of such complexes can be performed using various online servers like Cluspro, HDOCK, Hawkdock, Patchdock and so on. Peptide-mediated interactions are attracting growing interest because of their crucial roles in various regulatory processes characterised by dynamic protein interactions.

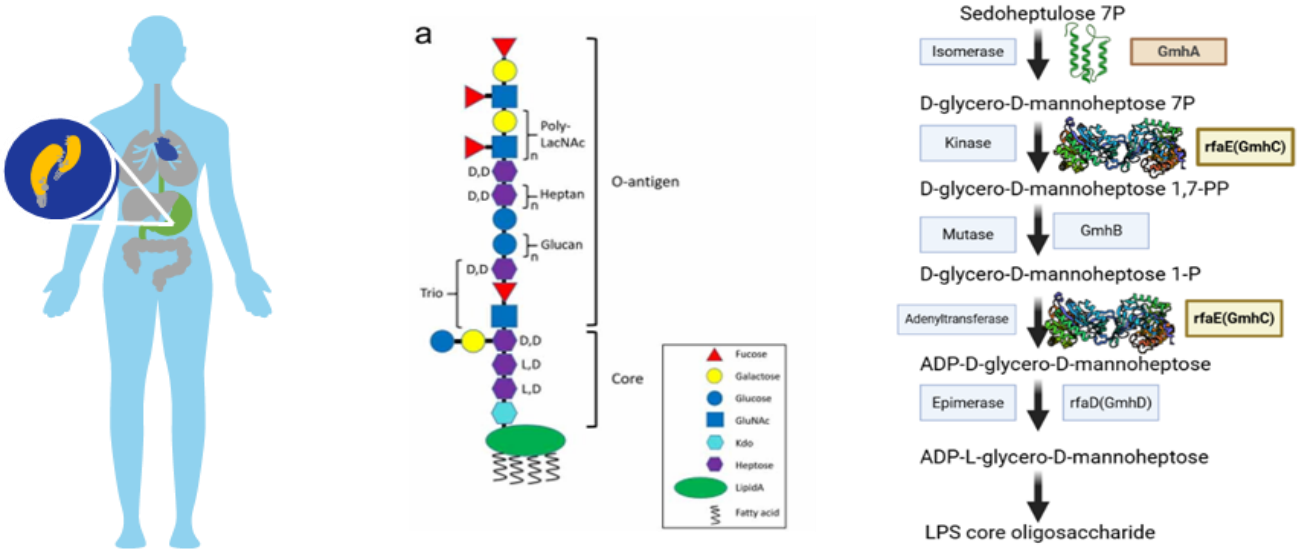


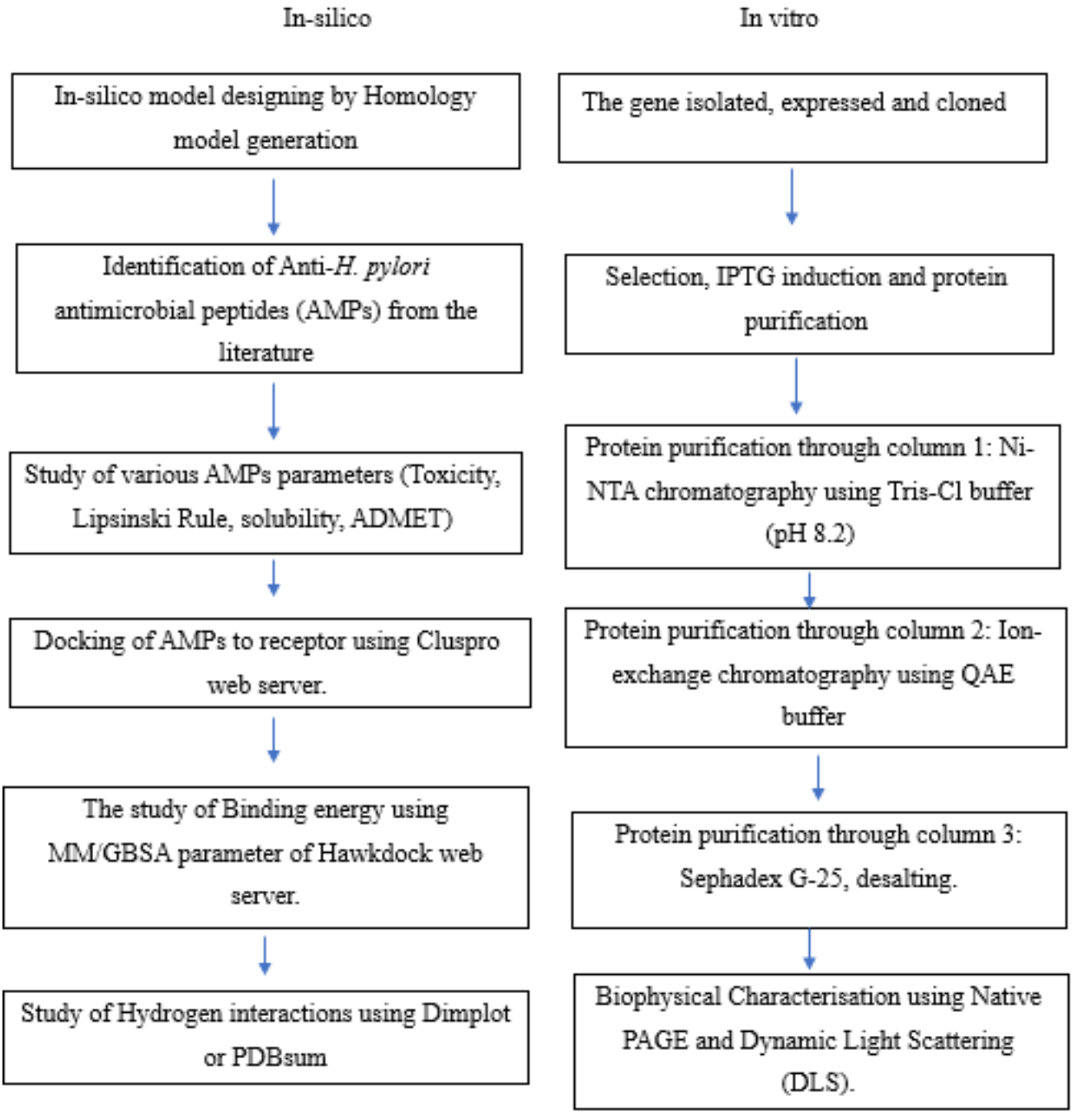
Figure 1 The human stomach infected with H. pylori a) shows the LPS layer of H. pylori, wherein our focus in on the L-glycero D-mannoheptose molecule, which gets synthesised by using Heptose synthesis pathway, represented in right side, where the gmhc enzyme is the focus of study.

The structures of these interactions offer a valuable foundation for their characterisation and manipulation and can serve as a basis for designing targeted inhibitors. The limited number of experimentally determined structures of peptide-protein complexes can be supplemented by a surge of modelling techniques that have emerged in recent years, demonstrating enhanced accuracy and relevance to an expanding range of systems (London et al., 2013).

Research Focus and Methodology

The main objective of the study was to computationally study the bifunctional enzyme gmhc from H. pylori and check the blocking efficiency of antimicrobial peptides when targeted against the gmhc as a receptor. Secondly, in vitro, this gene has been isolated, cloned and expressed into pET28a (+) vector; further, the protein was isolated and studied for biophysical properties.

The methodology for in-silico and in-vitro is as shown in the flowchart.



Key Findings:

Table 1: The sequence template for homology model

PDB ID	Organism	Seq identity (%)	Coverage	QMEAN	Reference
4e8y	*Bukholderia cenocepacia*	42.36	0.62	0.52	Lee et al.,2012
4e8z		39.80	0.65	0.52	
4e8z		39.80	0.65	0.51	

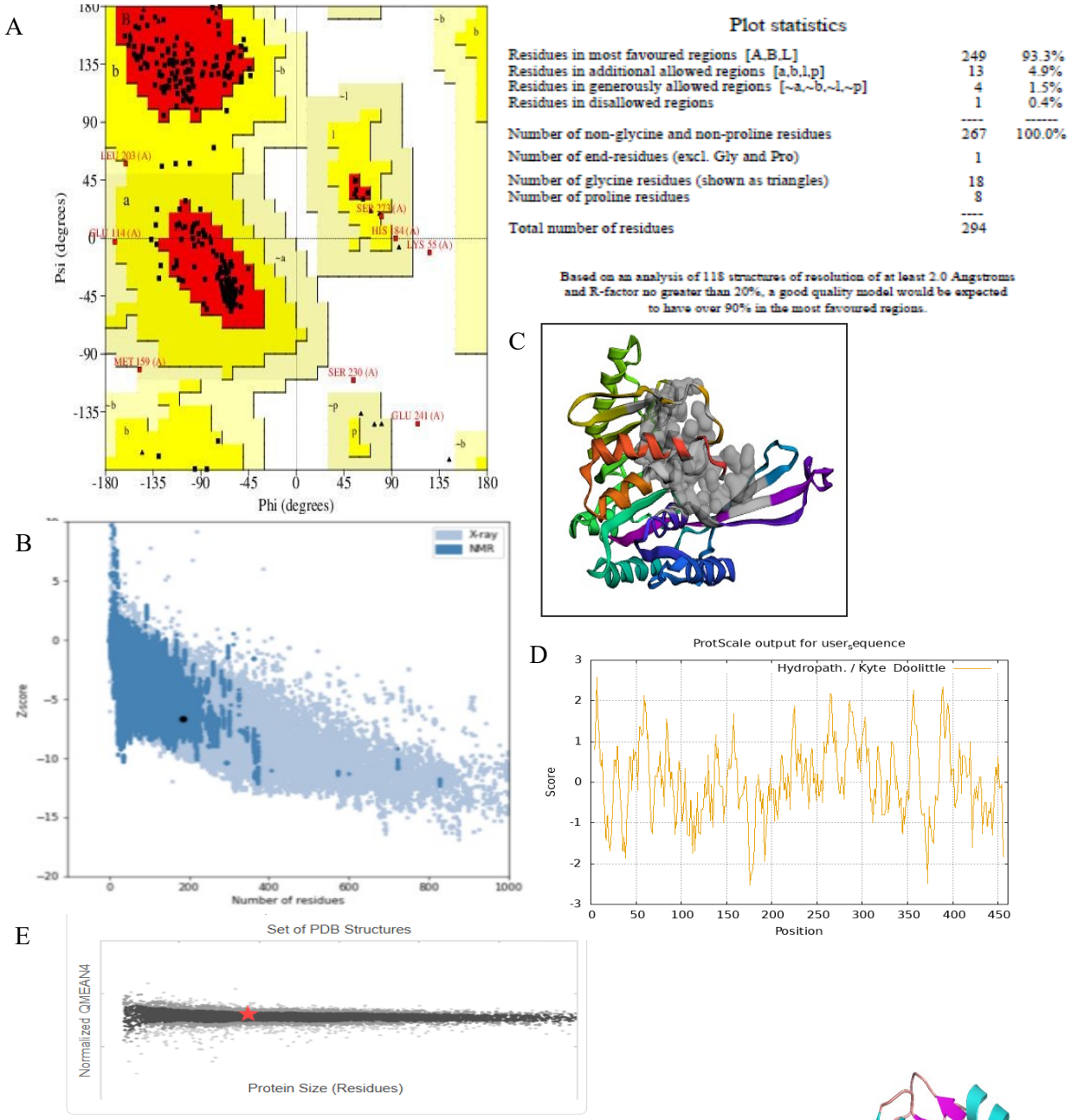


Figure 2 A: The validation of model using Ramachandran Plot. B: The Z Score plot indicating the model representation in present experimental data using ProSA web server. C: The active site prediction using CastpFold server. D: The solubility of protein using kyte and Doolittle paramter in Protscale web server and E: QMEAN score analysis using Expasy, which indicates that the qualitative mean energy of structure is stable.

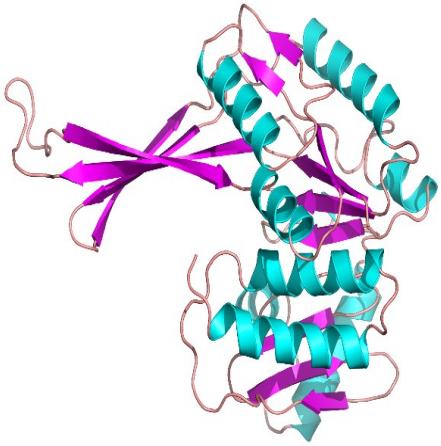
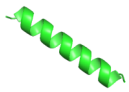
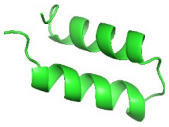
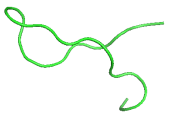
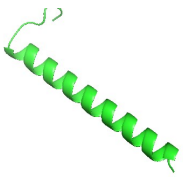


Figure 3: Homology model of gmhc based of 4e8y

Identification of Antimicrobial Peptides (AMPs)

Table 2: AMP selected via literature review to target H. pylori and gram-negative bacteria

Name of Antimicrobial Peptide	Sequence	3D Model	Reference
HF-18	GFFKKAWRKVKKAFRRVL		(Zhou et al., 2022)
Snakin1	GSNFCDSKCKLRCSKAGLADR-CLKYCGICCEECKCVPSGTYGNKHE CPCYRDKKNSKGKSKCP		(Mustafa et al., 2022)
EcAMP1	GSGRGSCRSQCMRRHEDEPWRV-QECVSQCRRRRGGGD		(Mustafa et al.,
SP1-1	RKKRLKLLKRLL		(Dangel et al., 2013)
Pexiganan	GIGKFLKKAKKFGKAFVKILKK		(Neshani et al., 2019) (Ge et al., 1999)
Bulgaricin BB18	KIYRGNVGHCGKSTVDWG-TAIGNGNNAASFL		(Simova et al., 2009) (Neshani et al., 2019)
Bicarinalin	KIKIPWGKVKDFLVGGMKAV-		(Rifflet et al., 2012) (Neshani et al., 2019) (Guzman et al., 2017)
Soly C	FSGGNCRGFRRRCFCTK		(Rigano et al., 2012) (Neshani et al., 2019)
Human cathelicidin LL-37	LLGDFFRKSKEKIGKEFKRIVQRIK-DFLRNLVPRTES		(Leszczyńska et al., 2009) (Neshani et al., 2019)

The docking of all the above AMPs with the target receptor gmhc was performed using the ClusPro server. The top five models were chosen from the server, based on the docking score. For the selection of the best pose, the selected model was analysed using the MMGB/SA parameter of the Hawkdock server. The MMGB/SA score was calculated the energy parameter of the basis of vander Waals interactions, electrostatic bond, Gibbs energy and surface area.

The above table states that **Snakin and EcAMP1** are the most appropriate AMPs, which block the activity of the gmhc receptor in *H. pylori.* The hydrogen bonds were obtained through the PDBsum server. The active sites of the gmhc receptor were stated from the CASTpFold server and literature review. The protruding twisted β-sheet has high electron density due to which is characterised as the active site for binding of the molecule (Lee et al., 2013). In Castpfold pocket Id 1, having a surface area of 769.917 and volume 931.412 considered the active site. In case of Snakin AMP, the amino acid residue common to the active site in gmhc receptor are Ser230, Arg192, Lys250, Glu231, Gly257, Asp13, Arg100, Arg110, whereas in case of EcAMP1, the common residues in active sites are Arg192, Ser230, Glu231, Thr256, Arg100, Arg110. These residues are present in the shallow of the twisted β parallel sheets present in the gmhc 3D model. Hence, the Snakin and EcAMP1 successfully block the activity of gmhc, resulting in the truncation of the LPS layer of H pylori.

Table 3 Keystone table with all the energies of AMP obtained from Hawkdock and No. Of hydrogen bonds from the PDBsum server.

AMPs	VDW	ELE	GB	SA	Total	No. of H2 bonds
HF-18	-69.87	-497.54	523.72	-9.16	-47.85	7
Snakin	-155.43	-949.21	1006.93	-21.54	-119.24	21
EcAMP1	-101.13	-699.79	719.48	-15.05	-96.49	23
SP1-1	-52.28	-536.39	556.55	-8.03	-75.03	17
Bicarinalin	-81.82	-522.72	549.5	-11.17	-66.76	11
Pexiganan	-81.34	-621.79	647.45	-10.88	-66.35	5
Soly C	-97.04	-710.65	729.41	-15.37	-93.64	12
Cathelicidin	-133.46	-786.68	844.04	-19.93	-96.03	18
Bulgarcin	-112.68	-323.44	370.19	-15.99	-81.93	15

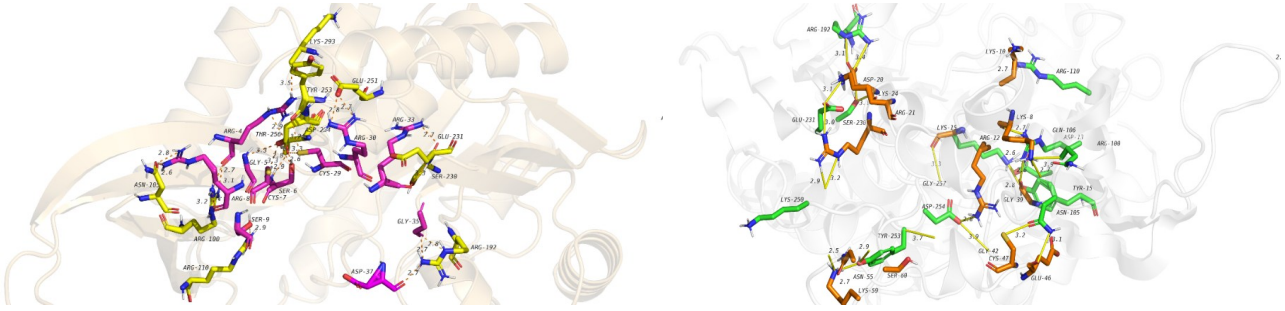


Figure 4 A) Top: The docked model Snakin and gmhC using Cluspro. B) Bottom: The docked model of EcAMP1 and gmhc using Cluspro.

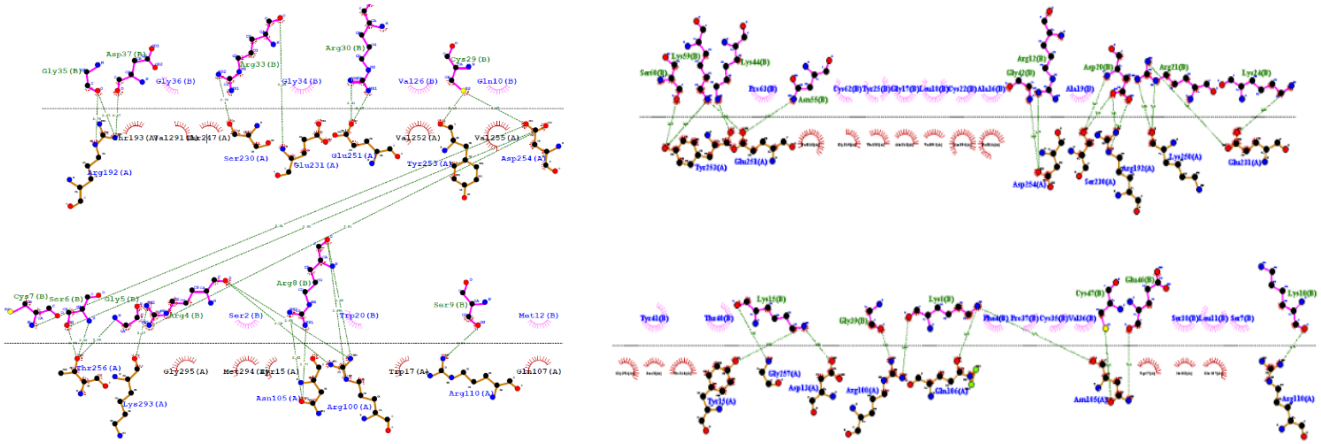


Figure 5 a) Left side: The dimplot showing hydrogen interactions between EcAMP1 and gmhc b) Right: The dimplot showing the hydrogen bond interaction between Snakin and gmhc chain A: Receptor, whereas chain B: Peptide

Purification of gmhc

The protein was successfully purified using Ni-NTA chromatography, ion exchange and desalting experiments. After passing the protein through 3 different columns, the purified protein was obtained.

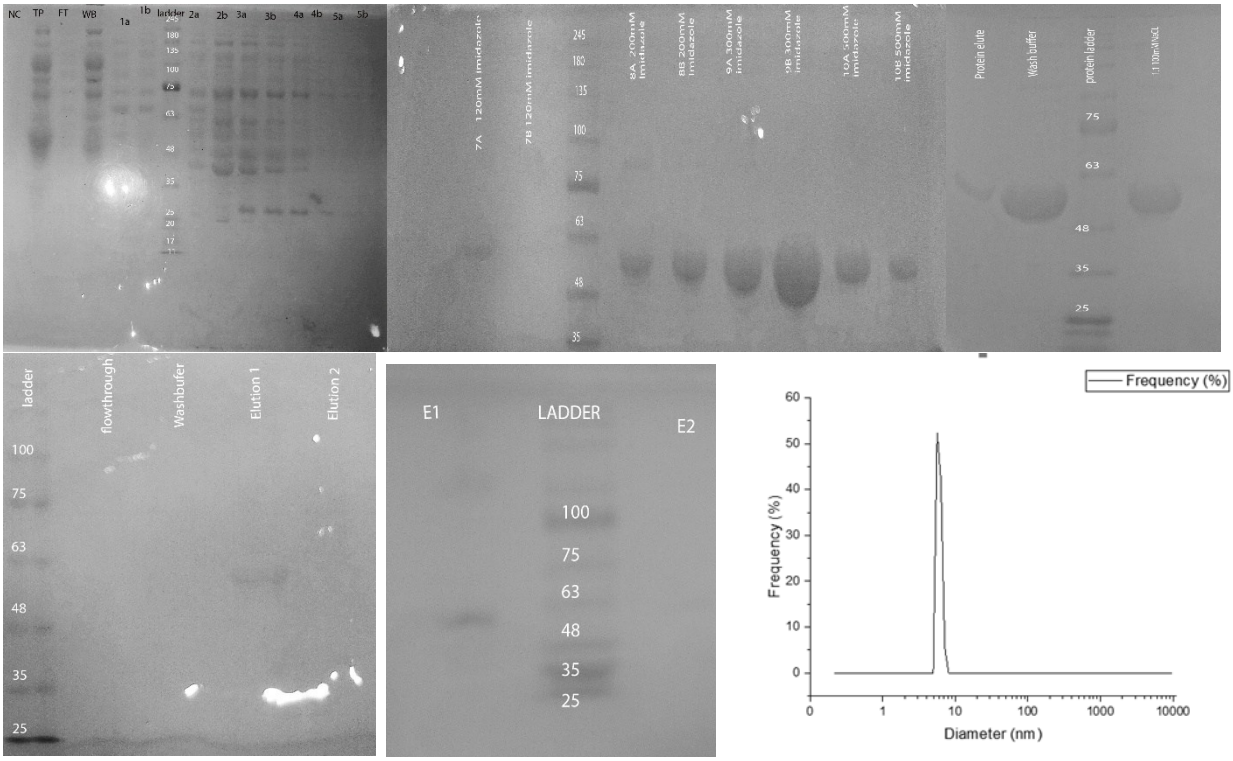


Figure 6 A: The Ni-NTA gel images using Tris-Cl (pH 8.2) buffer. B: The ion-exchange gel image using QAE buffer. C: Sephadex G25 column used for desalting. D: The native PAGE image. E: The DLS graph result, which shows that only a particle is present, as the graph is monodisperse.

To check the oligometricity of the gmhc, native PAGE was studied, which gave a result that the protein is a dimer, but as the concentration of the other band was less, it can be stated that the protein is a monomer. Other experiments need to be performed to confirm the oligometricity of the gmhc; therefore, a Dynamic light scattering experiment was performed. Based on the calculations, are mean is 5.691±0.09nm, whereas the Standard deviation is 0.4680. The Standard error is 0.095538. The Polydispersity Index is 0.006762, which states that the particle is highly monodisperse. 20 different runs were carried out using a single sample of purified gmhc, based on which mean, standard deviation. and Polydispersity index were calculated. Hence, gmhc is a monomer, based on the data of DLS. 5.69 +0.09 nm and Pdi (polydispersity index) is 0.0067 (=< 0.1) and monodisperse.

Conclusion:

This protein is part of the L, D-heptose synthesis pathway, which is an important part of lipopolysaccharide (LPS). Any blockage in the heptose synthesis can lead to truncation in the LPS layer of gram-negative bacteria or *H. pylori*. Hereby, in silico, gmhc homology model was designed as the target receptor. A certain new approach was taken by using antimicrobial peptides as the molecules to block the activity of gmhc, by docking these AMPs to the active site of the protein receptor. EcAMP1 and snakin were selected as the drug molecules which to their rigid binding energy property. **Snakin and EcAMP1** have also been studied before to work against other *H. pylori* proteins. In vitro, the transformed cells were provided for the purification of the protein. The induction of the recombinant protein, gmhc, was carried out by the addition of IPTG. Further, the protein was successfully purified using Ni-NTA chromatography, ion exchange and desalting experiments. After passing the protein through 3 different columns, the purified protein was obtained. The functional studies of the gmhc are a further study to be done. The biophysical properties can also be checked via various studies like NMR, DSA (Differential scanning calorimetry) and many more. The enzymatic studies of gmhc are another step ahead. To increase the efficiency of binding of AMPs, mutations can be created in the receptor gmhc. The peptides can be synthesised and tested in the lab on the H. pylori. Thus, the effective AMP can be experimentally tested on the model organism. In-vitro mutations can be generated in the receptor molecules, leading to a change in the activity of the protein and binding ability of the AMPs.

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