Aashi Maheshwari
Francis Howell High School
St. Charles, Missouri, USA
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India's Water Crisis: The Impact of Urban Expansion on Groundwater Depletion and Water Scarcity

INTRODUCTION

Water is one of the most essential resources for human survival, yet for millions of people in India, reliable access to clean drinking water remains uncertain. In the United States, access to running water is often taken for granted; most taps deliver water instantly and consistently throughout the day. The infrastructure supporting this convenience operates quietly in the background, rarely demanding attention. However, this level of reliability is not universal. In rapidly developing nations, including India, water insecurity affects millions of people. As urban development accelerates, natural landscapes that once absorbed and replenished rainfall are increasingly replaced with impermeable surfaces. Groundwater systems are strained, and the water crisis continues to intensify. This paper investigates the worsening health and safety of India's population due to the depletion of groundwater sources driven by the rapid growth of urban areas, which is preventing the delivery of safe and clean water to its citizens and farms.

BACKGROUND AND FAMILY

India is the most populous country in the world, with over 1.4 billion people living across 3.29 million square kilometers (Worldometer, n.d.). The population places significant pressure on natural resources, particularly freshwater. Although India spans diverse climates and geographic regions, its overall water availability is highly dependent on seasonal monsoon rainfall. Nearly three-quarters of the nation's annual precipitation falls within the period between June and September (Dohutia, 2025), concentrating a major portion of India's water supply within a short time frame. Rainfall also varies dramatically across regions, from less than 610 millimeters in arid western areas to nearly 4,000 millimeters in northeastern and coastal zones. The seasonal concentration and regional variability increase the reliance on groundwater throughout the year. Groundwater serves as a critical reserve during dry months and in regions with limited rainfall. With the monsoon contributing to nearly 60% of the nation's annual groundwater recharge, the ability of rainwater to infiltrate and replenish aquifers is critical for maintaining long-term groundwater sustainability.

Compounding the problem of water scarcity is the family structures rooted in Indian culture. Many Indian households operate within joint or extended family systems, where multiple generations share living spaces. By concentrating larger numbers of individuals within limited residential areas, these structures drastically increase population density and the daily demand for freshwater per unit area of living space. Multiple families often rely on a single local source for drinking, cooking, sanitation, and irrigation. As demand rises, groundwater extraction increases to meet household needs. Over time, this overextraction places a greater strain on local water sources, harming communities.

Historically an agrarian society, India has experienced rapid industrialization and urban expansion over the past three decades. Today, approximately 36.9% of India's population lives in urban areas, and that

number is projected to exceed 40% by 2030 (Press Information Bureau [PIB], 2024). Urban regions generate more than two-thirds of the country's gross domestic product, with major metropolitan hubs such as Mumbai, Delhi, Kolkata, Bengaluru, and Chennai serving as economic centers. While the major cities house many of India's citizens, a substantial portion of the population continues to reside in smaller cities and rural areas, which are continuously expanding. The speed and scale of this expansion have placed increasing strain on water resources, contributing to a growing groundwater crisis.

CHALLENGE AND IMPACT

Rapid industrialization and urbanization have significantly intensified water scarcity and unsafe drinking water conditions across India. In response to population growth and spatial limitations, urban expansion has increasingly replaced natural water-catchment areas with impervious concrete surfaces. Unlike soil or vegetation, concrete is highly impermeable, preventing rainwater from naturally infiltrating the ground and recharging aquifers.

This issue is currently prevalent in the majority of India's urban cities. In Bengaluru, for example, concrete surface coverage increased from 54.5 percent in 2010 to 86.6 percent in 2023, while vegetation declined from 28.2 percent to as low as 2.9 percent (The Times of India, 2024). As natural infiltration declines, groundwater levels are falling at alarming rates, estimated between 9 and 20 feet per year (Columbia Water Center, n.d). At the same time, India's urban population is increasing by approximately 2.3 percent annually (Macrotrends, n.d.), placing immense pressure on already-strained infrastructure systems. With India already nearly 13 times more densely populated than the United States (The World Bank, n.d.), the pressure on limited water resources is significantly amplified.

When rainwater is unable to seep into the ground, it becomes surface runoff, increasing both the risk and magnitude of urban flooding, particularly during monsoon seasons. Research indicates that for every 1 percent increase in impervious surface area, urban flood magnitude increases by approximately 3.3 percent (Johns Hopkins University, 2020). This damages infrastructure and represents a critical loss of water that could otherwise recharge depleted aquifers.

Beyond the increased flood risk, the reduction in natural groundwater is particularly concerning because India remains heavily dependent on groundwater to meet daily water demands. Approximately 48 percent of India's urban water supply is sourced from groundwater (Khambete, 2021). While national water infrastructure has expanded, with nearly 95 percent of households having access to basic drinking water and 73 percent of rural households connected to tap water (Press Information Bureau [PIB], 2024), water supply remains highly intermittent. Many cities receive water for only 4–8 hours per day (Khambete, 2021). Even in New Delhi, the capital city of India, more than 60 percent of residents receive piped water only during limited morning and evening windows (Snel, 2023).

Both rural and urban populations depend heavily on wells, particularly bore wells in urban areas. Bore wells are deep, mechanically drilled shafts designed to access groundwater from deeper aquifers. They are widespread, with the city of Bengaluru having approximately 15,000 bore wells (Radhakrishna, 2025). As groundwater levels decline, these wells are drilled progressively deeper, accelerating groundwater depletion.

Groundwater availability is a critical determinant of overall public health, with its depletion intensifying water contamination risks. As aquifer levels decline, the reduced dilution capacity increases the pollutant concentration. Nearly 70 percent of India's water is contaminated with microbes, nitrates, and heavy

metals (Sarkar, 2025). This problem is compounded by inadequate sewage treatment infrastructure; approximately 72 percent of sewage generated in urban areas remains untreated and is discharged into water bodies, including sources that connect with groundwater systems (Tyagi, 2025). As a result, increasing cases of waterborne diseases such as diarrhea, hepatitis, typhoid, and cholera continue to pose a severe health crisis in India, impacting an estimated 37.7 million Indians annually (ETHealthWorld, 2022). Diarrheal disease alone accounts for approximately 2.2 million deaths per year in India (Giri et al., 2022). Without restoring groundwater systems, these public health risks are likely to intensify over time.

Groundwater also plays a central role in agriculture. India is the world's largest extractor of groundwater, surpassing both the United States and China (The World Bank, 2012). Nearly 90 percent of extracted groundwater is used for irrigation (Meenakshi, 2026). Much of India's agricultural production focuses on water-intensive crops such as rice, wheat, and sugarcane. As population growth increases food demand, irrigation pressures intensify, causing over-extraction and further accelerating groundwater depletion.

EXPLORING SOLUTIONS

There are several potential approaches to addressing groundwater depletion in India. One commonly proposed method is stricter groundwater regulation. Currently, the Central Ground Water Authority (CGWA), along with state-level agencies, requires mandatory permission for borewell drilling, registration of drilling rigs, and imposes fines for violations (Central Ground Water Board, n.d.). These regulations are more actively implemented in metropolitan areas like Bengaluru, Delhi, and Mumbai.

But despite formal regulations, illegal borewell drilling remains widespread. India's water governance structure is largely decentralized, with significant authority delegated to state and local governments. While this allows for localized decision-making, it also creates inconsistencies in enforcement capacity, with many cities lacking sufficient technical resources or administrative personnel to consistently regulate groundwater extraction. As a result, compliance varies significantly across regions.

The issue of illegal extraction extends beyond individual households. In New Delhi alone, over 246 hotels were allegedly extracting groundwater illegally (Mishra, 2023). Furthermore, systemic corruption presents an additional barrier to effective enforcement. Both local and federal officials have faced accusations of bribery and regulatory negligence. In Goa, state authorities publicly acknowledged widespread illegal borewell drilling after facing heavy scrutiny (The Goan Network, 2025). Although groundwater regulation is necessary in theory, the practical challenges of enforcement make it difficult to rely on regulation alone as a long-term solution. Also, while regulation primarily seeks to limit over-extraction, it does not address the underlying issue of insufficient groundwater recharge: reduced natural infiltration. The depleted aquifers result in the growing demand for water remaining unsatisfied, prompting continued over-extraction. Without strategies that actively replenish groundwater supplies, regulatory measures alone cannot resolve the issue.

Another approach involves expanding green infrastructure in cities, such as creating green squares, restoring wetlands, and developing urban forests. Increasing permeable surfaces allows rainwater to seep into the soil and recharge aquifers naturally. The Indian government has implemented initiatives like the "Catch the Rain" campaign to promote recharge efforts in both rural and urban areas (National Water Mission, 2025). While green infrastructure is environmentally effective, it faces major feasibility challenges. India's urban population is projected to nearly double by 2050, reaching approximately 951 million people, and an estimated 144 million new homes will need to be built by 2070 (The World Bank,

2025). As population density increases, urban land becomes increasingly scarce and expensive. In rapidly growing cities, it becomes difficult to set aside large areas for green recharge spaces when housing and commercial development take priority. Any sustainable solution must account for environmental impact, rapid urban growth, and enforcement challenges, working within these structural constraints rather than depending entirely on regulation or land availability.

PROPOSED RECOMMENDATION

A viable method to recharge depleted aquifers while addressing India's rapid urban expansion is the development of a detention-infiltration vault recharge system embedded within existing watershed and urban planning frameworks. These underground vaults capture stormwater runoff, temporarily store it, filter out pollutants, and gradually release clean water into underlying aquifers. By integrating these vaults into municipal drainage networks, excess stormwater can be directed into the ground, thus recharging aquifers and increasing India's accessible water supply.

For successful implementation, several structured steps must be followed. First, governments must identify priority watersheds – land areas where rainfall naturally drains – by comparing updated topographical maps with current and planned urban development maps. Ideally, this assessment should occur for existing urban layouts and before new urban infrastructure is approved, ensuring that watershed protection and aquifer recharge are incorporated into the early stages of city planning. India already possesses the necessary datasets to support this process. High-resolution topographic maps from the Survey of India (SOI), the country's national mapping agency (Survey of India, n.d.), digital elevation models generated by ISRO's CartoSAT satellites (Cartosat-1, 2015), and hydrological layers produced by BISAG-N (Welcome to BISAG-N, 2020) collectively provide detailed information on terrain, slope, drainage lines, and watershed boundaries. In parallel, the Central Ground Water Board (CGWB), the scientific department under India's Department of Water Resources, has generated comprehensive aquifer maps through its National Aquifer Mapping and Management Programme (NAQUIM and NAQUIM 2.0) (Aquifer Mapping | CGWB, 2016). These maps identify recharge zones, groundwater flow directions, aquifer thickness, and water quality conditions. By overlaying these datasets with municipal land maps, state and local governments can identify the ideal catchment areas and designate them as priority zones for recharge infrastructure.

Once priority zones are identified, implementation of the detention-infiltration vaults would occur primarily at the local and state government level, with technical support from the CGWB. Similar infrastructure has been utilized in many countries. For instance, in Houston, Texas, USA, St John's School installed an underground stormwater detention vault with integrated infiltration features beneath its athletic fields to reduce flooding, constructed by the U.S firm StormTrap (StormTrap, 2022). Drawing on this demonstrated success, the proposed vaults in India would similarly be constructed beneath public infrastructure, such as roads, parking lots, bus depots, parks, and open fields.

Financing the capital costs of such infrastructure could be achieved by central government programs. AMRUT 2.0, India's flagship urban water mission, provides funding for stormwater management, aquifer recharge, and decentralized water systems (AMRUT 2.0, 2022). In addition, Atal Bhujal Yojana, the scheme that focuses on community-based groundwater management in water-stressed rural regions (Atal Bhujal Yojana, 2026), could also contribute towards funding the recharge planning and monitoring in peri-urban and agricultural zones. Local governments could utilize central government funding initiatives to implement the recharge infrastructure.

Beyond government schemes, the capital costs could also be covered by non-government financing sources. Climate and green finance mechanisms, such as the Green Climate Fund and the Global Environment Facility, prioritize investments that enhance climate resilience and reduce flood risk (Green Climate Fund, 2026a; GEF, n.d.), making them well-aligned with infiltration vault systems. Multilateral development banks, including the World Bank and the Asian Development Bank, already fund water and urban resilience projects in India and could support larger-scale deployments. At the city level, municipal bonds would also offer a way to fund water infrastructure.

Following the initial capital investment, the ongoing operation and maintenance (O&M) of the infiltration vaults could be funded through a dedicated cess tax. State governments would allocate revenue from this source to private engineering firms responsible for the infrastructure construction and long-term maintenance. To ensure accountability and incentivize performance, groundwater levels in each priority zone would be monitored against predefined thresholds. If groundwater levels meet or exceed these targets, a portion of the revenue would be used to provide performance-based bonuses to the private firms, encouraging consistent maintenance and maximizing the effectiveness of the infiltration detention vaults.

A broader set of funding mechanisms can be integrated into the system to make the overall plan more feasible. Land value capture could also be explored to make private-sector participation financially viable (A. Gupta, personal communication, August 29, 2026). After the detention filtration vaults are implemented, the resulting improvements in stormwater management, flood reduction, and the public infrastructure would likely increase surrounding land values and development potential. A portion of this incremental value could be captured through development charges, betterment levies, or other value-capture tools. The revenue generated could then be directed toward funding groundwater recharge infrastructure and long-term O&M costs. In this way, the economic benefits created by climate-resilient infrastructure help finance its own implementation.

Another strategy is the use of Transferable Development Rights (TDR) to encourage private landowners to make strategically located parcels available for groundwater recharge and stormwater detention (A. Gupta, personal communication, August 29, 2026). When a parcel is identified as a critical recharge or drainage area, the owner could be compensated through development rights that can be transferred to another designated zone where additional development can be accommodated. This would allow the city to protect critical water infrastructure and recharge areas while providing an economic benefit to landowners. Therefore, TDR could reduce the public cost of land acquisition and support the creation of a larger network of urban water resilience infrastructure.

It is important to note that while water infrastructure challenges affect much of India, the crisis is particularly acute in Tier 2 and Tier 3 cities, which are mid-sized and smaller urban centers that often lack the regulatory enforcement capacity and infrastructural investment of major metropolitan regions. A WWF report identifies 30 Indian cities that are projected to face major increases in water-related risks by 2050, most of which are Tier 2 and Tier 3 cities (Deol, 2020).

Given these conditions, it would be advantageous to initiate pilot projects in a Tier 2 or Tier 3 city, with a focus on those near agriculture hubs. These cities are large enough to demonstrate measurable impact, yet small enough to allow greater administrative flexibility and lower land acquisition costs. A measurable increase in groundwater levels over a defined period would provide reliable data to create a framework

for scalability across broader urban and rural regions of India. This could be done through a public-private partnership model, in which most capital and O&M responsibilities are transferred from the government to private firms. Under this arrangement, the government would make annuity payments to firms over a 15-20 year period, which aligns with the typical duration of infrastructure projects in India.

A primary limitation of this proposal is the high initial capital and maintenance costs associated with excavation, materials, filtration systems, and long-term monitoring. After a successful pilot and transition into a public-private partnership, project costs will be shared between the government and participating private firms. Additionally, the long-term economic benefits may outweigh these upfront investments. India experiences extensive flood-related damage each year, with more than 40 million hectares of its 329 million total hectares classified as flood-prone (Kumar, 2025). By capturing and slowing stormwater runoff, detention-infiltration vaults would not only recharge aquifers but also mitigate flooding intensity, thereby reducing infrastructure damage and municipal economic loss. Another concern involves the risk of contamination from polluted urban runoff. This risk can be mitigated through multi-layer filtration systems built into the vault design and through careful mapping to avoid highly contaminated industrial zones.

CONCLUSION

As rapid urbanization accelerates groundwater depletion in India, India's population faces declining access to clean water, placing public health and safety at increasing risk. As cities expand into natural catchment areas, aquifers are depleted faster than they can recover, placing millions at risk of long-term water insecurity, particularly residents of Tier 2 and Tier 3 cities, where infrastructure and regulatory capacity are often more limited. Underground detention-infiltration vaults offer a practical response by capturing monsoon runoff, filtering contaminants, and gradually recharging aquifers. In doing so, they would provide more reliable water for households and agriculture while simultaneously reducing urban flooding. Ultimately, strengthening groundwater systems in this way will not only protect infrastructure and agriculture but also safeguard public health and long-term economic resilience for future generations.

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