

Assessing Air Quality, Climate Change, and Migration Dynamics in Delhi NCR: A System Dynamics Approach

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Abstract

As climate change accelerates and environmental degradation worsens, urban centers like Delhi NCR are under increasing pressure from internal migration. Poor air quality—especially in rural and peri-urban regions—emerges both as a driver of out-migration and a deterrent for in-migration to already burdened cities. This study develops a system dynamics (SD) model that integrates climate variables, air pollution metrics, economic indicators, governance quality, and migration behavior to simulate population flows into the Delhi NCR region. The model reveals critical feedback loops among air quality, public health, labor dynamics, and migration incentives. Drawing on national climate projections, air quality indices, and migration data, the model forecasts scenarios through 2060 and evaluates the impact of policy interventions, including emissions control, urban reforms, and rural aid. Findings show that, without decisive action, Delhi NCR could face unsustainable migration, heightened health risks, and worsening urban stress. The research calls for integrated policy frameworks that align climate adaptation, public health, and migration governance in India's most densely populated region. Beyond forecasting population pressures, the study highlights the broader socio-economic implications of unchecked climate-driven migration. Rising health costs from air-pollution-related diseases, coupled with declining labor productivity, may weaken the region's economic competitiveness and exacerbate inequalities. Migrant populations—often employed in informal sectors—are particularly vulnerable to inadequate housing, limited healthcare access, and unstable livelihoods, thereby amplifying cycles of poverty and environmental stress. Moreover, unplanned migration could overwhelm existing infrastructure, strain public services, and fuel social tensions between resident and migrant communities. By using the SD model as a decision-support tool, policymakers can test the long-term consequences of different strategies, from aggressive emissions reduction to investments in rural resilience that reduce migration push factors. Ultimately, the study underscores that migration in the climate era is not merely a demographic challenge but a governance test requiring cross-sectoral coordination, forward-looking planning, and a commitment to environmental justice.

Keywords: Climate change, Air quality, System dynamics, Internal migration, unsustainable migration

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INTRODUCTION

Delhi NCR, a megacity of over 30 million people, faces growing challenges due to environmental degradation and internal migration. Air quality in the region is consistently among the poorest in the world, posing significant public health risks. Climate change, through rising temperatures, disrupted rainfall patterns, and extreme weather events, is further undermining rural livelihoods, thereby increasing migration toward urban centers. However, the very environmental conditions that draw migrants from distressed rural areas also deter them from settling in highly polluted urban spaces.

This study employs a systems dynamics modeling approach to investigate how climate change and air pollution interact with socio-economic drivers to influence migration to Delhi NCR. The model aims to answer three core research questions: How do air quality and climate stress interact to shape migration behavior? What are the long-term implications of current trends for urban sustainability? And which policy responses are most effective at mitigating negative outcomes? Through simulation-based forecasting, the study provides a roadmap for policy frameworks that enhance resilience and sustainability in urban planning.

LITERATURE REVIEW

Research on climate-induced migration has shown that changing precipitation patterns, rising temperatures, and weather extremes have a significant impact on rural livelihoods, particularly in agriculture-dependent economies like India. These conditions act as strong push factors for migration, prompting millions to relocate to urban centers in search of security and employment [1-3].

Air quality, particularly in Delhi NCR, is a major determinant of public health and urban livability. PM2.5 concentrations often exceed safe thresholds, contributing to a rise in respiratory and cardiovascular illnesses. These health concerns influence mobility patterns, deterring people from moving to or staying in polluted urban regions.

System dynamics has emerged as a robust tool for modeling complex, interrelated phenomena such as climate impacts, pollution, and migration. Although system dynamics has been applied in studies ranging from urban planning to climate resilience, few have holistically modeled the interaction between air quality, climate stress, and migration in Indian urban contexts [4].

This study fills a key research gap by integrating these environmental and socio-economic factors into a single SD model tailored to Delhi NCR. It captures feedback loops and system behaviors over time, offering a predictive lens through which to evaluate policy effectiveness and urban resilience.

METHODOLOGY

The system dynamics model, developed in Vensim, is structured around five interdependent modules: climate change, air quality, public health, economic factors, and migration dynamics. The climate change module incorporates variables such as temperature rise, erratic monsoon behavior, and extreme weather events. These environmental stressors reduce agricultural productivity, leading to increased rural out-migration.

The air quality module tracks pollution levels, particularly PM2.5 and AQI, based on emissions from transportation, industrial activity, and biomass burning [6]. These values directly affect the public health module, which estimates changes in morbidity and mortality, as well as impacts on labor productivity and healthcare burden.

Economic dynamics are represented by employment availability, wage differentials, and infrastructure capacity in urban areas. These influence the perceived economic utility of migration. The migration dynamics module synthesizes all these factors through a utility function that simulates net migration to Delhi NCR. Feedback loops are incorporated to reflect how a rising population affects pollution, infrastructure, and urban stress over time.

Model data were sourced from a range of official datasets. Climate projections were obtained from the Indian Meteorological Department (IMD), while real-time pollution data came from the Central Pollution Control Board (CPCB). Migration trends were based on Census 2011 and estimates by Rajan and Bhagat (2022). Employment and health data were drawn from the NSSO and epidemiological studies on pollution impacts.

Three future scenarios were modeled through 2060. The Business-as-Usual (BAU) scenario assumes no major policy interventions, allowing environmental degradation and migration trends to continue unchecked. The Moderate Intervention scenario incorporates partial emission control measures and limited urban planning improvements. The Aggressive Intervention scenario introduces comprehensive reforms, including strict emissions standards, green infrastructure development, and rural economic aid.

The model was validated using historical data from 2010 to 2020 for air quality, migration, and health metrics, ensuring that it accurately reproduces observed patterns before projecting into future scenarios [5].

RESULTS

In the Business-as-Usual scenario, Delhi NCR experiences a 35% increase in net in-migration by 2060, largely due to worsening rural climate stress. However, as pollution levels worsen—PM2.5 concentrations rise by 20% and AQI frequently exceeds hazardous levels—migration rates begin to decline post-2050 due to deteriorating living conditions. Public health burdens rise dramatically, with a 40% increase in pollution-related morbidity. Urban infrastructure becomes severely strained, leading to housing shortages, transport congestion, and diminished quality of life.

Under the Moderate Intervention scenario, air quality improves modestly, with PM2.5 levels declining by about 10% by 2060. Migration stabilizes after 2040, reflecting marginal improvements in urban livability and infrastructure. Public health outcomes improve, with a 20% reduction in pollution-related illnesses, which helps reduce healthcare costs and restore some labor productivity. Urban systems remain under stress, but modest investments in housing and transport help manage growing demand.

In the Aggressive Intervention scenario, in-migration peaks in 2045 before tapering off, as rural economic aid and climate adaptation efforts reduce push factors. By 2060, the net increase in migration is limited to 5% over 2025 levels. PM2.5 levels drop by 30%, and average AQI values improve to moderate levels [7]. Health outcomes improve significantly, with a 35% drop in morbidity and related productivity losses. Enhanced urban resilience, through green infrastructure and stronger governance, significantly eases pressure on services and improves overall quality of life.

DISCUSSION

These findings underscore the interconnectedness of environmental degradation, health, and migration in shaping urban futures. In the absence of policy action, Delhi NCR is projected to enter a vicious cycle of declining livability, rising health costs, and unsustainable migration flows. Moderate interventions yield some benefits, but are ultimately insufficient to reverse long-term stress. Only comprehensive and integrated measures — targeting both environmental mitigation and social resilience — prove effective in stabilizing the region's demographic and ecological balance [8].

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Key feedback mechanisms were identified. The pollution–health–migration loop illustrates how deteriorating air quality impairs health, reduces urban attractiveness, and indirectly limits labor force participation. Similarly, the climate–rural–urban loop demonstrates how climate-driven agricultural losses escalate rural out-migration, increasing urban population and associated emissions — reinforcing the environmental crisis.

Policy priorities emerging from the study include strict enforcement of emission regulations, investments in green infrastructure and affordable housing, and proactive rural development to address the root causes of migration. Urban resilience depends on multi-level governance that aligns environmental, economic, and migration policies across jurisdictions within the NCR.

Beyond the immediate findings, the study highlights the importance of adopting a systems perspective when planning for the future of megacities like Delhi. The interconnected loops of environment, health, and migration reveal that piecemeal solutions are unlikely to succeed. For instance, improving public transportation without curbing industrial emissions may slow, but not stop, the health impacts of pollution. Similarly, promoting renewable energy without addressing rural vulnerability risks sustaining the migration pressure that undermines urban sustainability [9].

Aggressive interventions also carry co-benefits that extend beyond NCR. Cleaner air reduces regional health burdens, while investments in rural adaptation can stabilize agrarian economies and slow ecological degradation in surrounding states. These ripple effects underline the national significance of policy choices made in NCR. The findings further emphasize the role of citizen participation and behavioral change — such as adoption of energy-efficient practices and reduced private vehicle dependence — as critical complements to top-down governance [10].

Ultimately, the study paints a stark but hopeful picture: while inaction locks Delhi NCR into an unsustainable trajectory, bold, integrated, and forward-looking policies can meaningfully shift outcomes. The challenge lies not only in technical solutions but also in building political will, institutional capacity, and social consensus to implement them at the required scale and speed.

CONCLUSION

This study demonstrates that climate change and air quality are central to understanding internal migration patterns in India. Through a system dynamics model tailored to Delhi NCR, it shows how environmental and socio-economic systems are deeply interlinked, producing both direct and indirect consequences for urban sustainability. Without bold and integrated policy actions, Delhi NCR faces a future of worsening health outcomes, overburdened infrastructure, and fragile social stability. Aggressive, multi-sectoral strategies—anchored in emissions control, urban design, and rural support—offer a viable path toward resilience and sustainable urban development.

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