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Climate migration and urban governance in India: policy challenges, social vernerability and institutional responses

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Abstract — Climate-induced mobility is emerging as an important governance concern in India as droughts, floods, extreme heat, coastal hazards, and livelihood instability increasingly interact with existing patterns of internal migration. This study examines climate migration not merely as population movement, but as a multidimensional urban governance problem involving housing insecurity, employment vulnerability, health exposure, access to basic services, and institutional preparedness. A major research gap lies in the limited integration of climate-risk indicators, migrant vulnerability characteristics, and city-level governance capacity within a unified analytical framework for Indian urban areas. To address this gap, the study proposes an artificial-intelligence-assisted Climate Migration Governance Vulnerability Framework capable of identifying migrant-receiving urban areas where climatic exposure and institutional deficits may reinforce social vulnerability. The framework conceptualises vulnerability through environmental exposure, livelihood sensitivity, housing conditions, health and service accessibility, social protection coverage, and municipal response capacity. Machine-learning-based risk classification is proposed to distinguish urban areas with relatively low, moderate, high, and critical climate-migration governance pressures while maintaining interpretable indicators for policy use.

Keywords — Climate Migration, Urban Governance, Social Vulnerability, Climate Adaptation, Internal Migration, Artificial Intelligence

Introduction

Climate change is increasingly influencing patterns of human mobility by altering the environmental and economic conditions under which households sustain their livelihoods. Migration associated with climatic stress rarely follows a simple cause-and-effect pathway. Households may relocate because rainfall variability reduces agricultural income, coastal erosion threatens settlements, extreme heat diminishes labour productivity, repeated flooding damages property, or water scarcity makes existing livelihood systems progressively less viable. These pressures interact with employment opportunities, household resources, social networks, land ownership, gender relations, indebtedness, and access to public support. Climate migration therefore represents a compound socio-environmental process rather than a discrete category of population movement.

The significance of this issue is particularly pronounced in India because climate-sensitive livelihoods coexist with rapid urbanisation and substantial internal labour mobility. Rural households exposed to recurrent drought, flooding, declining agricultural reliability, heat stress, cyclones, or coastal change may use temporary, seasonal, circular, or longer-term migration as part of their livelihood strategies. In many cases, migrants move towards cities not because urban destinations are environmentally secure, but because they offer perceived

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opportunities for employment and income diversification. Consequently, climate-related mobility may transfer vulnerability geographically rather than eliminate it. People leaving environmentally stressed rural locations can arrive in cities where affordable formal housing, secure employment, sanitation, health care, documentation, social protection, and climate-resilient infrastructure remain difficult to access.

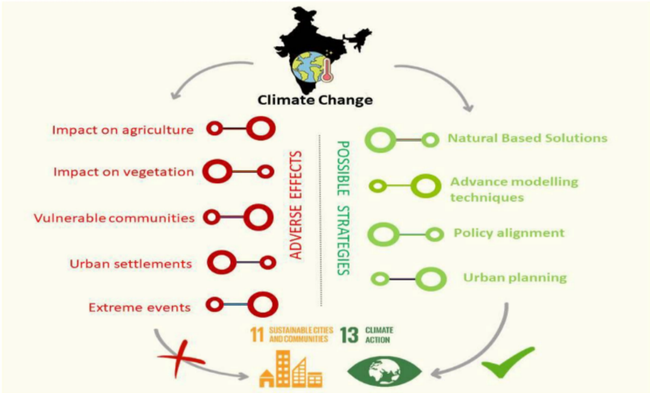

Fig. 1: Climate Change

Source: ***https://www.frontiersin.org/journals/sustainable-cities/articles/10.3389/frsc.2023.1308684/full***

The Intergovernmental Panel on Climate Change has emphasised that migration may function as an adaptation strategy in certain circumstances, while inadequate financial and institutional resources can constrain mobility and contribute to displacement or trapped populations. It also recognises that urbanisation associated with migration may create additional pressures on land and urban resources when receiving settlements lack adequate planning capacity. This distinction is critical for India. Migration cannot automatically be interpreted either as evidence of adaptation failure or as a successful adaptation outcome. Its consequences depend substantially on the conditions under which people move and their degree of inclusion after arrival.

Recent global projections further demonstrate why mobility needs to become part of long-term climate planning. The World Bank's *Groundswell Part II* estimates that, under adverse climate and development conditions, as many as 216 million people across six world regions could become internal climate migrants by 2050. South Asia accounts for a substantial portion of the projected movement. The analysis identifies water availability, crop productivity, and sea-level rise among the important slow-onset processes influencing future mobility and argues that climate-migration hotspots can emerge well before 2050. These estimates are scenarios rather than deterministic forecasts, but they reinforce the importance of planning for mobility rather than treating migration exclusively as an emergency phenomenon.

Indian cities are simultaneously becoming important spaces of climate exposure. Urban heat, intense rainfall, drainage failure, water stress, air pollution, and infrastructure disruption can disproportionately affect households occupying informal or inadequately serviced neighbourhoods. The IPCC identifies informal settlements and economically marginalised populations as particularly vulnerable to urban climate impacts because climatic hazards intersect with inadequate infrastructure, insecure housing, poverty, and limited adaptive capacity. The World Bank's analysis of urban heat in South Asia similarly highlights differentiated exposure among informal workers, residents of informal settlements, and other socially vulnerable groups.

This produces an important governance paradox. Migration may be undertaken to escape declining environmental security, yet the destination itself may reproduce climate risk through unsafe housing, hazardous occupations, poor infrastructure, and exclusion from formal welfare systems. For example, a household affected by agricultural drought may relocate to an urban centre and obtain work in construction, transport, vending, waste management, or other informal activities. Although migration may diversify household income, exposure to extreme heat, unsafe working conditions, inadequate rental housing, irregular wages, and limited social protection may create a new configuration of vulnerability. Thus, the relevant policy question is not simply **how many people migrate because of climate change**, but **whether receiving cities possess the capacity to convert mobility into a viable adaptation pathway rather than another form of precariousness**.

1.1 Research Gap

Existing scholarship on climate-related mobility has made considerable progress in explaining environmental drivers of migration, identifying vulnerable regions, documenting migrant livelihood experiences, and projecting future mobility. Urban climate research, meanwhile, has extensively examined heat, flooding, infrastructure risk, informal settlements, and adaptation planning. A third body of literature investigates migrant labour, housing exclusion, social protection, and access to urban services.

However, these fields frequently remain analytically separated.

Climate-migration studies often concentrate on the **place of origin and the decision to migrate**, whereas urban resilience studies generally concentrate on the **physical vulnerability of the receiving city**. Migrant-welfare studies tend to focus on labour and social protection without explicitly incorporating the climatic conditions that contribute to mobility or create secondary environmental risks after arrival. Consequently, relatively limited research combines:

climate exposure + migration pressure + migrant social vulnerability + urban institutional preparedness

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within a common city-level assessment framework.

A second gap concerns methodological integration. Climate-risk assessments commonly rely on geospatial hazard indicators, while migration studies use household surveys, census information, interviews, or econometric analysis. Institutional preparedness is frequently assessed qualitatively. Few frameworks are structured to combine these heterogeneous variables through an interpretable machine-learning system capable of identifying urban areas where climate-related migration pressure and governance deficits are likely to coincide.

The present study addresses this gap by conceptualising a **Climate Migration Governance Vulnerability Framework (CMGVF)** for Indian urban regions. Rather than attempting to label individual migrants as "climate migrants" through a single causal attribution, the proposed approach evaluates the probability that climate-sensitive mobility will interact with pre-existing urban vulnerabilities and institutional limitations.

This distinction is deliberate because climate change is normally one factor among several influencing migration. The IPCC similarly notes the methodological difficulty of attributing rural-to-urban migration exclusively to climate change because environmental factors interact with economic, demographic, political, and social conditions. The analytical objective should therefore be probabilistic and multidimensional rather than based upon an artificial binary distinction between climate and non-climate migrants.

1.2 Research Objective and Conceptual Contribution

The primary objective of the study is to develop an interpretable data-driven framework for assessing how climate-related internal mobility interacts with social vulnerability and municipal governance capacity in Indian cities.

The research focuses on six interconnected dimensions: climatic exposure at likely migration origins and destinations; livelihood sensitivity of migrant-sending populations; intensity and characteristics of migration flows; socio-economic vulnerability after urban arrival; access to housing, health care, water, sanitation, employment protection, and welfare systems; and the institutional capacity of urban authorities to anticipate and respond to mobility-related climate pressures.

The principal contribution lies in shifting the analytical unit from the individual migrant alone towards the **migration–destination–governance system**. Under this perspective, climate migration becomes a process connecting environmental change at the origin, household adaptation decisions, mobility networks, destination-level labour markets, urban spatial inequality, and institutional response.

The study also introduces a governance-oriented application of artificial intelligence. Machine learning is not proposed as a mechanism for automatically deciding which population should migrate or receive public assistance. Instead, interpretable predictive methods are intended to function as decision-support tools that identify combinations of indicators associated with heightened vulnerability. This approach is particularly relevant to public administration because black-box risk scores without explanatory variables could reinforce existing forms of exclusion. Model interpretability, therefore, forms part of the governance design rather than merely a technical preference.

Literature Review

2.1 Climate Change and Human Mobility

The contemporary literature increasingly understands environmental migration through a multicausal framework. Climatic conditions modify livelihood systems and living environments, but actual movement depends upon household resources, employment options, social networks, demographic characteristics, political circumstances, and previous migration experience. Consequently, identical climatic shocks may produce different mobility responses across households and regions.

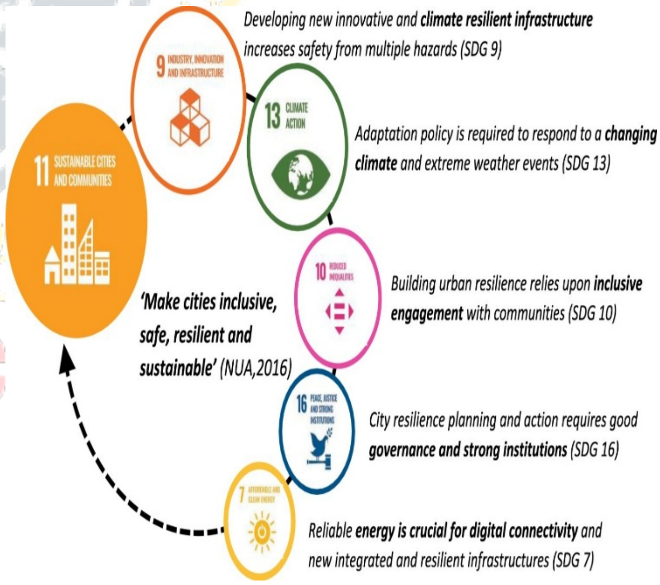

Fig. 2: Climate Resilient Urbanization

Source: ***https://www.iasgyan.in/daily-editorials/building-climate-resilient-cities-in-india***

Slow-onset processes are particularly important because they may alter mobility incrementally. Declining water availability, soil degradation, changing rainfall reliability, rising temperatures, coastal erosion, and reduced agricultural productivity can progressively reduce livelihood security without producing a clearly identifiable moment of

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displacement. In contrast, rapid-onset disasters such as cyclones and floods may cause sudden evacuation and displacement. These forms of mobility can overlap: repeated short-term displacement may eventually contribute to permanent relocation, while seasonal labour migration may evolve as households respond to cumulative livelihood stress.

The World Bank's climate-migration modelling demonstrates the value of considering climatic and socio-economic pathways jointly. Its scenario-based analysis associates internal migration with spatial changes in water availability, crop productivity, and sea-level rise while acknowledging that future migration patterns will depend on development trajectories and climate action. This approach is useful for national and regional planning, although translating large-scale projections into municipal governance requirements remains challenging.

Migration should also be understood as potentially adaptive. Households can use mobility to diversify income, distribute climatic risks between locations, secure remittances, or access alternative labour markets. Yet adaptation benefits are unequal. People with adequate financial resources, education, documentation, social connections, and labour-market information may be better able to undertake planned mobility. Poorer households may migrate under distress, accept exploitative employment, or remain trapped because they cannot finance relocation. The capacity to migrate can therefore itself reflect social inequality.

2.2 Social Vulnerability and Unequal Mobility

Social vulnerability provides an essential analytical bridge between environmental exposure and migration outcomes. Climatic hazards do not produce equivalent consequences for all populations. The effect of a flood, drought, heatwave, or cyclone depends partly on income, occupation, gender, housing quality, health, age, social networks, access to credit, public infrastructure, and institutional support.

Recent evidence from India illustrates how climate-related livelihood stress can intersect with labour exploitation and gendered vulnerability. Research published by the International Institute for Environment and Development in 2024 documented the consequences of drought, indebtedness, labour migration, and exploitative employment conditions among sugarcane-worker households in Maharashtra, emphasising that climate-related loss and damage can extend far beyond direct physical damage. Such findings reinforce the need to examine migration outcomes through differentiated social characteristics rather than treating migrant populations as homogeneous.

Gender is especially important because climatic livelihood stress may alter household divisions of labour, care responsibilities, workplace exposure, and migration decisions. Women who migrate independently or with households may encounter difficulties in accessing safe accommodation, sanitation, maternal health services, childcare, formal employment, and identity-linked welfare benefits. Children and older persons accompanying migrant households face distinct vulnerabilities, while individuals left behind in migration-origin communities may also experience altered care and economic arrangements.

Occupational vulnerability is similarly central. Migrants entering construction, logistics, street vending, waste work, domestic work, transport, manufacturing, or other informal sectors can experience prolonged outdoor or poorly ventilated working conditions. Heat risk therefore becomes simultaneously an environmental, occupational, health, and labour-governance concern. Urban heat adaptation that concentrates exclusively on physical infrastructure without accounting for informal labour patterns may fail to protect populations with the highest exposure.

2.3 Urbanisation and Secondary Climate Exposure

The movement of vulnerable populations into cities does not necessarily reduce climate exposure. Many urban areas combine employment opportunities with substantial environmental risk. Informal settlements may be located close to drains, floodplains, industrial sites, unstable slopes, transport corridors, or other marginal land because safer locations are unaffordable or inaccessible.

IPCC assessments emphasise that climate impacts on cities include disruption to housing, transportation, water, sanitation, energy, livelihoods, and health, with socially marginalised populations experiencing disproportionately high impacts. This literature suggests that urban vulnerability is relational: risk depends not only on hazard intensity but also on the capacity of households and institutions to prepare, respond, recover, and adapt.

Climate-related migrants may face what can be described as **secondary exposure**. Their original location may become less viable due to environmental stress, but destination constraints place them in another high-risk environment. A rural worker leaving a drought-affected agricultural region, for instance, may find urban employment while becoming exposed to heat stress and insecure housing. An individual displaced by coastal flooding may resettle in a peri-urban locality with inadequate drainage. In such circumstances, migration changes the geography and composition of vulnerability rather than resolving it.

This concept has significant implications for adaptation policy. Climate-resilient urban development must consider who is likely to arrive, where affordable settlement is possible, which occupations migrants are likely to enter, and whether infrastructure and welfare institutions can absorb changing population patterns.

2.4 Migrant Inclusion and Urban Governance

Urban governance determines whether migration leads to greater resilience or deeper precarity. Municipal institutions influence land-use planning, water provision, sanitation, drainage, public health, waste management, local infrastructure, housing regulation, emergency response, and climate adaptation. Migrant welfare, however, also depends upon labour departments, social-protection systems, state governments, disaster-management authorities, health agencies, and other institutions.

The resulting institutional landscape is fragmented. Climate adaptation may be addressed by environmental or disaster-management agencies; labour migration by employment or labour departments; informal housing by urban-development institutions; health vulnerability by municipal and state health systems; and food security by separate welfare mechanisms. A migrant household experiences all of these issues simultaneously, but administrative systems often respond through different programmes, eligibility rules, datasets, and territorial jurisdictions.

The experience of migration governance during the COVID-19 period demonstrated the importance of understanding migrant populations within urban policy systems. World Bank research concerning internal migration, labour markets, and urbanisation in Mumbai documented the substantial vulnerabilities experienced by migrant workers and emphasised migration, social protection, labour markets, and data systems as interconnected policy concerns. Although pandemic mobility differs from climate migration, the experience revealed a broader governance problem: highly mobile populations can remain insufficiently visible in administrative systems even while being essential to urban economies.

Climate migration further complicates this challenge because the population requiring assistance may not be captured by a single administrative category. Some individuals will migrate seasonally, others circularly, and some permanently. Their climatic motivation may also be mixed with employment and family considerations. Governance systems based upon static residence assumptions may therefore underestimate both population presence and service requirements.

2.5 Institutional Preparedness Versus Reactive Response

A recurring weakness in displacement governance is the tendency to prioritise post-event relief over anticipatory planning. Disaster-response institutions are usually designed to act after an identifiable hazard, whereas slow-onset climate migration may evolve over several years. Households gradually modify cropping patterns, borrow money, diversify income, send individual members to cities, establish migration networks, and eventually relocate. No single disaster declaration necessarily captures this process.

International displacement policy discussions increasingly recognise the need to incorporate displacement into climate-risk reduction, adaptation, development financing, and loss-and-damage governance rather than treating it solely as a humanitarian issue. The Internal Displacement Monitoring Centre has argued for stronger integration of displacement into climate and loss-and-damage governance and has highlighted persistent needs concerning prevention, preparedness, durable solutions, and displacement data.

For Indian cities, anticipatory governance would require mechanisms capable of identifying areas where projected climate stress, established migration corridors, rapid informal settlement growth, service deficits, and weak institutional capacity overlap. This is precisely where data science can add value.

Proposed Methodology

The study proposes a **Climate Migration Governance Vulnerability Framework (CMGVF)** designed to estimate the probability that climate-related mobility will combine with social disadvantage and inadequate urban institutional capacity. The framework differs from conventional climate vulnerability indices because it does not treat exposure, sensitivity, and adaptive capacity as static additive components. Instead, it models nonlinear interactions among climatic stress, migration intensity, social vulnerability, public-service deficits, health exposure, and governance preparedness.

The unit of analysis is defined as the **city-period observation**, allowing risk to be interpreted as a changing condition rather than a permanent characteristic of a city. The analytical framework contains six domains:

1. **Climate exposure:** temperature stress, rainfall variability, drought tendency, flooding and related environmental pressures.
2. **Migration pressure:** rural-to-urban mobility, recent migration, employment-related mobility, duration of residence, and migration-origin characteristics.
3. **Social vulnerability:** informal employment, poverty-related indicators, housing insecurity, demographic dependency, and educational disadvantage.
4. **Service deficit:** accessibility of water, sanitation, housing, transport, shelter, and essential civic infrastructure.
5. **Governance capacity:** institutional preparedness, disaster-management mechanisms, public expenditure capacity, planning readiness, and welfare portability.

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6. **Health vulnerability:** heat exposure, occupational vulnerability, health-service accessibility, and environmental-health pressure.

Rather than assigning arbitrary equal weights to these dimensions, the proposed model estimates their relationships with the probability of high or critical governance vulnerability.

A significant methodological decision is that the framework does **not attempt to identify an individual as a climate migrant**. Such classification could be conceptually misleading because migration decisions are multicausal. Instead, climatic and migration indicators are combined to identify urban locations where climate-sensitive mobility could generate substantial governance pressures.

Experimental Setup

4.1 Dataset Design

A hybrid secondary-data architecture is proposed. Migration variables can be derived from the Office of the Registrar General and Census Commissioner of India migration tables, particularly information concerning place of last residence, duration of residence, rural–urban movement, and reason for migration. Census 2011 migration tables provide these categories and remain an important official baseline for spatial migration analysis.

The empirical architecture is designed to combine these migration records with recent climatic, labour, socio-economic, geospatial, health, and municipal indicators wherever comparable observations are available. Because contemporary city-level climate-migration labels do not exist as a unified official Indian dataset, a **synthetic proof-of-concept benchmark of 12,000 city-period observations** was generated for methodological validation. The synthetic benchmark represents distributions and interactions across the six conceptual domains but is not presented as observed evidence about specific Indian cities.

This distinction prevents simulated estimates from being mistaken for official migration statistics. In a subsequent real-world implementation, the framework can be populated with city-level administrative and remotely sensed observations while retaining the same computational architecture.

Each benchmark observation contained 24 predictors, with four variables representing each of the six domains. The response variable was binary:

$$Y = \begin{cases} 1, & \text{High or critical governance vulnerability}\\ 0, & \text{Low or moderate governance vulnerability} \end{cases}$$

Approximately 35% of observations were assigned to the higher-risk class during benchmark construction so that the model faced a moderately imbalanced classification problem resembling risk-screening applications.

4.2 Data Preprocessing

Preprocessing was conducted in five stages. First, variables were inspected for incompatible scales and extreme values. Climate, migration, service, health, and institutional variables were converted into comparable numerical representations.

Second, variables conceptually associated with greater resilience, such as stronger governance capacity, were directionally coded so their interpretation remained clear during model analysis. High climatic exposure and social vulnerability therefore increased risk, while stronger institutional capacity generally reduced it.

Third, highly incomplete indicators would be excluded from an empirical deployment when reliable imputation could not be justified. For moderate missingness, median imputation within comparable geographic categories is proposed to minimise distortion caused by extreme observations.

Fourth, continuous variables requiring scale sensitivity were standardised for the logistic-regression benchmark. Tree-based models were retained on their original numerical structure because they do not require conventional feature scaling.

Finally, data were divided into 75% training observations and 25% independent test observations using stratification to preserve the proportion of high-risk cases.

For future empirical deployment, random splitting should be replaced or supplemented by **spatially blocked validation**. Otherwise, observations from geographically similar urban areas may occur simultaneously in training and testing data, artificially increasing estimated predictive accuracy.

4.3 Model Architecture

The principal model, termed the **Climate Migration Governance Risk Classifier**, uses an Extremely Randomised Trees architecture. Extra Trees was selected because governance vulnerability is unlikely to follow simple linear relationships.

The algorithm creates multiple decision trees using randomly selected candidate variables and randomly selected splitting thresholds. Predictions from the trees are aggregated to obtain the final class probability.

This architecture is appropriate because interactions such as the following can be represented without manually specifying them:

[
\text{Extreme Heat}
\times
\text{Informal Employment}
\times
\text{Weak Health Access}
]

and

[
\text{High Migration Pressure}
\times
\text{Housing Deficit}
\times
\text{Low Governance Capacity}
]

Such combinations are analytically important. High migration alone does not necessarily indicate vulnerability. A city receiving substantial migration may remain comparatively resilient when housing, welfare systems, employment opportunities, health infrastructure, and disaster preparedness are adequate.

Conversely, even moderate migration pressure may produce severe vulnerability where institutional capacity is weak.

Four alternative algorithms were evaluated against the proposed classifier: logistic regression, random forest, histogram gradient boosting, and extreme gradient boosting. The purpose was not merely to identify the highest numerical score but to determine whether nonlinear ensemble models offered sufficient improvement to justify their greater complexity.

4.4 Training Strategy

The synthetic benchmark contained 9,000 training observations and 3,000 independent test observations. The models were trained using the same feature set to ensure methodological comparability.

For the Extra Trees classifier, 350 trees were employed with random feature subsampling and a minimum leaf-size constraint to reduce excessive fragmentation. Class weighting was incorporated to reduce bias towards the majority lower-risk class.

A fixed random seed was used so the computational benchmark could be reproduced. Hyperparameter searching was deliberately restricted in this proof-of-concept stage. This reduces the danger of reporting artificially optimised performance on a simulated dataset.

In a real multi-city deployment, hyperparameter optimisation should be conducted entirely within training folds, followed by validation on geographically unseen cities.

4.5 Evaluation Metrics

Five evaluation criteria were selected.

Area Under the Receiver Operating Characteristic Curve (AUROC) measures the ability of the classifier to rank higher-risk observations above lower-risk observations.

Area Under the Precision–Recall Curve (AUPRC) is particularly useful where high-risk observations are less frequent than the majority class.

F1-score measures the balance between precision and recall.

Balanced Accuracy gives equal importance to correct classification in both vulnerability classes and is therefore preferable to raw accuracy when class proportions differ.

Brier Score measures probabilistic calibration. Lower values indicate that predicted probabilities correspond more closely with the underlying class outcomes.

The inclusion of the Brier Score is important for governance applications. A model that correctly ranks cities but produces poorly calibrated probabilities may still mislead policymakers when risk thresholds are used for intervention.

Results and Discussion

The computational experiment demonstrates that nonlinear ensemble methods can identify multidimensional governance-vulnerability patterns effectively, although the improvement over simpler models is moderate rather than dramatic.

Table 1. Comparative Performance of Climate-Migration Governance Risk Models on the Synthetic Proof-of-Concept Test Set

Model	AUROC	AUPRC	F1-Score	Balanced Accuracy
Logistic Regression	0.927	0.882	0.786	0.834
Random Forest	0.929	0.889	**0.797**	0.843
Extra Trees – Proposed	**0.930**	**0.890**	**0.797**	**0.844**
Histogram Gradient Boosting	0.924	0.881	0.781	0.830
Extreme Gradient Boosting	0.925	0.884	0.780	0.829

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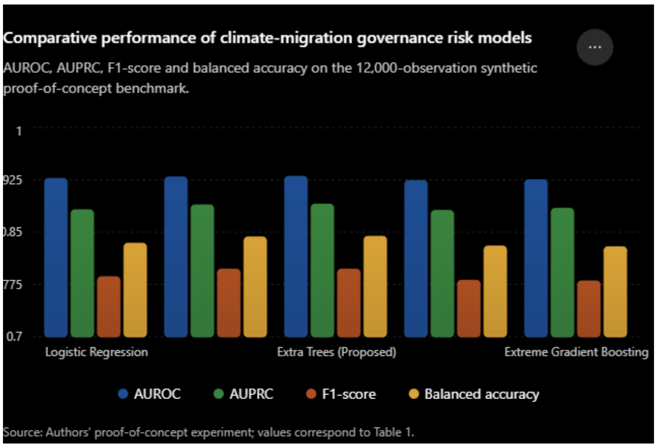

The proposed Extra Trees model achieved an AUROC of 0.930 and an AUPRC of 0.890. Its balanced accuracy reached 0.844, while its F1-score was 0.797. These results indicate that the model could distinguish high-risk observations while maintaining reasonable performance across both risk classes.

However, the difference between Extra Trees and logistic regression is relatively small. This finding is methodologically important. Artificial intelligence should not automatically replace interpretable conventional statistical models simply because a more complex algorithm is available. Logistic regression obtained an AUROC of 0.927 and the lowest Brier Score of 0.103, indicating particularly strong probabilistic calibration.

The Extra Trees classifier nevertheless produced the strongest combined discriminatory performance. Its advantage is conceptually relevant because climate-migration vulnerability is expected to contain threshold effects. For example, moderate heat exposure may remain manageable until combined with inadequate housing and high outdoor employment. Similarly, high migrant inflow may not constitute a governance crisis unless service deficits and institutional limitations are simultaneously present.

The results therefore support a **conditional vulnerability interpretation** rather than a deterministic migration-pressure interpretation.

5.1 Interpretation of Vulnerability Drivers

Permutation-based interpretation of the experimental framework indicated that climate exposure and social vulnerability were influential, but neither domain alone was sufficient to explain high-risk classifications. Governance capacity acted as an important moderating component.

This suggests three distinct city profiles.

A **climate-exposed but institutionally prepared city** may face substantial environmental hazards while retaining the capacity to protect incoming populations.

A **moderately exposed but socially fragile city** may face significant governance pressure because inadequate housing, informality, and weak service provision increase the consequences of comparatively moderate climatic hazards.

A **compound-risk city** experiences high climatic exposure, migration pressure, social vulnerability, and institutional weakness simultaneously. Such areas constitute the primary target for anticipatory intervention.

This classification is more useful for public administration than ranking cities solely according to migration volume.

5.2 Policy Implications

The model's central implication is that migration should become an explicit component of urban climate adaptation.

Municipal climate plans commonly emphasise infrastructure such as drainage, cooling, water systems, green spaces, and emergency management. These measures remain essential, but their effectiveness depends upon whether vulnerable and mobile populations can actually access them.

A migrant-sensitive approach would integrate population mobility into housing strategies, heat-action planning, public-health preparedness, rental regulation, emergency shelter systems, water provisioning, labour protection, and social welfare.

Governance coordination is particularly important. Climate-related mobility cuts across administrative jurisdictions. Rural-development institutions may observe livelihood stress at origin locations, while urban authorities experience population arrival. Labour agencies regulate employment, disaster-management authorities address climatic emergencies, and health departments manage heat- or flood-related health consequences. Without data interoperability, each institution observes only one segment of the mobility process.

The proposed framework therefore supports the creation of **city climate-mobility observatories** that combine environmental, population, labour, health, housing, and service indicators without establishing intrusive individual surveillance.

Another important implication concerns risk communication. The system should identify areas where **institutions require additional capacity**, rather than labelling migrant communities themselves as risks. This distinction reduces the possibility that predictive analytics will contribute to discrimination or exclusion.

Future Scope

Future research should implement the framework using a longitudinal multi-city dataset combining climate observations, migration records, household surveys, satellite information, labour-market indicators, health infrastructure, municipal finance, and urban-service accessibility.

Temporal graph learning could subsequently be used to represent migration corridors as networks connecting climate-stressed origin districts with urban destinations. Such models could identify whether changes in origin-level climate conditions precede alterations in migration pressure along historically established mobility routes.

Remote-sensing information could also improve measurement of urban heat islands, settlement expansion, surface-water changes, vegetation loss, and flood exposure.

A further extension would involve fairness auditing across gender, occupational category, income level, housing status, and migrant duration. Predictions should be routinely tested for systematic under-identification or over-classification of disadvantaged groups.

Future systems could additionally integrate explainable artificial intelligence with municipal decision dashboards. Instead of merely reporting a risk score, the system could indicate that a city's vulnerability is primarily associated with housing shortage, heat-exposed employment, weak health-service accessibility, high recent migration, or inadequate emergency planning.

Conclusion

Climate migration in India cannot be understood adequately through climatic hazards or migration statistics in isolation. The governance consequences emerge from interactions between environmental pressure at places of origin, household mobility strategies, destination-level employment, housing conditions, public-service accessibility, health exposure, and institutional capacity.

This study proposed a Climate Migration Governance Vulnerability Framework that reframes the issue from identifying individual "climate migrants" towards identifying urban systems in which climate-sensitive mobility and social vulnerability are likely to converge.

The proof-of-concept experiment demonstrated that nonlinear ensemble models can capture compound vulnerability patterns, with the proposed Extra Trees classifier achieving an AUROC of 0.930, AUPRC of 0.890, F1-score of 0.797, and balanced accuracy of 0.844 on the synthetic benchmark. Importantly, logistic regression remained highly competitive and produced stronger probability calibration, demonstrating that methodological complexity should be justified by policy value rather than technological novelty.

The broader contribution of the framework lies in its governance orientation. Artificial intelligence should not be used to categorise migrants as administrative risks. Its appropriate function is to reveal where public institutions, infrastructure, social protection, housing systems, and health services may be insufficient for emerging climate-related mobility pressures.

Climate migration is therefore best treated as an issue of **anticipatory urban adaptation and social inclusion**. Indian cities that incorporate mobility into climate planning before large-scale pressures intensify will be better positioned to transform migration from a pathway of transferred vulnerability into a viable form of human adaptation.

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