Sustainable urban development: a case study on green infrastructure implementation in Kota City, India

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ABSTRACT

Kota city is known as an educational city which having a rapidly growing population. As urbanization accelerates, there is an increasing need for sustainable urban development practices to address the city's environmental and social challenges. One such approach is the implementation of green infrastructure, which incorporates nature-based solutions to enhance the city's ecological health, reduce environmental stress, and improve the quality of life for its residents. The implementation of sustainable urban management approaches like green infrastructure; storm water management; water filtration plants; solar, wind, nuclear and hydro power generation; sustainable transportation and red-light free zone would help to reduce the energy demand, pollution of city as well as the drinking water for each person. These approaches can help for sustainable urban development.

1. Introduction

Sustainable urban development is crucial to creating cities that support the well-being of residents while protecting the climate for future generations. Green infrastructure is one such solution that integrates natural systems into urban planning to address environmental, social, and economic challenges. Sustainable urban development increasingly relies on the implementation of green infrastructure (GI) to address environmental challenges and enhance urban ecosystems [1]. This strategy brings natural processes into city planning, enhancing climate change resilience along with community well-being.

Kumar (2024) [2] assessed the contribution of green infrastructure in sustainable urban development by using case studies, with benefits such as better air and water quality, increased biodiversity, and climate resilience highlighted, and recommendations for successful integration into urban planning and policy provided. GI offers several benefits, such as better air and water quality, increased biodiversity, and less urban heat island effect. Availability of green areas is responsible for human health, mental well-being, and recreation. Chandratreya (2024) [3] discussed the green infrastructure (GI) as a green urban development strategy, mentioning methods such as rain gardens and green roofs. Raghubanshi(2024) [4] critically compared the green city projects internationally, comparing plans, achievements, and setbacks of incorporating sustainability strategies into urban growth, determining optimum practices

and recommendations for improving city sustainability and the quality of life in the wake of urbanization and climate pressure. The case study demonstrated how GI was influential in stormwater management, enhancing water quality, and encouraging climatic resilience within cities. Methods like rain gardens, permeable pavements, and green roofs have worked effectively in stormwater management and restoring habitats. Green city initiatives' comparative studies identify successful strategies and challenges in adopting sustainability principles in different regions.

Sokolova et al (2024) [5] analyzed the function of green infrastructure in delivering urban ecosystem services via a bibliometric analysis, underlining the need for integrated solutions to improve human well-being, urban resilience, and city sustainability. He et al (2024) [6] introduced a comprehensive framework for urban green infrastructure, integrating ecological principles and adaptive management to reconcile biodiversity conservation with sustainable urban development, enhancing ecosystem resilience and services in urban landscapes. Adesina et al (2024) [7] explored the integration of green infrastructure into urban planning for sustainable development, assessing its environmental, social, and economic benefits, and identifying best practices and challenges in implementation across diverse urban settings. Pachouri and Kothari (2024) [8] investigated the effectiveness of green infrastructure in five Indian cities, demonstrating its positive impact on environment, economy, and society, but highlights maintenance costs, funding, and public awareness as key challenges to its implementation. This literature analysis of , Neto et al (2024) [9] examined the multifunctional networks and water-focused approach of Green Infrastructure, revealing diverse definitions and applications, and challenging the assumption that GI is exclusively limited to water-related issues, with 4,395 identified articles. Singla (2024) [10] explored the intersection of green building technologies and urban planning to foster sustainable urban development, highlighting innovations that mitigate environmental impact, enhance quality of life, and reduce energy consumption and carbon emissions in urban environments.

Urban Green Infrastructure (UGI) plays a pivotal role in shaping sustainable cities by enhancing environmental quality, social well-being, and economic resilience. It involves different elements like green space, urban forests, green rooftops, and pervious surfaces. UGI helps in reducing environmental problems, achieving social health, and facilitating economic development [11]. Green infrastructure provides different possibilities for responding to climate change threats in small towns such as reconfiguring green areas management strategies, arresting erosive runoffs, appreciating wetlands, and greening waterways and riverbanks [12].

Urban green infrastructure networks within the context of eco-city are efficient ways of addressing environmental emergencies resulting from urban sprawl. The Ghare-Kahriz River corridor in Arak, Iran, is a perfect example of how such networks are needed. This paper seeks to improve the environmental performance of the Ghare-Kahriz corridor through the formulation of a multi-functional urban green infrastructure network. The findings revealed that the hot spot with minimum vegetation was adjacent to the river corridor. Plategies for linking and reinforcing existing patches and corridors in ecosystems by ecologic planning of the Ghare-Kahriz urban river corridor are proposed.

An integrated sustainable development strategy is essential for the reconstruction of cities after conflict, with economic, social, and environmental dimensions, and using innovative technologies, energy efficiency, and green building to enhance quality of life and urban sustainability [13]. Li (2024) [14] examined the sustainable development strategies in urban planning, focusing on green building standards, energy efficiency, renewable energy, and biodiversity conservation to ensure balanced economic, social, and environmental development in cities. Breed et al (2023) [15] explored the

operationalizing green infrastructure planning in sub-Saharan African cities through collaborative approaches, using a case study of Tshwane, South Africa, to identify locally informed objectives, planning principles, and strategies for GI planning and management. Urban green infrastructure plays a key role in sustainable community planning and improving quality of life. It requires reorganization of urban gray infrastructure and conversion of spaces into green spaces and sustainable mobility infrastructure [16]. Bacic et al. (2024) [17] developed a fuzzy decision-making valuation model for urban green infrastructure in Zagreb, utilizing fuzzy AHP for weighting criteria and TOPSIS for prioritizing city districts, aiding sustainable urban development through effective land management and spatial planning. Sagovits and Pozoukidou (2022) [18] presented the methodology used to develop a strategic spatial planning approach for green infrastructure in the metropolitan city of Thessaloniki, Greece. This can be seen as one of the most appropriate and diverse approaches that can change constantly to constantly change.

In this case study, green infrastructure, -zoos and fauna repositories as well as case studies used to discuss effects, effects, withholding and challenges and challenges. Green infrastructure is an interconnected network of natural systems (parks, greenery, urban forests, wetlands, permeable surfaces, and so on), which provides users in urban areas around ecological, social and economic benefits. Unlike built infrastructures that rely on man-made infrastructure like roads and buildings, green infrastructure utilizes natural environments to manage stormwater, reduce pollution and improve quality of life.

2. Case Study: Kota City, India

2.1. Background of Kota City

In the southern region of Rajasthan, Kota is situated beside the Chambal River as show in Fig. 1. After Jaipur and Jodhpur, it is Rajasthan's third-largest city. 25.18°N 75.83°E are the coordinates on the map.[20] It is 221.36 km2 (85.47 sq mi) in size. Kota, India is the third-largest city, has actively integrated green infrastructure into its urban development to address sustainability challenges such as climate change, rapid urbanization, and water management.

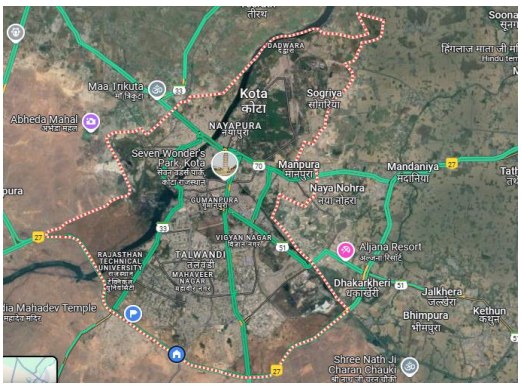


Fig. 1. Google map of Kota city

Kota was established as a walled city in the fourteenth century. A Kotya Bhil warrior created it by erecting a mud wall around the stronghold at Akelgarh. The Kotya Bhil warrior who constructed a modest stronghold at Akelgarh 800 years ago and erected a protective mud wall around it all the way to Retwali is responsible for the foundation of modern-day Kota. Rao Madho Singh reinforced the wall and fortress in 1580. The thermal power plants, gas power plants, nuclear power plants, biomass power plant and hydro power plants are established by government in Kota city or near to Kota. The nuclear and hydro power plants are helps to increase the sustainability index reduce the environment pollution

[19]. With more over 1.5 million residents as of 2024, Kota, India, is the third most populous city in Rajasthan. Kota has experienced significant urban growth and population pressure, leading to increased demand for resources and higher environmental degradation. With an average of 1.5 billion residents added to the city every decade, the municipality faced challenges like heat atoll effects, pollution and loss of biodiversity. In response, the city began focusing on sustainable urban design by incorporating green infrastructure strategies to enhance the urban environment and promote resilience. The key initiatives taken for Green Infrastructure development in Kota.

2.2. Green roof and Plantation at Roofs

Kota has introduced the concept of green buildings which involves covering buildings with plantation at the roof top to reduce energy consumption and provide stormwater management. The roof is also covered by the green mesh which insulates buildings, lowering energy needs and mitigating the urban heat island effect. In addition vegetated facades on buildings are being used to improve air quality and biodiversity while reducing heat absorption. Some of important rooftop gardens are shown in Fig. 2.

(a) Clarks Premier Kota

(b) B2bf cafe in Talwandi, Kota

(c) Green roof at a house

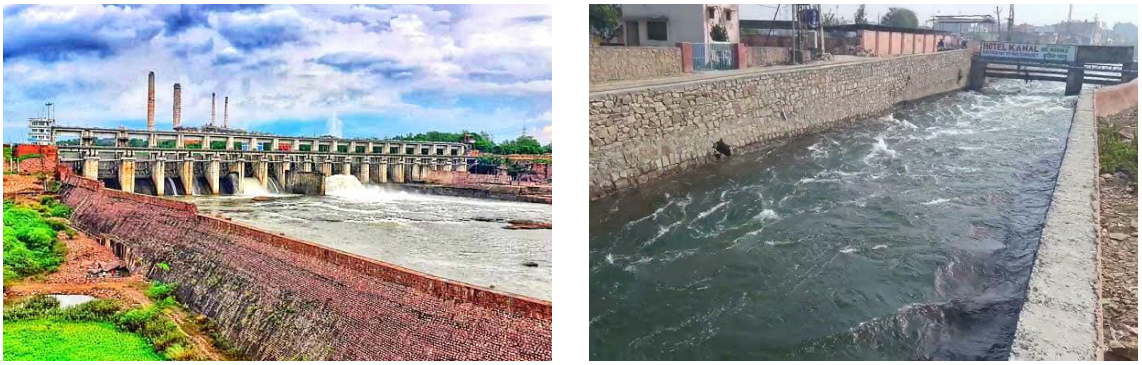
(d) Green roof with garden at a house

Fig. 2. Green rooftop and roof plantation in Kota city

2.3. Stormwater Management

Kota's Stormwater Harvesting Program has helped the city manage runoff by capturing rainwater which is automatically managed because the Kota city is situated at the bank of Chambal River and the inclination of the city surface is god created or managed towards the river. The collected water in the Kota barrage in Chambal River is using for irrigation and other uses through right and left main canals

as shown in Fig. 3. This reduces the demand for potable water and prevents pollution from stormwater entering the city's drainage systems. The city also uses "filtration plants" for water filtration from open channels and wide open channels to allow rainwater from ground to the running off into storm drains and falls in to Chambal River.



(a)Kota Barrage (b)Left main canal

Fig. 3. Kota Barrage and Left main canal in Kota city

2.4. Urban Forests and Green Parks

Aiming to increase the tree canopy, Kota has planted thousands of trees to enhance air quality, reduce heat, and improve the aesthetic value of the city. Urban forests are also part of the city's strategy to combat the urban heat island effect by providing shade and cooling. The city's urban forestry efforts have included greening public spaces and streets to create ecological corridors for wildlife and offer green areas for residents. Parks such as the Royal Park and the Royal Botanic Gardens are central to Kota's green infrastructure strategy. These spaces help reduce pollution, offer recreational opportunities, and provide habitat for native species. New parks and green spaces are being created as part of residential and commercial developments, ensuring that nature is integrated into daily urban life.

The main gardens in Kota city are Chambal Garden, Traffic Park, C.V. Garden, Seven Wonders, Sukhdham Kothi, Nehru Park, Ganesh Udyan, River front and City Park as shown in Fig. 4. The many small garden or green parks are available in each society which is developed by UIT and Housing Board. The state government has taken initiatives by "Ek Ped Maa Ke Naam" which helps to increase the forest and green belt. Sh Om Birla Lok Sabha Speaker Government of India has also initiated the bulk plantation (in Lakhs) in Kota City and distributed plants to the peoples. He also supports the peoples who want to work with green and clean Kota.

(a)Kota Barrage (b)Left main canal

(c)Traffic Park front view

(d) Traffic park side back view

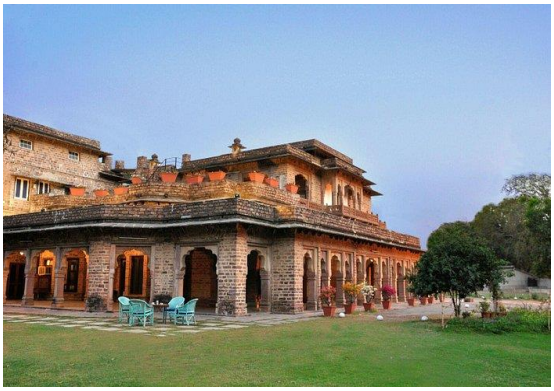
(e) Chhar Bag

(f) Seven wonders

(g) C.V. Garden view-1

(h) C.V. Garden view-1

(i)Jagmandir Kishore Sagar



(j) Sukhdham Kothi

(k)Main Gate Nehru Garden

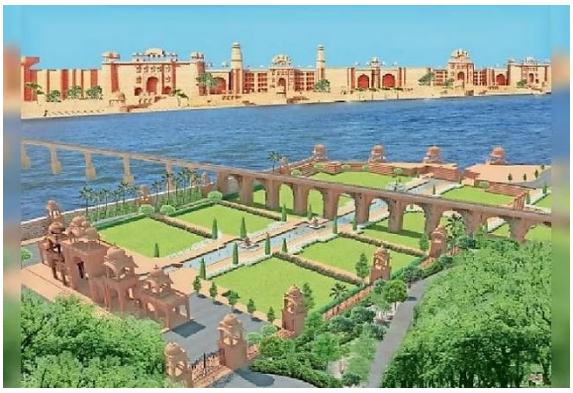
(l) Nehru Garden

(m)Ganesh Udyan-1

(n) Ganesh Udyan-II

(o) City Park-I

(p)City Park-II



(q)River Front-I

(r) River front-II

Fig. 4. Green Parks in Kota City

2.4.1. Benefits of Green Infrastructure in Kota

- Water Conservation: Rainwater harvesting and natural water body restoration have improved the city's water management systems.
- Heat Reduction: Green spaces and urban forests help cool down the city and combat the urban heat island effect.
- Improved Quality of Life: Parks and green areas offer recreational opportunities, improving residents' health and well-being.
- Biodiversity Conservation: The integration of green corridors and water bodies has enhanced local biodiversity.
- Flood Mitigation: Restoring lakes and wetlands has helped reduce urban flooding during the monsoon season. For this diversion channel was constructed for divert the flood water which was coming from dense forest to Kota city.
- Development of Green Infrastructure: Community woods provide local flora and fauna habitat and help decrease the carbon foot print of the city.
- Air and Water Quality: Wetland restoration and leveraging tree plantation to create skies shall lead to better quality of life for the residents.
- Improving Air Quality: Urban forests and tree plantation projects help to minimize air pollution via air filtration and improvement of air quality.
- Water Sustainability: Rainwater treatments and stormwater management reduce strain on supply, helping ensure sustainability for the water use for the city.
- Climate Change Adaptation: Green spaces and arboreal planting mitigate urban heat island effects, which also lowers temperatures and promotes thermal comfort for residents

2.5. Rooftop Solar PV systems

In India's Rajasthan state, Kota City has a good level of solar irradiance due to its climate conditions, and this is effect directly the power generation by rooftop solar photovoltaics. The average sunny day per year for Kota is 300, making it highly suitable for solar energy generation [20]. The area receives good sunshine for the transformation of solar energy into electric power, which stands at about 5.5-6.0 kWh per square meter per day. The Government Policies and Incentives have been taken for the rooftop PV systems as follows: Rajasthan Solar Energy Policy: The state of Rajasthan has a supportive solar policy that propagates solar systems, including rooftop solar. Net Metering: The net metering system allows the grid to be fed with the excess electricity produced by the rooftop solar systems, whereby the consumers get credits which reduce their electricity bills; Central Government Incentives: The Government of India under its National Solar Mission (NSM) and other schemes such as Grid-connected Rooftop Solar Programme offer subsidies to reduce the initial capital cost for households and businesses.

There is increasing awareness about the benefits of rooftop solar among residential users in Kota, especially in areas where electricity tariffs are high and power cuts are frequent. Solar systems can help reduce electricity costs and provide a reliable power source. Many industries in Kota, particularly in the manufacturing and education sectors, are exploring solar power as a sustainable and cost-effective energy

source. Commercial buildings and factories are increasingly adopting rooftop solar to meet their energy demands. Some of the examples for academic institutions, home applications and industrial applications are shown in Fig. 5.

(a) 650kW PV Plant at RTU Kota (b) 10kW at roof top solar PV

Fig. 5. Roof top Solar PV in Kota City

Kota's sunny climate and the support of government policies make rooftop solar PV a viable and attractive option for residents and businesses. While the challenges like awareness and initial costs are exist the increasing adoption of solar energy and available incentives point towards a bright future for rooftop solar PV in Kota.

2.6. Sustainable Transport: The "Green Loop"

Kota's "Green Loop" project involves creating a network of cycling paths and green walking routes that connect key areas of the city. These routes, integrated into green corridors, encourage active transportation while reducing car dependency and traffic congestion. Bharat stage- VI transportation automobiles are registered in Kota city. The CNG and Electric Vehicles (EV) are the promising sustainable options for transportation in present time. The persons of Kota city prefer CNG and EV systems in present time. Approximately 3000 E-Rickshaw, 2000-EV cars are registered in last year and it continuously increasing day by day. So many CNG pumps and EV charging stations are allotted by the government at various feasible locations in the city as well as on highways. The pollution check of vehicles is compulsory as per government norms and there is a penalty also imposed if any person doesn't have pollution certificate of their vehicle. Some CNG and EV vehicles in Kota city are presented in Fig. 6.

(a) CNG Auto (b) EV Auto (c) EV Car

Fig. 6. Sustainable transportation system in Kota City

2.7. Effect of Green belt on environmental temperature of particular areas in Kota city

The atmospheric temperature of various locations have been measured which is presented in Fig. 7. It is observed that the dense forest or dense green area like Chhar Bagh, Nehru Park and C.V. Garden

found lowest temperatures for whole day and for other areas temperatures is depends on the greenery of the area so that location temperature is observed accordingly in the same Fig. 7. The highest temperatures or peak temperature is observed by 48 °C at 2 PM at KUK where lowest green belt is observed.

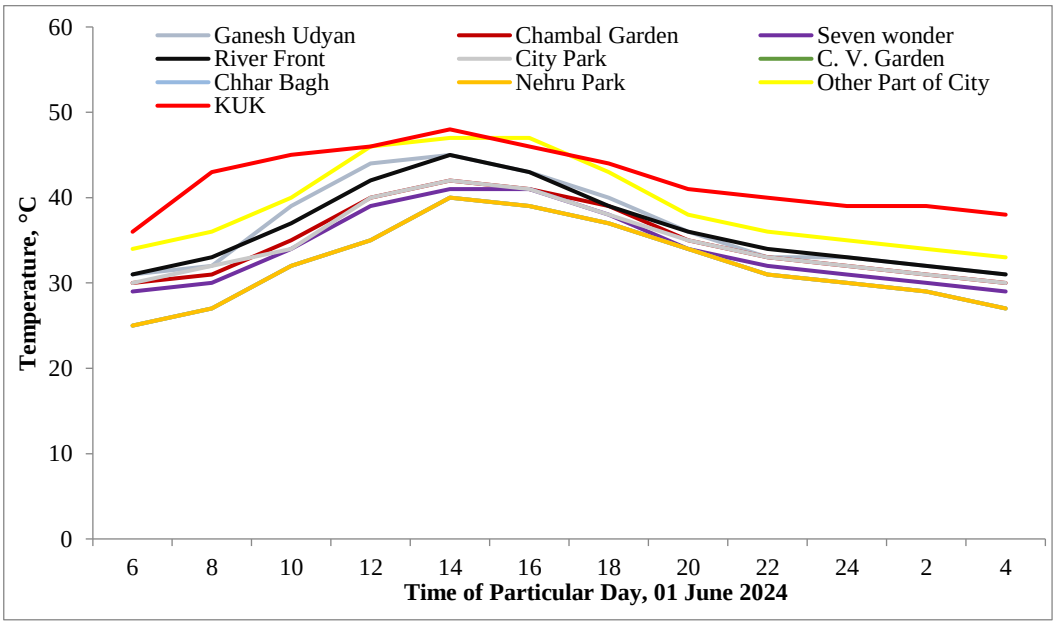


Fig. 7. Effect of Green belt on environmental temperature of particular areas in Kota city

3. Results and Discussion

3.1. Benefits of Green Infrastructure in Kota

3.1.1. Environmental Benefits

- Water Management: The city's green infrastructure reduces stormwater runoff and improves water quality. By using rain gardens and permeable pavements, Kota mitigates flooding and reduces the burden on the traditional drainage system.
- Biodiversity Conservation: Besides Minimizing biodiversity loss, the establishment of green corridors and the planting of trees can introduce habituated for a variety of species and support the maintenance of ecosystem services that benefit human survival.Climate Resilience: Green infrastructure will benefit Kota in terms of climate change adaptation by way of urban cooling, thus serving as a repertoire against heat waves-pertinent especially in a city that faces major fluctuations in temperature.

3.1.2. Social benefits

- Health and Well-being: Access to green spaces encourages physical activity, reduces stress, and enhances mental health. Green areas provide space for recreation and social interaction, improving the quality of life for residents.
- Equity: By making parks and green spaces a priority for developing neighbourhood, the city guarantees every resident, regardless of socio-economic standing, is afforded access to nature.

3.1.3. Economic Benefits

- Cost Savings: Green infrastructure concepts such as rainwater harvesting and the employment of green roofs reduce the long-term maintenance cost on infrastructure since they lessen reliance upon traditional systems.
- Property Value Increases: Properties located near parks or green spaces have higher property values. This can lead to increased tax revenues for the city and attract investment.
- Job Creation: The installation and maintenance of green infrastructure create jobs in landscaping, horticulture, and urban planning

3.2. Conclusions and recommendations

- Initial Costs: Implementing green infrastructure projects may have up-front costs associated with design, installation, and long-term maintenance. Though benefits will be apparent after implementation, some cities may have difficulty managing this initial credit burden.
- Space Constraints: The biggest limiting factor for most city green space strategies concern the land availability within a given boundary. In densely occupied cities, the land needed for parks, green roofs, or even tree planting will be minimal. Meeting the rising demand for green space together with the increasing need for housing and infrastructure will invariably remain a challenge.
- Maintenance and Management: Green infrastructure requires regular maintenance to ensure its effectiveness. Cities need to have adequate resources and management strategies in place to maintain green spaces, manage invasive species, and monitor the health of vegetation.
- Community Engagement: Successful green infrastructure projects rely on community engagement and support. It is essential to involve local residents and businesses in the planning and maintenance processes to ensure long-term sustainability.

3.3. Sustainable Architectural Work Required for future

Sustainable architectural work is crucial for the future, considering the growing challenges of climate change, resource depletion, and urbanization. Architects play a pivotal role in designing buildings that minimize environmental impact, promote energy efficiency, and contribute positively to the well-being of occupants and communities. The following are the key aspects of sustainable architectural work that will be required in the future [21]–[30].

3.3.1. Energy Efficiency and Net-Zero Buildings

- Passive Design: Future architecture will prioritize passive design strategies such as natural lighting, ventilation, and insulation to reduce energy consumption.
- Net-Zero Energy Buildings: These buildings will generate as much energy as they consume, often through renewable sources like solar panels, wind turbines, or geothermal systems.
- Energy-Efficient Materials and Technologies: The use of materials like high-performance insulation, energy-efficient windows, and smart systems for lighting and HVAC (heating, ventilation, and air conditioning) will be essential to reduce energy needs

3.3.2. Carbon Footprint Reduction

- Low-Carbon Materials: Sustainable buildings will incorporate materials with lower embodied carbon, such as recycled or locally sourced materials, and products with a minimal environmental impact.

- Carbon Sequestration: Some buildings may include technologies or design strategies that capture and store carbon, reducing the amount of carbon released into the atmosphere.

3.3.3. Circular Design and Waste Minimization

- Adaptive Reuse: Repurposing existing buildings rather than demolishing them will become more common, reducing the need for new construction materials and minimizing waste.
- Recycling and Upcycling: Architects will design buildings that can be easily deconstructed and the materials reused at the end of their life cycle, promoting a circular economy.
- Modular Design: Buildings that are flexible and adaptable, using modular components, will allow for easier changes and future expansion without significant waste.

3.3.4. Water Conservation and Management

- Rainwater Harvesting: In sustainable designs, collecting rainwater and using it in toilets and irrigation works and other non-potable applications will take center stage.
- Greywater Recycling: Recycling greywater from sources like sinks, showers, and washing machines for non-potable applications will reduce such water use.
- Water-Efficient Landscaping: Water-efficient landscapes in buildings will showcase drought-tolerant plants in conjunction with efficient irrigation systems.

3.3.5. Sustainable Urbanism and Green Infrastructure

- Green Roofs and Walls: Planting greenery on roofs and walls in buildings will help insulate structures, mitigate urban heat islands, and improve air quality.
- Urban Farming: Building space for edible plants such that green roofs or vertical farms will thus enhance food security and reduce food miles.
- Integrated Green Spaces: Constructs that flow into the parks and greenways help sustain biodiversity, besides fostering health among residents.

3.3.6. Smart Technologies and Building Automation

- Smart Systems: Developers will incorporate modern smart technology to monitor and control energy consumption, lighting, temperature, and other factors to optimize resource use.
- Building Information Modeling (BIM): BIM and other digital instruments will be embraced by architects in optimizing designs and maintaining low waste, high efficiency, and a sustainable building life cycle.

3.3.7. Resilience to Climate Change

- Mitigation of Climate Change: Concerns about climate change will be addressed by designing buildings to respond to the local climate conditions either through passive cooling, internal heat protection, or other strategies for mitigating the estimated impacts of climate change.
- Flood-Resilient Architecture: In areas susceptible to flooding, buildings will either be elevated or constructed with materials and mechanisms allowing for flood resistance.

- Heat Island Effect Mitigation: In areas with dense populations, sustainable architecture will target on decreasing the urban heat island effect through careful use of reflective surfaces, shading, and more vegetation.

3.3.8. Social Sustainability

- Sustainable Architecture: The affordably Housing aspects will include provide a background of environment-friendly and energy-efficient housing.
- Community-Friendly Design: As light homes are designed for the community, they will serve as spaces for social interactions, mental health, and plus access for all.
- Equity and Inclusivity: Making sure that all designs for sustainability are available to all social groups, particularly vulnerable groups and populations.

It helps passive ways of improving the ventilation in buildings, the heating and cooling of buildings of considerable performance.

4. Conclusion

The implementation of green infrastructure in the City of Kota is an excellent example of how cities can integrate nature into the built environment for the mitigation of environmental, social and economic challenges. Kota is now paving the path for a more sustainable, resilient, and livable urban space by the adoption of various initiatives, such as green roofs, stormwater management, urban forests, sustainable transport, etc. And while there are challenges (costs, space, maintenance, etc.), the benefits of green infrastructure—from greater biodiversity and improved public health to lower infrastructure costs—make it a win-win solution for sustainable urban development. With an enduring focus on nature-based solutions, Kota offers a blueprint for cities trying to use green infrastructure to address the challenges of dense urbanization. Despite these challenges, green infrastructure has a bright future in India. With increasing awareness, cities are slowly starting to invest in sustainable urban planning which yields myriad benefits including climate resilience, environmental protection and public health. Green infrastructure is essential for sustainable urban development in India. The story is different in numerous other cities such as Kota, Bengaluru and Delhi that have approached stormwater management, air pollution generation, heat islands and better human well-being through different types of green infrastructure solutions. Yet, with obstacles like space limitations, funding, and maintenance, these plans need to find solutions before reaching their full potential. Through continued innovation, public–private partnerships, and community involvement, green infrastructure can be a core element in India's journey to sustainable urbanization. While India has made significant strides in implementing green infrastructure, challenges remain: 1) Space Constraints: In densely populated cities, available land for green spaces is limited, which makes it difficult to implement large-scale green infrastructure projects; 2) Financial Resources: The upfront costs of implementing green infrastructure—such as restoring lakes or creating green roofs—can be substantial, and local governments may struggle with funding; 3) Maintenance: Long-term maintenance of green infrastructure projects requires ongoing investment and community engagement to ensure their success; 4) Climate Change: Extreme weather events such as floods and heat waves may stress existing green infrastructure, requiring ongoing adaptation. The proposed Sustainable approaches for future work in Kota: (Initiate the Procurement of EV buses for city transportation, more aware to the peoples is required for rooftop solar PV installations, more aware to the peoples is required for clean and green Kota city, the wind mills may be installed at the bank of

Chamber River where low wind more than 3 m /s is available throughout the year, more water ponds are required to collect the rain water and beautification of city

Declarations

Author contribution. Shiv Lal contributed article gramework, basic concept, data verification and editing; Saaransh Choudhary contributed the primary writing of manuscript and Ashok Kumar Kakodia edited the manuscript

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