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Sponage Cities:
A Resilient Approach to Urban living for Disaster Management

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Abstract : With increasing challenges due to natural disasters, and climate change, "Sponge Cities" has emerged as a ground-breaking solution for effective disaster management. The main goal of building these cities is to limit the impact of floods and increase the overall resilience of urban cities. These cities prioritize sustainable water management, steering away from traditional drainage-centric approaches that often create water scarcity during extreme weather events. Sponge Cities actively absorb water through innovative features like rooftop gardens, permeable roads, rainwater harvesting, and strategically placed blue and green spaces such as ponds, lakes, and parks. These elements prevent flooding and address water scarcity concerns by efficiently storing and distributing water resources. These components absorb rainwater and reduce surface runoff by acting as natural sponges. Green areas also contribute to the visual appeal of urban landscapes, improve air quality, and promote the well-being of city dwellers in addition to flood avoidance. Pioneered by China, Sponge Cities have been successfully implemented in various urban areas, significantly reducing flood risks and creating more livable and sustainable environments. Beyond flood prevention, these cities enhance urban landscapes, contribute to the well-being of people, improve air quality, and reduce the harsh effects of climate change. Residents play a crucial role in transforming their city into a sponge city by actively participating in public awareness and educational initiatives, engaging in community-driven efforts, and supporting public-private partnerships. These collective actions foster a more sustainable and enjoyable urban environment.

In summary, Sponge Cities represent a crucial shift in disaster management, offering a sustainable approach to urban planning.

Index Terms **- City, Flooding, Sustainable, Urban Planning**

I. INTRODUCTION

Flooding is the most common and prevalent natural disaster in the world, wreaking havoc on lives and economy alike. Recent global environmental concerns are primarily the result of intensified human activity, fast population increase, and hastened urbanization. The effect of urban storm water runoff on the urban environment has become one of the more pressing concerns among these challenges. Urban flooding disasters are caused by a combination of causes, including rainfall patterns, the extent of urban development, and the insufficiency of drainage systems. As sewage pipes and storm water pipes are mixed and misconnected, the sewage water is discharged into urban water channels, resulting in water pollution that deteriorates the water management system. It is urgently needed to develop an effective system for water management and waterlogging prevention.

The concept of the “sponge city” was developed in 2013 to address urban water management challenges in China and rebuild a harmonious relationship among people, water and city. The sponge city concept refers to a way of urban management that allows cities to resolve waterlogging, improve water storage and discharge capacity, enhance water quality, and alleviate heat island effects through nature-based and grey solutions, by applying the concept’s six technical measures - "infiltration, retention, storage, purification, utilization and discharge".

In2015, Wuhan started to implement the sponge city demonstration project, which consists of two demonstration areas and 288 pilot projects. The remarkable success of the Wuhan Sponge City Program highlights its effective waterlogging prevention measures and underscores the potential of nature-based solutions. In the summer of 2020, despite facing intense and record-breaking precipitation during a prolonged rainy season, Wuhan experienced no significant waterlogging issues. The implementation of sponge projects played a crucial role in significantly alleviating waterlogging problems in the city.

Looking beyond Wuhan, Chennai, India, is actively pursuing the transformation into a sponge city by implementing cutting-edge water management techniques aimed at reducing urban flooding. Similar initiatives are underway in Kochi's City Centre, focusing on ecological balance improvement and water conservation to create a sponge city. These endeavors reflect a global trend toward sustainable urban development, with the sponge city model playing a pivotal role in reshaping urban landscapes and fostering a more resilient and environmentally conscious approach to urbanization.

1.1 Benefits of Sponge Cities -

1) Captures and reuses rainwater.
2) Enhances overall water quality.
3) Lowers the likelihood of floods.
4) Lessens issues with travel and traffic.
5) Lessens the severity of urban heat islands.
6) Rainfall can be directed towards a canal, so reducing the frequency of flash flooding. Prolonged periods of rain can also be managed.

II. NEED OF THE STUDY

Kolhapur, located in the western part of Maharashtra, faces unique urban flooding challenges due to its distinctive climate characterized by heavy rainfall from June to September.

As the largest city in south Maharashtra, Kolhapur has witnessed substantial population growth since the late 19th century, particularly in the post-independence era. This growth has strained resources, resulting in issues related to infrastructure, water management, and settlement patterns. The years 2019 and 2021 witnessed severe flooding, displacing thousands and causing extensive infrastructure damage. During floods, key infrastructure, especially roads, plays a vital role. Data obtained from photographs aids in evaluating the impact and preparing for contingencies

The concept of Sponge Cities involves transforming urban areas and infrastructure, including parks, streets, and buildings, into entities that can "act like sponges." This innovative approach to urban management enables cities to naturally absorb, store, and purify rainwater, addressing waterlogging concerns, preventing urban flooding, enhancing water storage and discharge capacity, improving water quality, and mitigating heat island effects. The integration of both nature-based and grey solutions forms the core of the sponge city concept.

III. THE IMPLEMENTATION OF THE SPONGE CITY CONCEPT

Implementation relies on four fundamental principles, each contributing to the sustainable and efficient management of water resources within urban environments.

a) Optimising City Surfaces to Improve Rainwater Absorption and Retention:

This first principle deals with improving the absorption and retention of rainfall. This procedure is essential for managing and lowering storm water runoff and providing a sustainable water source. Trenches under roadways and other ductile iron pipe systems provide an advanced rainwater-gathering method. Comprehending hydrological properties is essential for the seamless integration of urban drainage systems with natural water networks, guaranteeing an all-encompassing strategy for water resource use.

b) Water Ecology Management:

A vital component of the Sponge City idea, the second principal concerns water ecology management. This entails incorporating ecological waterfront design and putting self-purification technologies into place. Water purification is greatly aided by restoring aquatic habitats through healthy landscapes that are impacted by soil, plants, microbes, and water flow processes. Artificial and natural ecological shoreline designs are essential to prevent riverbank erosion, highlighting the significance of balancing urban growth with environmental sustainability.

c) Green Infrastructure Utilisation:

The third principle emphasizes the role of green infrastructure in storm water purification, restoration, adjustment, and reuse. Green infrastructure, marketed to preserve the environment and promote sustainable urban growth, includes natural solutions, including filter drains, green roofs, and detention basins. The advantages of integrating biological features into urban landscapes are numerous, as evidenced by the benefits of green roofs, which include lowering storm water runoff, enhancing air and water quality, and lessening the impact of the urban heat island effect. Rain gardens and bio swales are two examples of bio-retention systems that use soil layers and living plants to filter pollutants from runoff.

d) Permeable Pavement Incorporation:

The fourth principle promotes using permeable pavements in urban road building to improve the city's overall permeability and water management. This state-of-the-art method allows for enhanced rainwater infiltration and groundwater purification using absorbent materials in ground pavement construction. Consisting of continuous voids, pervious concrete facilitates air and water movement, mitigating flooding and aiding in environmental restoration. The Sponge City framework highlights the several advantages of urban permeable pavement technology, including noise reduction and ecological soil enhancement.

In summary, based on these four guiding principles, the Sponge City idea offers an all-encompassing and scientifically sound method of managing urban water resources by fusing sustainable practices, engineering, and ecology to improve urban settings.

3.1 Global Success in Implementing the Sponge City Concept:

Drawing inspiration from international approaches like "Low Impact Development" (USA), "Water Sensitive Urban Design" (Australia), "Sustainable Urban Drainage Systems" (UK), and "Low Impact Urban Design & Development" (New Zealand), China introduced the innovative "sponge city" concept to redefine the interplay between people, water, and urban environments. In 2013, Chinese President

Xi-Jinping emphasized the need for cities to be constructed as absorptive entities, utilizing natural forces to accumulate, infiltrate, and purify rainwater, resembling a sponge in a novel form of urbanization. Since then, the "sponge city" concept has gained prominence.

The widespread adoption of the Sponge City model, characterized by holistic urban planning, has effectively addressed challenges such as urban flooding, water resource management, and sustainable development in various countries. The Sponge City model's practical application is context-specific and calls for community involvement, infrastructural development, and regulatory changes.

IV. PATH OF SPONGE CITY CONSTRUCTION

A Systematic and Realistic Approach to Urban Water Management

a) Preservation of the original rivers, lakes, marshes, ponds, and ditches is foundational to urban development. This approach involves meticulous efforts to maintain and protect these natural features, respecting the existing biological framework. This initial step sets the stage for sustainable urban growth, emphasizing the importance of retaining the city's original ecosystem.

b) Regular systematic ecological restoration and repair activities are integral to address any harm inflicted on water bodies and other natural habitats. A designated percentage of ecological space is consistently preserved, and specialized water ecological infrastructure is developed to support ongoing restoration efforts. This measure ensures the continual renewal and maintenance of the urban ecosystem.

c) Incorporating low-impact development into the construction process is crucial to regulating the intensity of urban development while minimizing disturbances to the natural aquatic ecosystem. Strategic excavation and improvement of rivers, lakes, and ditches increase the number of water areas, aiding in the collection, infiltration, and purification of precipitation. This expands the urban "sponge" both quantitatively and qualitatively.

d) Managing urban precipitation-generated surface runoff is a key focus, emphasizing robust drainage systems to ensure appropriate water flow. The installation of permeable zones is essential for superficial infiltration. A comprehensive flood disaster risk management system is implemented, prioritizing safety and adaptive measures for building mitigation, personal hedging, and disaster prevention.

e) Sponge city construction actively supports sustainable urban growth through these meticulous methods, facilitating the coexistence of urbanization and the preservation of natural water ecosystems. This approach ensures resilient and environmentally conscious city development. By correctly implementing the sponge city concept, it has the potential to lower carbon emissions, contribute to the fight against climate change, enhance water quality, and reduce the frequency and intensity of floods.

V. WUHAN SPONGE CITY PROGRAM: ACHIEVING HARMONY AMONG PEOPLE, WATER AND CITY

Wuhan, located in central China, is well-known as the “city of one hundred lakes” and has abundant water resources and extensive water systems. However, water management and waterlogging prevention in Wuhan is challenging. Wuhan has suffered from waterlogging for years mainly due to the low-lying built-up area and the uneven distribution of precipitation.

Wuhan is one of the sponge pilot cities in China. The sponge infrastructures applied in Wuhaninclude nature-based solutions, such as rain gardens, grass swales and bio-retention facilities, and greyinfrastructure, such as permeable pavements, infiltration trenches, and rainwater storage modules. The target of the Wuhan Sponge City Programme is set as 20% and 80% of the urban area should achieve the sponge city requirements by 2020 and 2030 respectively and absorb 60%-85% of the annual rainfall.

Several key points lead to the success of the Wuhan Sponge City Programme:

1) Applying whole-process management in waterlogging prevention;
2) Integrating sponge projects in Wuhan Comprehensive Planning with the collaboration of different city departments;
3) Developing localized strategies and technical standards;
4) Establishing a fund-raising mechanism and attracting social participation for risk- and benefit-sharing.

5.1 Case Study 1

Qingshangang Wetland Sponge Project

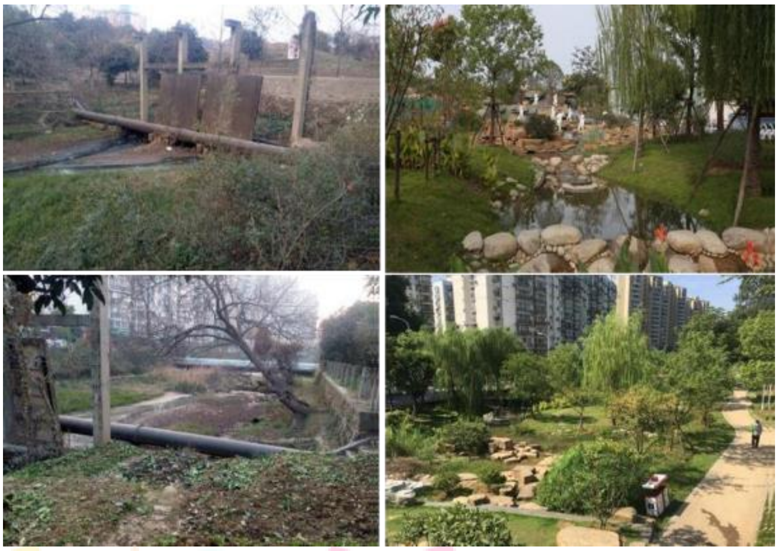
Area: 0.76 km2

Location: Qingshan District (Demonstration Area)

Background - The river channel in Qingshangang area was congested with silt and wastes, which reduced the drainage capacity and water mobility. The sewage outlets were discharged directly into the water body, leading to heavy pollution and eutrophication in the channel. The deteriorated water ecosystem also caused severe biodiversity loss. Moreover, the open space around the area was constructed into shanties and vegetable farmlands, so the landscape quality of the area was extremely poor. Therefore, this sponge renovation project aimed at enhancing the drainage capacity, improving the ecological environment of the area and forming a connected public recreational park.

Plan & Design the Qingshangang sponge project was designed to capture 85% of the annual rainfall on-site and reduce at least 70% of water pollution. To fulfil the targets, it was important to divert the sewage and rainfall pipes and control pollution. The pollution control employed ecological treatments, such as ecological drainage, floating islands, wetland and subsurface wetland, and taking advantage of the 8-meter elevation to treat combined sewer overflows. In the green space along the canal, the sewage water is discharged through sponge facilities rather than going directly into the water bodies. The rainwater can be reused for green areas. As for the water environment, channel dredging was conducted to improve water quality and flow capacity, and aquatic plants were planted to restore the water ecosystem. Besides, the project integrated sponge design into landscape design with the purpose of enhancing landscape quality. Some streets and residential areas were transformed into sponge-like areas to reduce the pollution at the source. The project has laid out numerous sponge facilities, such as grass swales, rainwater gardens and infiltration pavement and rainwater storage modules, in the project area.

Results - Through different sponge measures, the black and odorous water bodies were eliminated and the drainage capacity in the catchment was significantly improved, which alleviated the waterlogging issue effectively simultaneously. The main indicators of the sponge project have reached the goal of the annual runoff control rate of 85% and achieved the flood control standard of effectively coping with a 50-year rainstorm. This project is a demonstration project, driving the renovation of surrounding areas. The urban greenways connecting surrounding parks have formed an interconnected landscape pattern, creating a recreational area for citizens.



Before and after construction of Qingshangang Wetland Sponge Project.

5.2 Case Study 2

The Sponge Project in the Gangcheng No.2 Middle School

Area: 0.02 km^2

Location: Qingshan District

Participating units: Hubei Design Branch of Pan-China Construction Group Co. LTD

Background

The school is located in the low-lying area with low quality of pipes,leading to poor discharge capacity of the internal drainage system and a high risk of waterlogging. The school is at the source of the catchment area with the misconnection of rainwater and sewage pipes and initial storm water runoff pollution, which cause threats to the water quality in the downstream water bodies. Thus, pointand nonpoint source pollution should be reduced at the source. Thewater consumption of school roads and green space is relatively large. The rainwater recycling and collection can realize rainwater recycling utilization and save water resources. The landscape quality in the school is relatively low, so the environment should beoptimized to improve the satisfaction rate of the school.

Plan & Design

In this sponge renovation project, the design standard was comparatively high as the school was a high-risk area for waterlogging. The goal for the annual rainfall capture ratio was 80% and the recurrence interval for storm sewer design was 5 years. Different solutions were applied to resolve different problems. The project designed the renovation of the misconnected storm water and sewage pipes to completely separate rainfall and sewage. The storm water pipes were planned to tackle issues of the blocked storm water pipes and the poor discharge capacity. Clearing and dredging the open channel was critical for siltation and poor waterquality. Regarding waterlogging issues, a storage tank was constructed in the school to collect rainwater and pump it to open channels to increase the water drainage capacity. Moreover, this sponge project planned to replace the current storm water inlets or construct new ecological rainwaterdrains to reduce pollution and increase the drainage efficiency. Also, sponge infrastructure, including a rain garden, permeable pavement for pedestrians, a perviousplayground and parking area, levelledflower beds and ecological dry creek, were built to slow down the dischargespeed and reduce the pressure for drainage facilities. The project also conducted unified management of sponge landscape patterns to solve the problemsof unreasonable landscape layout, the mixed flow of people and vehicles, and poor landscape quality(bare loess). To tackle the issue of the shortage of parking spaces at school, a permeable parking space was built to the west of the table tennis field and to the north of the teaching building. In addition, the project also constructed a sponge publicity board at school for sponge education.

Results

This sponge project has constructed a 400m rainfall storage tank and 4 water pumps on campus. The collected rainwater can be used for campus greening and road flushing to reuse rainwater. After construction, the waterlogging points would not exceed 15cm and would disappear in half an hour.No waterlogging happened during the storm event in August 2017 when the hourly precipitation reached 113.5mm.

Before and after construction of the sponge project in the Gangcheng No.2 Middle School

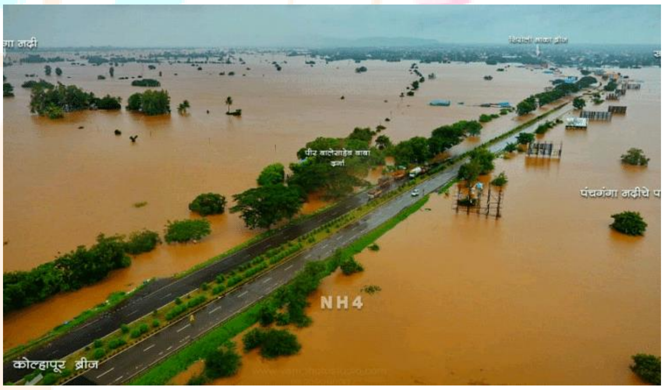
During project construction, rainwater and sewage were separated, the overflow of sewage on rainy days was reduced, and the impact on the downstream sewage treatment facilities was successfully reduced. The project also eliminated waterlogging issues in the area with the construction of new rainwater pipes and gutter inlets. Regarding the landscape sponge renovation, the sponge indexes were effectively improved through the construction of low-impact development facilities. Other results will come out after the completion of the entire project.

VI. CHALLENGES OF URBAN FLOODING IN KOLHAPUR, MAHARASHTRA

During the months of July & August 2019, 2021 Kolhapur districts experienced extreme floods for long durations. Heavy losses to life, property & crops etc. had been reported. Different opinions at various levels were put forth concerning these flood events. Sangli & Kolhapur districts faced heavy flood situations in past also & floods of 2005 & 2006 were noteworthy. However, 2019 flood event was comparatively much more severe which lasted more than a week & losses experienced were also on higher scale. The reason behind this kind of flood situation is very straight forward that is the heavy rainfall happened in the Krishna river basin. So that the excessive amount of water released from Koyana dam. This water did not passed down through Almatti dam properly. Hence flood situation was generated.

6.1 Impact on Panchganga River System:

The Panchganga river system, a vital resource for Kolhapur, has suffered from the consequences of rapid urbanization. Activities such as artificial mining, valley development, irrigation, and dam construction have altered the natural flow of the river. Industrialization and agricultural expansion, including the establishment of sugar refineries, have led to deforestation in the river basin and encroachment on riverbanks. Primary causes of recurrent floods in Kolhapur include heavy rainfall, development in floodplains, and the vulnerability of towns along the Panchganga River and its tributaries. Monsoon rainfall, geography, river flooding, and rapid urbanization with inadequate storm water drainage collectively contribute to an elevated risk of flooding. Reduced discharge carrying capacity of river Warna and Panchganga due to siltation, vegetation growth and encroachments further delayed the reception of floods. The lateral slope of the flood plains is very gentle. The flood plains are almost flat. This has resulted into spreading of flood on larger area on both the banks of the river.



6.2 Environmental Consequences:

The urbanization of Kolhapur has resulted in environmental issues such as deforestation, soil erosion, and disruptions to river ecosystems. River siltation, exacerbated by agricultural activities and deforestation, amplifies the risk of floods. The development of roads and communities along riverbanks further heightens the flood danger. Climate change worsens the situation by increasing the frequency and intensity of rainfall, leading to more severe floods.

Mitigating flood risks necessitates innovative solutions, including adopting the Sponge City concept, resilient urban planning, and sustainable practices, to ensure the long-term viability of urban areas in the region.

6.3 To transform Kolhapur into a sponge city and improve its water management, residents and local authorities can take several steps:

a) **Permeable Surfaces**: To reduce surface runoff, porous materials can be used in roadways, walkways, and other surfaces to allow rainfall to seep into the ground.

b) **Green Spaces and Urban Vegetation**: Creating more parks and gardens, among other green areas, aids precipitation absorption and enhances soil water retention. In addition to improving the urban environment's beauty, vegetation supports biodiversity.

c) **Retention Ponds and Wetlands**: Building wetlands and retention ponds facilitates collecting and storing rainwater during periods of high precipitation. These natural structures lessen the chance of flooding downstream by serving as makeshift reservoirs.

d) **Green Roofs**: Planting vegetation on rooftops lowers the urban heat island effect, offers insulation, and aids in the absorption of rainfall. In densely crowded places, green roofs can provide extra green space and aid in the retention of water overall.

e) **Rainwater Harvesting Systems**: By putting in place these systems, rainwater can be gathered and stored for various applications, including irrigation, non-potable water supply, and groundwater replenishment.

f) **Smart Infrastructure**: Water management may be improved by combining technology with intelligent infrastructure elements like sensors and monitoring systems. This covers adaptive control methods, early warning systems, and real-time water level monitoring.

g) **Community Engagement**: A vital component of the Sponge City approach is including the community in water management procedures, educating people about water conservation, and promoting wise water use.

Kolhapur's citizens may greatly aid in transforming their city into a sponge city by banding together, implementing these strategies, lowering the likelihood of flooding, improving water resilience, and fostering a more sustainable and habitable environment.

The Sponge City concept emphasizes the significance of balancing urban growth with environmental conservation, which is consistent with the ideas of sustainable urban development. Sponge Cities seek to build resilient and adaptable urban landscapes that can withstand extreme weather events and support long-term water sustainability by combining natural and engineered water management systems.

6.4 Challenges in Implementing Sponge Cities.

Despite the enthusiasm surrounding this innovative approach to urban development, several obstacles hinder its successful implementation and scalability.

a) **Technical Challenges**: A significant technical impediment arises from the lack of a comprehensive research foundation, diminishing the overall positive impact of Sponge City initiatives. Thorough investigation is imperative to understand the regional context and ensure successful execution.

b) **Physical Difficulties**: Retrofitting existing infrastructure to align with sponge city principles necessitates intricate changes. Incorporating permeable surfaces, green spaces, and water management systems into established urban environments can be challenging.

c) **Financial Difficulties**: Sponge city endeavours often entail substantial costs. Securing funding for comprehensive projects integrating sustainable water management practices and green infrastructure poses a financial hurdle.

d**) Legal and Regulatory Challenges**: Aligning the innovative features of sponge cities with existing legal and regulatory frameworks can be challenging. Overcoming legal obstacles demands precise regulations and adjustments to accommodate novel ideas.

e) **Public Acceptance Challenges**: The success of Sponge City initiatives hinges on public acceptance. Addressing misconceptions, garnering community support, and enhancing education and general awareness of the benefits of these efforts present challenges.

f) **Collaboration Obstacles**: Agency and stakeholder participation are crucial for effective implementation. Establishing seamless data-sharing and communication channels among project participants may pose difficulties.

Resolution of these issues is essential for the successful and widespread adoption of the sponge city concept.

VII. CONCLUSION

A city designed as a sponge, equipped with features like rain gardens, rooftop gardens, rainwater harvesting, permeable roads, and blue and green spaces, mirrors the absorbent nature of a sponge. This innovative approach, known as the "Sponge City," adeptly responds to environmental changes and manages natural disasters by actively absorbing water during heavy rainfall and releasing it as needed during dry spells. The initiatives associated with Sponge City not only promote sustainable development but also emphasize the importance of green infrastructure by efficiently collecting rainfall for future use and aiding in flood management. Enhancements can be achieved by incorporating underground water tunnels, pervious concrete roads, and green building concepts to enhance overall sustainability.

A meticulous sector-wise division of the area, featuring detention ponds with ample holding capacity based on regional rainfall patterns, is crucial for successful implementation. These ponds can serve dual purposes as recreational spaces and water sources, with surplus water easily evacuated through an exit drain connected to the central drainage system.

The Sponge City program exemplifies how nature-based solutions can enhance climate resilience by mitigating the impact of landslides, floods, droughts, urban heat islands, and desertification. Beyond water management, the integration of green infrastructure elements like rain gardens, bio-swales, wetlands, permeable pavement, and green roofs also benefits diverse ecosystems.

To unlock its complete potential, the Sponge City approach must be embraced as a fundamental aspect of urban development, and seamlessly incorporated alongside traditional grey infrastructure. Kolhapur's application for Sponge City principles will show remarkable outcomes, including the replenishment of groundwater tables, mitigation of air and water pollution, heightened rainwater collection in dry periods, resilience against flooding, harnessing solar energy, and an overall reduction in heat intensity. Our proposal advocates for the assimilation of Sponge City concepts into Kolhapur's urban planning regulations, highlighting the significance of public awareness, strategic infrastructure investments, and collaborative efforts for successful implementation.

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