

UNDERSTANDING THE IMPACT OF URBANIZATION AND CLIMATE CHANGE ON WATER SCARCITY IN JAIPUR CITY

Parveen Kumar, *Ph.D. Research Scholar, GRD School of Planning, Guru Nanak Dev University, Amritsar, Punjab, India*

Dr. Gopal K. Johari, *Associate Professor, GRD School of Planning, Guru Nanak Dev University, Amritsar, Punjab, India*

ABSTRACT

Jaipur, the capital of Rajasthan, is one of the fastest expanding cities in semi-arid India, and its growth trajectory has placed mounting pressure on an already limited water resource base. This paper examines the interconnected role of urbanisation and climate change in driving water scarcity in Jaipur City, drawing on secondary data, planning records and published literature. The urbanisable extent of the city has grown many times over since the first master plan was notified, converting agricultural and open land into built-up surfaces, encroaching upon natural drainage channels and local water bodies, and steadily reducing the land available for rainwater infiltration and aquifer recharge. At the same time, a hot semi-arid climate marked by high evapotranspiration, erratic and declining rainfall, and rising temperatures has reduced the reliability of both surface and groundwater sources. The paper argues that urbanisation and climate change do not act independently but interlock with one another, and with governance and infrastructural deficits, to produce a compounding water crisis. It adopts a multidisciplinary approach that draws together the level of urbanisation, city topography, hydrology, and socio-economic and environmental dimensions of the problem. The paper concludes by outlining the principles of water-sensitive urban planning, centred on nature-based solutions, protection and restoration of local water bodies, wastewater recycling, decentralised rainwater harvesting, and a circular-economy approach to the urban water cycle, as a pathway towards a more water-resilient Jaipur.

Keywords: *Urbanization; Climate Change; Water Scarcity; Jaipur; Nature-based Solutions; Water-sensitive Planning*

1. INTRODUCTION

Water scarcity has emerged as one of the most pressing challenges confronting rapidly urbanising cities in the developing world, and Indian cities occupying semi-arid and arid climatic zones are especially exposed. Urbanisation changes the physical and hydrological character of a city: agricultural land, open ground and natural drainage channels are progressively replaced by roads, rooftops and paved surfaces, which reduces the capacity of the land to absorb rainfall and recharge groundwater, even as the resident and floating population, and with it the demand for water, continues to rise (Kumar et al., 2017). Climate change compounds this pressure by altering the timing, intensity and reliability of rainfall, raising temperatures and evapotranspiration rates, and increasing the frequency of both dry spells and short, intense downpours that generate runoff rather than recharge (IPCC, 2022).

Jaipur City, the capital of Rajasthan and one of India's major metropolitan centres, illustrates this dynamic with particular clarity. Located in a hot, semi-arid tract at the edge of the Aravalli hill system, Jaipur has historically depended on a combination of surface tanks, step-wells, seasonal rivers and groundwater to meet its water needs. Since the notification of its first statutory master plan, the city's urbanisable area has expanded manifold, drawing in adjoining agricultural tracts and satellite towns, while its natural drainage system, centred on the Dhund River and the Amanishah Nala (also known as the Dravyavati River), has been substantially altered by encroachment, channelisation and the discharge of untreated sewage. The consequence has been a steady depletion of groundwater reserves and a widening gap between the demand generated by a growing urban population and the supply that the city's hydrological base can sustainably provide.

This paper undertakes a detailed analysis of the complex relationship between urbanisation, climate change and water scarcity in Jaipur City. It examines the various factors contributing to the intensifying water crisis, including rapid and largely unplanned urban expansion, population growth, the alteration of natural drainage and local water bodies, and a changing climate that is placing additional stress on already limited resources. The paper further considers what has been termed the interlocking set of problems brought on by urbanisation, whereby land-use change, infrastructural deficits and climatic stress reinforce one another rather than operating in isolation. Finally, drawing on the principles of water-sensitive urban planning, the paper outlines a set of nature-based and conservation-oriented approaches through which Jaipur, and cities like it, may move towards a more resilient and sustainable urban water future.

2. REVIEW OF LITERATURE

The relationship between urbanisation and water resources has been examined extensively in the international literature. Classic accounts of the urban hydrological cycle establish that the conversion of permeable, vegetated land to impervious surfaces reduces infiltration, increases surface runoff, and lowers the volume of rainfall that reaches underlying aquifers, even where total precipitation remains unchanged (McKinsey Global Institute, 2016). In the Indian context, this effect is amplified by the pace of urban growth: India's urban population expanded rapidly across the twentieth and early twenty-first centuries, and studies of major metropolitan regions consistently report declining groundwater levels as built-up area increases and natural recharge zones are lost to construction (Kumar et al., 2017). Groundwater, which the Central Ground Water Board estimates meets roughly half of urban domestic water demand in India, is being withdrawn faster than it is replenished in the great majority of urban aquifers, a trend closely associated with the loss of open and vegetated land during urban expansion (Central Ground Water Board, 2022).

A second strand of literature addresses the specific vulnerability of semi-arid and arid cities. Semi-arid urban regions are characterised by high inter-annual rainfall variability, elevated rates of evapotranspiration and a narrow margin between water availability and demand, so

that comparatively small shifts in rainfall timing or volume can translate into significant supply stress (Food and Agriculture Organisation, 1985). Climate projections for India indicate rising mean temperatures, more variable monsoon behaviour, and a tendency towards fewer but more intense rainfall events, a pattern that is expected to reduce the efficiency of natural recharge even where total seasonal rainfall does not decline substantially (Goswami et al., 2006; Intergovernmental Panel on Climate Change, 2021). For cities such as Jaipur, situated within the Thar desert margin, this combination of high natural variability and a warming climate has been identified as a long-standing structural constraint on water security (Khandelwal, 2022).

A third body of work concerns the loss and degradation of urban water bodies. Many Indian cities historically maintained interconnected networks of lakes, tanks and step-wells that stored monsoon runoff, supported groundwater recharge and buffered dry-season demand; encroachment upon, and infilling of, these water bodies during urban expansion has been documented as a recurring feature of Indian urbanisation and a significant contributor to both flooding and water scarcity within the same city (Ministry of Water Resources, 2020). Related studies of Jaipur specifically describe the historical role of the Dhund River in the city's natural drainage, and the progressive narrowing, encroachment and pollution of these channels as urban development has proceeded outward from the historic walled city (Jalan & Sharma, 2014).

A fourth and more recent strand of literature addresses planning responses to the urbanisation water scarcity nexus, with particular attention to nature-based solutions and water-sensitive urban design. This literature emphasises decentralised approaches, including rainwater harvesting, bioretention systems, permeable pavements, constructed wetlands and the restoration of natural drainage corridors, as measures capable of restoring infiltration capacity and recharge potential within already built-up areas (Kabisch et al., 2017). Studies of Rajasthan's own traditional water-management systems similarly point to a long history of decentralised harvesting and community-based water stewardship that offers a template for contemporary adaptation, including state-led rainwater harvesting and watershed programmes that have demonstrated measurable improvements in groundwater recharge in parts of the state. Taken together, this body of work establishes that the physical mechanisms linking urbanization, climate change and water scarcity are well understood in general terms, and that a range of planning responses exists; what is comparatively less developed, particularly for a rapidly growing, semi-arid city such as Jaipur, is a synthesis that connects city-specific patterns of urban expansion and hydrological change to these planning responses in an integrated way.

3. OBJECTIVES OF THE STUDY

The paper is guided by three objectives:

- To examine the contribution of rapid and largely unplanned urbanisation to water scarcity in Jaipur City, with particular attention to land-use change, loss of natural drainage capacity and the depletion of local water bodies;

- To assess how climate change, through rising temperatures, increased evapotranspiration and rainfall variability, compounds this urbanisation-driven pressure on water resources; and
- To outline the principles and practical measures of water-sensitive urban planning that could help address the resulting water crisis, with an emphasis on nature-based solutions appropriate to Jaipur's semi-arid setting.

4. RESEARCH METHODOLOGY

This paper adopts a qualitative, desk-based research design appropriate to a multidisciplinary and integrative analysis of the urbanisation-climate-water scarcity relationship. The study draws on secondary data and documentary sources spanning three broad categories. The first comprises official planning and administrative records, including successive Jaipur master plans, Jaipur Development Authority project documentation, and state government policy statements relating to water resources, urban development and climate adaptation. The second comprises meteorological and hydrological records and assessments, drawing on published India Meteorological Department data and Central Ground Water Board assessments of groundwater availability and extraction, to characterise long-term rainfall variability, temperature trends and the state of groundwater resources in the Jaipur region. The third comprises the peer-reviewed and literature on urban hydrology, climate change and water-sensitive planning, both international and India-specific, used to situate Jaipur's experience within the wider body of research on urbanisation and water scarcity.

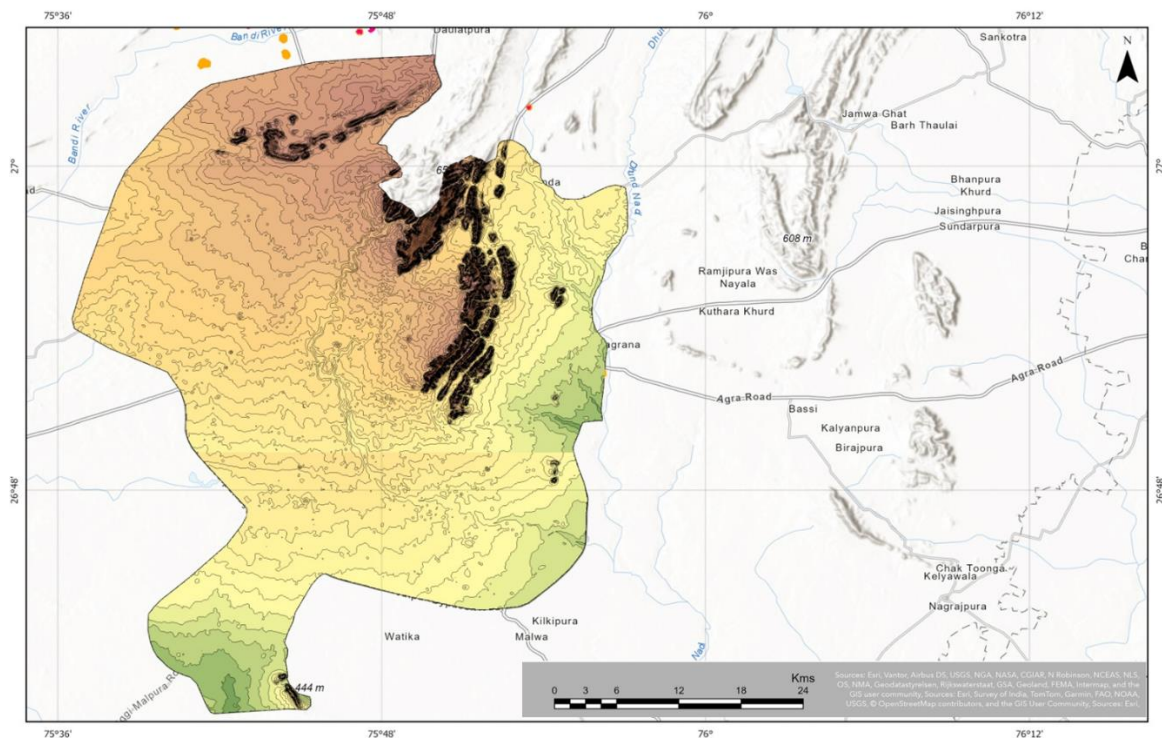
The database and research methodology were structured around a comparative, longitudinal reading of land-use change and hydro-climatic variability, in which successive master plan land-use allocations were examined alongside long-period rainfall and temperature records to identify points of convergence between the pace of built-up expansion and indicators of water stress. Content relating to the condition of the city's natural drainage system and local water bodies was reviewed to assess the extent of physical alteration and encroachment over the period of urban growth. Findings across these sources were then synthesised thematically, following the multidisciplinary approach set out in the introduction, to connect the level of urbanisation, city topography, and hydrological, socio-economic and environmental factors into an integrated account of water scarcity in Jaipur. Finally, the water-sensitive planning literature was reviewed to identify measures, particularly nature-based solutions, of demonstrated relevance to semi-arid Indian cities, from which recommendations appropriate to Jaipur's specific physical and institutional context were drawn. In accordance with the scope of this paper, the analysis is confined to available data, records, and published literature.

5. STUDY AREA PROFILE

Jaipur City, founded in 1727 and designated the capital of Rajasthan, lies within a hot semi-arid climatic zone at the northern margin of the Aravalli hill range. The city is partly enclosed by hill formations, including the Nahargarh and Jhalana ranges, with elevations across the urban area ranging from roughly 280 metres along the Bandi and Dhund river corridors to

around 530 metres in the surrounding hills. This topography channels the city's natural drainage southward and eastward through two principal watercourses, the Dhund River and the Amanishah Nala, which together form a fork-like drainage pattern before converging downstream; a number of smaller seasonal channels drain the surrounding hill slopes into this network.

Figure 1 Physiography of Jaipur City



Source: Esri

Since the preparation of Jaipur's first statutory master plan, the city's urbanisable footprint has expanded substantially, drawing agricultural land, satellite towns and previously rural tracts into the built-up area, a pattern reflected in successive master plans prepared by the Jaipur Development Authority.

According to the comprehensive 2011 Master Plan, the rural area encompasses a significant expanse of 1,087 square kilometres, which accounts for approximately 55.51% of the total land area within the jurisdiction. Out of this vast rural landscape, a portion of 391 square kilometres has been identified as suitable for organisation and development, representing around 19.94% of the overall area. This distinction highlights the limited space available for planned growth within the rural sector.

In addition to the development and organisational aspects, the Master Plan also emphasises ecological sustainability, designating 481 square kilometres specifically for ecological preservation efforts. This area is crucial for maintaining biodiversity and protecting the natural environment from urban encroachment and degradation.

To provide a clearer perspective on land use distribution, a detailed comparative analysis between the land use strategies outlined in the 2011 Master Development Plan and those proposed in the upcoming 2025 Plan is presented in the table below. This analysis provides insights into changes and trends in land management and organisation over the specified period.

Table 1: Land Utilisation as per MDP-2011 and MDP-2025

SN	Land Use	Master Plan-2011		MDP-2025	
		Area (Sq. Km)	Percentage	Area (Sq. Km)	Percentage
1	Urbanisable Area	391	19.94	1587	54.30
2	Ecological Area	481	24.55	894	30.40
3	Rural Area	1087	55.51	450	15.31
Total area		1959	100	2931	100

Source: Master Development Plan, Jaipur

Land-use analysis based on satellite imagery over the past several decades shows the urban core expanding outward at the expense of agricultural and open land, with vegetation cover becoming increasingly fragmented at the urban periphery even as the spatial extent of the city's water bodies has remained comparatively static, meaning that a shrinking share of the total urban area now performs a water-absorbing and recharge function (Jalan & Sharma, 2014). The city's historic reliance on tanks, step-wells and the Dhund-Amanishah drainage system for water security has, over this same period, given way to a heavier dependence on deep groundwater extraction and piped supply drawn from increasingly distant sources, a shift that is itself indicative of the pressure that urban growth has placed on locally available water.

6. URBANISATION, CLIMATE CHANGE AND WATER SCARCITY: AN INTERLOCKING SET OF PROBLEMS

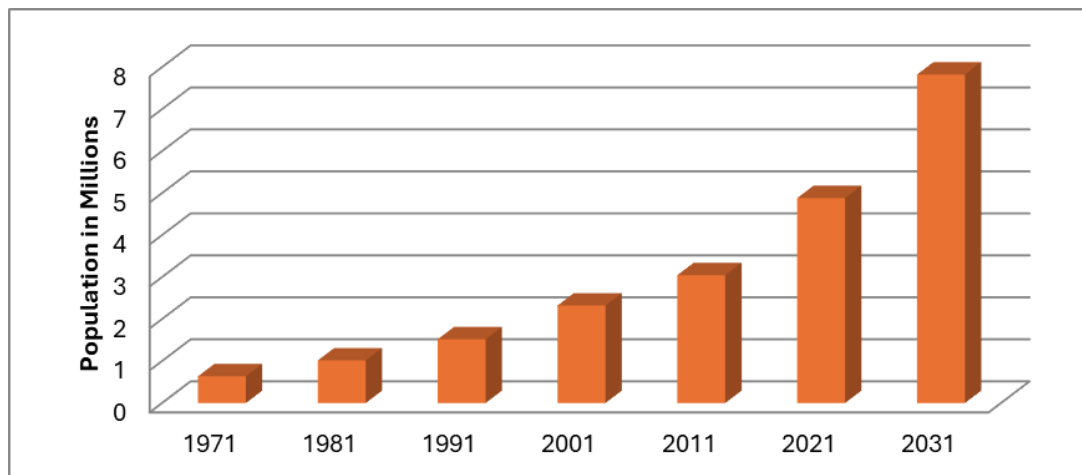
6.1 Urbanisation and the Changing Urban Water Balance

The most immediate driver of water scarcity in Jaipur is the sheer pace and pattern of its physical growth. As agricultural and open land at the city's periphery has been converted to residential, commercial and industrial use, the proportion of the urban surface capable of absorbing rainfall has steadily fallen. Roads, rooftops and paved courtyards shed rainfall as runoff rather than allowing it to infiltrate, so that even where total rainfall in a given season is unchanged, a smaller share of it reaches the water table. This effect is reinforced by the layout of successive master plans, in which residential land use alone accounts for close to half of the city's developed area, with commercial, industrial and circulation uses making up most of the remainder, leaving a comparatively small and fragmented share of land under water bodies, open forest and other permeable cover. Because urban expansion in Jaipur has proceeded largely outward from the historic walled city along existing transport corridors, newly developed peripheral areas have frequently been laid out with limited regard to the underlying

drainage pattern, placing development directly across natural flow paths and reducing the connectivity of the drainage network as a whole.

Population growth compounds this loss of natural recharge capacity by directly raising demand. Jaipur is the largest city in the state of Rajasthan. Jaipur city had a total population of 30.73 lakhs as per the Census of India, 2011.

Figure 2: Population Change in Jaipur City



Source: Census of India

As the resident population of Jaipur has grown, alongside a substantial daily influx of commuters, students and visitors associated with the city's administrative, educational and tourism functions, per-capita and aggregate domestic, commercial and institutional water demand have risen correspondingly. Because surface supply from existing reservoirs has not expanded proportionately, an increasing share of this demand has been met through groundwater extraction, both through the municipal supply system and through private borewells, particularly in peripheral and newly developed localities where piped coverage remains uneven. The result is a widening structural gap between the volume of water the city draws upon each year and the volume that natural recharge processes are able to replace, a gap that groundwater assessments consistently identify as a defining feature of urban water stress in Indian cities more generally.

6.2 Encroachment, Degradation and Loss of Local Water Bodies

A second and closely related dimension of the problem concerns the fate of Jaipur's local water bodies and natural drainage channels. The Dhund River and the Amanishah Nala, together with a number of smaller seasonal watercourses draining the surrounding hills, historically constituted the city's principal natural drainage and groundwater recharge infrastructure. Over the period of rapid urban expansion, this system has been substantially altered: encroachment upon the channel and floodplain of the Amanishah Nala, discharge of untreated or partially treated sewage directly into the watercourse, and construction within areas that once functioned

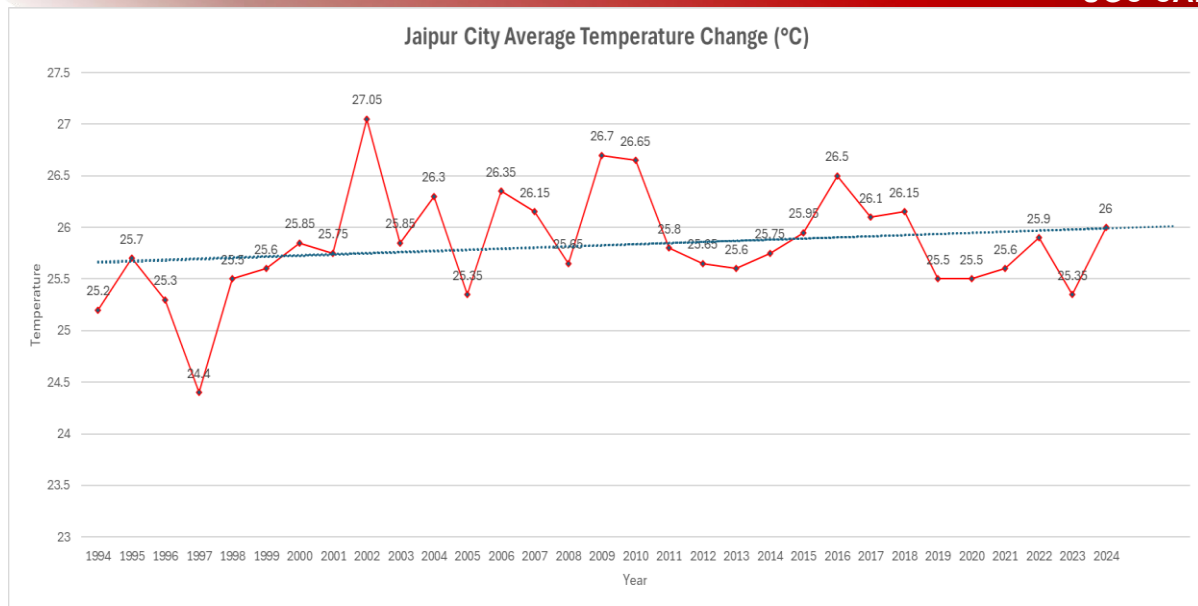
as natural retention and infiltration zones have all reduced the capacity of the system to perform its historic hydrological role. Similar pressures have affected smaller tanks, ponds and step-wells across the city, many of which have been reduced in extent, disconnected from their catchments, or lost outright to development.

The consequence of this degradation is twofold. On one hand, the loss of storage and infiltration capacity in local water bodies removes a supplementary source of water that could otherwise buffer dry-season demand and support local groundwater recharge; the protection of lakes, ponds and wetlands as supplementary water sources is accordingly identified as a foundational element of water-sensitive planning. On the other hand, the same encroachment and channel narrowing that reduces recharge capacity also increases the risk of localised flooding during intense rainfall events, since runoff that would previously have been absorbed or safely conveyed is instead forced through a constricted and partially blocked drainage network. Jaipur therefore exhibits a pattern that has been observed more widely across urbanising Indian cities, in which flood risk and water scarcity are not opposing conditions but two expressions of the same underlying loss of natural water infrastructure (Ministry of Water Resources, 2020).

6.3 Climate Change and the Compounding of Water Stress

Climate change interacts with these urbanisation-driven pressures in ways that further reduce the reliability of Jaipur's water supply. As a semi-arid city, Jaipur has always experienced considerable year-to-year rainfall variability, but the broader warming trend observed across Rajasthan and northern India over recent decades has been associated with rising temperatures, increased rates of evaporation from open water storage, and a tendency towards more erratic rainfall, in which dry spells and short, high-intensity downpours become more frequent even where total seasonal rainfall does not change substantially (Intergovernmental Panel on Climate Change, 2021, 2022). Rising temperatures increase evapotranspiration losses from reservoirs, tanks and irrigated land in and around the city, while also raising domestic and institutional water demand for cooling and hygiene during an increasingly long and intense hot season. Since 1994, the city of Jaipur has experienced a notable shift in its climate patterns, with the maximum temperature consistently surpassing the average threshold. This trend indicates a significant rise in temperature levels over the years. Detailed analyses reveal that the average temperature in Jaipur has been on a steady upward trajectory, reflecting broader climatic changes affecting the region. As a result, the residents of Jaipur have been increasingly facing hotter conditions, which may have implications for daily life, agriculture, and overall environmental health in the area.

Figure 3: Jaipur City Average Temperature Change



Source: IMD

Because intense, short-duration rainfall generates a higher proportion of surface runoff relative to infiltration than more evenly distributed rainfall of the same total volume, a climate trend towards fewer but heavier rainfall events tends to reduce the efficiency of natural groundwater recharge even in years of near-average total rainfall. In a city where impervious surface cover has already expanded substantially due to urbanisation, this climatic shift removes a further margin of resilience: rainfall that does fall is both less effectively absorbed, owing to the loss of permeable land, and less evenly distributed across the year, owing to changing rainfall patterns. The two processes reinforce one another, so that the water stress experienced in Jaipur cannot be attributed to urbanisation or to climate change in isolation, but reflects their combined and mutually reinforcing effect on the city's hydrological balance.

6.4 Interlocking Problems and Socio-Economic Dimensions

The problems generated by urbanisation in Jaipur extend beyond the purely physical dimensions of water supply and are better understood as an interlocking set of challenges. Uneven piped water coverage across the city means that the burden of water scarcity is not distributed evenly: peripheral, informal and lower-income settlements are frequently the last to receive extended piped networks and are correspondingly more dependent on tanker supply, shared standposts and private groundwater extraction, all of which are more vulnerable to seasonal and climatic disruption than a centrally managed piped system.

The Public Health and Engineering Department is tasked with providing water supply in Jaipur city. Within the total municipal area of 467 square kilometres, 215 square kilometres are served by the piped water supply system. Currently, 2.97 million residents of Jaipur are connected to this water supply. The city's present water demand stands at 462 million litres per day (MLD),

while the total supply is only 374 MLD, resulting in a shortfall of 90 MLD. Below are the details regarding water production and supply:

Table 2: Water Production and Supply

1	From Bisalpur system	275 MLD
2	From tube wells (1900 Nos. operated on rotation)	97 MLD
3	From single point tube wells (117 no)	2 MLD
4	Total Supply	374 MLD
5	Deficit	90 MLD

Source: PHED, Jaipur

Encroachment upon natural drainage channels, in turn, is often associated with informal settlement in low-lying and flood-prone land precisely because such land is undesirable for formal development, meaning that the same communities most exposed to water scarcity during dry periods are frequently also most exposed to flooding during intense rainfall. Governance and institutional capacity constitute a further interlocking dimension: the pace of statutory planning revision has in practice lagged behind the pace of actual urban growth, so that development frequently precedes, rather than follows, an updated understanding of the drainage and recharge implications of new construction. Taken together, these dimensions indicate that addressing water scarcity in Jaipur cannot be reduced to a single technical fix, such as augmenting supply from a new source, but requires attention to the land-use, infrastructural, climatic and institutional processes that interact to produce the problem in the first place.

7. TOWARDS WATER-SENSITIVE URBAN PLANNING: NATURE-BASED SOLUTIONS FOR JAIPUR

Addressing water scarcity in a city shaped by the interlocking pressures described above requires a planning approach that treats water not as a utility to be supplied from ever more distant sources, but as an integral part of the urban landscape to be managed, conserved and, where possible, restored within the city itself. This is the underlying premise of water-sensitive urban planning, an approach that emphasises nature-based solutions during the planning process in place of, or alongside, conventional engineered infrastructure. Several inter-related principles follow from this approach and are of particular relevance to Jaipur's semi-arid setting.

7.1 Completing the Urban Water Cycle

A first principle of water-sensitive planning is to give the urban water cycle a chance to complete itself rather than routing rainfall away from the city as quickly as possible through conventional storm drains. In practice, this means designing streets, open spaces and building plots so that rainfall is allowed to slow down, spread out and soak into the ground close to where it falls, rather than being concentrated into high-velocity runoff that overwhelms

downstream channels. For Jaipur, where a growing share of the urban surface has become impervious, even modest interventions of this kind, applied across a large number of individual sites, can meaningfully restore lost infiltration capacity at the city scale.

7.2 Protecting and Restoring Local Water Bodies

A second and closely related principle is the protection of local water bodies, including lakes, ponds, wetlands and the remaining reaches of the Dhund-Amanishah drainage system, as supplementary sources of water and as functioning components of the city's hydrology rather than as residual open space available for development. This entails mapping and legally securing the boundaries of existing water bodies, restoring their connectivity to surrounding catchments where this has been severed, and, where feasible, reversing encroachment that has narrowed or degraded them. Restoration of urban lakes, tanks and drainage corridors of this kind has been shown elsewhere in India to recover both flood-buffering and dry-season storage functions simultaneously, addressing the paired problems of flooding and scarcity.

Table 3 Restoring Natural Drainage Paths in Jaipur City

Technology	Flood Reduction	Groundwater Recharge	Ecology	Cost	Suitability for Jaipur
Nallah restoration	Excellent	High	Excellent	Medium	Excellent
Channel naturalization	Excellent	High	Excellent	Medium	Excellent
Floodplain restoration	Outstanding	Excellent	Outstanding	High	Very Good
Constructed wetlands	Excellent	High	Outstanding	Medium	Excellent
Bioswales	High	High	High	Low	Excellent
Green drainage corridors	Outstanding	High	Outstanding	High	Excellent

Source: Compiled by author

7.3 Promoting Nature-Based Solutions for Stormwater Management

A third principle concerns the promotion of nature-based solutions for stormwater management as an alternative, or complement, to purely engineered drainage. Nature-based solutions, including bioswales, retention ponds, green roofs, permeable pavement and vegetated swales, provide a range of ecosystem services beneficial to the urban environment, capturing and slowing runoff, supporting groundwater recharge, moderating local temperatures and improving air quality, while requiring comparatively modest capital investment relative to large engineered drainage infrastructure (Kabisch et al., 2017). Retention ponds and constructed wetlands, in particular, can be integrated into city parks and public open space, combining recreational value with flood control, sediment settling and natural water treatment functions, while permeable pavements and bioretention areas can be incorporated into streetscapes and parking areas without requiring large dedicated sites.

Table 4 Comparative Runoff Coefficients of Conventional and Permeable Pavement Materials for Jaipur City

Surface Category	Pavement/Surface Material	Typical Runoff Coefficient (C)	Approximate Rainfall Converted to Runoff (%)	Approximate Infiltration (%)	Urban Flood Reduction Potential	Groundwater Recharge Potential	Suitability for Urban Areas
Conventional	Reinforced Cement Concrete (RCC) Pavement	0.90–0.95	90–95	5–10	Very Poor	Very Low	Roads, highways
Conventional	Asphalt/Bituminous Road	0.85–0.95	85–95	5–15	Very Poor	Very Low	Urban roads
Conventional	Conventional Concrete Paver Blocks	0.60–0.80	60–80	20–40	Poor	Low	Footpaths, parking
Conventional	Brick Paving (Mortar Joints)	0.60–0.75	60–75	25–40	Moderate	Moderate	Heritage areas
Conventional	Stone Slab Pavement	0.70–0.85	70–85	15–30	Poor	Low	Plazas, markets
Semi-Permeable	Gravel Surface	0.25–0.45	25–45	55–75	Good	High	Parking, parks
Semi-Permeable	Compacted Earth	0.30–0.45	30–45	55–70	Moderate	Moderate	Open grounds
Permeable	Permeable Interlocking Concrete Pavers (PICP)	0.10–0.30	10–30	70–90	Excellent	Excellent	Parking lots, footpaths, residential streets
Permeable	Pervious Concrete	0.10–0.25	10–25	75–90	Excellent	Excellent	Parking areas, institutional campuses
Permeable	Porous Asphalt	0.15–0.30	15–30	70–85	Excellent	Excellent	Low-volume roads
Permeable	Grass Pavers / Turf Blocks	0.05–0.20	5–20	80–95	Outstanding	Outstanding	Overflow parking, parks, emergency access
Permeable	Gravel Stabilisation System	0.10–0.30	10–30	70–90	Excellent	Excellent	Parking, pedestrian areas
Natural Surface	Grass Lawn	0.10–0.25	10–25	75–90	Outstanding	Outstanding	Parks, open spaces
Natural Surface	Landscaped Garden	0.10–0.20	10–20	80–90	Outstanding	Outstanding	Residential and institutional landscapes

Source: Compiled by author

Permeable pavements allow rainfall to infiltrate through the pavement surface into an underlying aggregate layer, where it is temporarily stored before gradually infiltrating into the soil or being discharged through underdrains. This reduces peak runoff and delays the movement of stormwater into drainage systems.

7.4 Recycling and Reusing Wastewater

A fourth principle is to treat wastewater as a resource to be recycled and reused at comparatively low cost and low energy, rather than as a liability to be disposed of as quickly as possible. Decentralised and low-energy treatment approaches, including constructed wetlands and natural treatment systems, can render wastewater suitable for non-potable uses such as landscape irrigation and groundwater recharge, reducing the net demand placed on freshwater sources while simultaneously reducing the volume of untreated effluent reaching natural drainage channels such as the Amanishah Nala.

7.5 Scaling Up Water Conservation and Rainwater Harvesting

A fifth principle is to increase water-conservation approaches at multiple scales, from the individual plot to the city as a whole, with on-site rainwater harvesting as a central component. Mandating rooftop rainwater harvesting structures connected to storage tanks or recharge wells for new construction, and retrofitting existing buildings where feasible, allows a substantial share of the city's rainfall to be captured and either used directly or returned to the aquifer, rather than being lost as runoff. Rajasthan's own tradition of decentralised, community-managed water harvesting, reflected in state-supported watershed and water-conservation programmes, provides a locally rooted precedent for this approach and demonstrates that such measures can produce measurable improvements in groundwater recharge and land conservation in dry regions when implemented at scale.

Table 5 Rainwater Harvesting Technology Comparison

Technology	Flood Reduction	Groundwater Recharge	Cost	Maintenance	Suitability for Jaipur
Rooftop Storage	High	Medium	Low	Low	Excellent
Recharge Pit	Very High	Excellent	Low	Low	Excellent
Recharge Trench	Very High	Excellent	Medium	Low	Excellent
Recharge Well	High	Outstanding	High	Medium	Very Good
Underground Tank	High	Low	High	Medium	Very Good
Eco Blocks	Very High	Excellent	High	Low	Excellent

Source: Compiled by author

7.6 Community-Oriented and Circular Approaches

A sixth principle concerns the social and ecological value of water-sensitive design, planning and designing the built environment in accordance with community needs and locally experienced water issues, so that interventions are appropriately located and genuinely used and maintained by residents, rather than existing only as engineered features. This requires connecting the urban water cycle across disciplinary boundaries, through collaboration between urban planners, hydrologists, engineers and community organisations, so that

decisions on land use, drainage and water supply are made with a shared understanding of their combined hydrological effect. Embedding these interventions within a circular-economy framework, in which water, and the nutrients and resources it carries, are reused and recycled within the urban system rather than treated as a one-way flow from source to disposal, further increases the benefit that nature-based solutions can deliver, supporting the transformation of cities such as Jaipur towards a more resilient, sustainable and healthy urban environment capable of withstanding the combined pressures of continued urban growth and a changing climate.

8. CONCLUSION AND RECOMMENDATIONS

Water scarcity in Jaipur City cannot be understood as the product of a single cause but must instead be read as the outcome of an interlocking set of processes in which rapid and largely unplanned urbanisation, the degradation of natural drainage and local water bodies, and a changing, semi-arid climate reinforce one another. Urban expansion has steadily reduced the proportion of the city's surface capable of absorbing rainfall and has placed development directly across historic drainage paths, even as population growth has raised the volume of water the city must find each year. Encroachment upon the Dhund River, the Amanishah Nala and the city's smaller water bodies has simultaneously reduced recharge capacity and increased flood risk, demonstrating that scarcity and flooding are two expressions of the same underlying loss of natural water infrastructure rather than unrelated problems. Climate change compounds these pressures by raising temperatures and evapotranspiration and by shifting rainfall towards a more erratic pattern of dry spells and intense downpours, further reducing the efficiency of whatever infiltration capacity remains.

Addressing this compounding crisis requires moving beyond a narrow focus on augmenting supply from distant sources towards a water-sensitive approach to urban planning, grounded in nature-based solutions appropriate to Jaipur's semi-arid context. On the basis of the analysis presented in this paper, the following measures are recommended. First, existing local water bodies and the remaining reaches of the city's natural drainage system should be formally mapped, legally protected and, where degraded, actively restored, so that they can continue to perform both their recharge and flood-buffering functions. Second, rooftop rainwater harvesting should be made mandatory for new construction and actively promoted for retrofit in existing buildings, extending Rajasthan's own tradition of decentralised water conservation into the urban context. Third, nature-based stormwater management measures, including bioswales, permeable surfaces and constructed wetlands, should be systematically incorporated into the design of new streets, public spaces and developments, rather than treated as optional or ornamental additions. Fourth, decentralised, low-cost wastewater recycling should be scaled up to reduce net freshwater demand and to relieve pressure on already stressed natural drainage channels. Fifth, statutory planning processes should be strengthened to ensure that the pace of plan revision keeps pace with the pace of actual urban growth, so that new development is guided by, rather than precedes, an updated understanding of its hydrological implications. Pursued together, and grounded in genuine collaboration between planners, hydrologists, engineers and the communities most directly affected, these measures offer a realistic pathway towards a more water-resilient Jaipur,

capable of absorbing the combined pressures of continued urbanisation and a changing climate rather than being progressively depleted by them.

REFERENCES

- Central Ground Water Board. (2022). Dynamic ground water resources of India. Ministry of Jal Shakti, Government of India.
- Food and Agriculture Organization. (1985). Rainfall and evapotranspiration. FAO.
- Goswami, B. N., Venugopal, V., Sengupta, D., Madhusoodanan, M. S., & Xavier, P. K. (2006). Increasing trend of extreme rain events over India. *Science*, 314(5804), 1442-1445.
- Government of Rajasthan, Forest Department. Climate resilient Rajasthan: Mukhya Mantri Jal Swavlamban Abhiyan as a climate change adaptation model for tropical dry regions of India. Government of Rajasthan.
- Guru Ramdas School of Planning, Guru Nanak Dev University. (n.d.). Study area profile records, Jaipur City.
- Intergovernmental Panel on Climate Change. (2021). Climate change 2021: The physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the IPCC. Cambridge University Press.
- Intergovernmental Panel on Climate Change. (2022). Climate change 2022: Mitigation of climate change. Contribution of Working Group III to the Sixth Assessment Report of the IPCC. Cambridge University Press.
- Jaipur Development Authority. (n.d.). Dravyavati River rejuvenation project. Government of Rajasthan.
- Jalan, S., & Sharma, K. (2014). Spatio-temporal assessment of land use/land cover dynamics and urban heat island of Jaipur City using satellite data. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XL-8.
- Kabisch, N., Korn, H., Stadler, J., & Bonn, A. (Eds.). (2017). Nature-based solutions to climate change adaptation in urban areas. Springer.
- Khandelwal, S. (2022). Changing pattern of water supply system in Jaipur metropolitan (Rajasthan, India). *International Journal of Applied Research*, 8, 34-39.
- Kumar, M. D., Bassi, N., Kishore, A., & Bhaduri, A. (2017). Groundwater in urban India: Challenges of governance and management. In *Water Policy in India* (Reprint). Sage.
- McKinsey Global Institute. (2016). Urban world: The global consumers to watch. McKinsey & Company.
- Ministry of Water Resources, River Development and Ganga Rejuvenation. (2020). Report of the working group on urban water bodies. Government of India.