Complexities of Riverfront Development for the Hilly City of Paonta Sahib in India

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Abstract

The rapid urbanization, industrial growth, and socio-cultural activities along riverbanks in hilly cities are transforming land use and intensifying water infrastructure challenges. Paonta Sahib, a culturally significant town in Himachal Pradesh on the Yamuna River, along the foothills of the Himalayas exemplifies these pressures due to its religious tourism, industrialization, and mining activities. This study explores sustainable riverfront development at Paonta Sahib, addressing socio-cultural, environmental, and technical concerns essential for eco-sensitive urban planning. A SWOT analysis highlights strengths such as Paonta Sahib's strong cultural identity and economic potential, alongside weaknesses like limited water infrastructure and unregulated land use. Opportunities for eco-sensitive zoning and circular economy practices are proposed as strategies to mitigate environmental impacts, with financial projections indicating a 68 million INR annual cost recovery over a 35-year development period. Additionally, pollutant scenario analysis is recommended to support effective water quality management. Findings emphasize the importance of collaborative efforts between local authorities, technical experts, and communities to address the extreme hydrological, environmental, and planning challenges faced by riverbank cities. This balanced approach seeks to enhance Paonta Sahib’s urban identity while preserving ecological integrity, offering a model for sustainable development in similar hilly settlements. The proposed framework aims to guide future policies for resilient riverfront urbanization, emphasizing adaptive planning, community engagement, and infrastructure that support both economic growth and environmental sustainability.

1. Introduction

Water has been a crucial substance for the survival of human beings. All historical developments have been on the banks of rivers and have been crucial for human settlements and the development of places. The connection between water and humans helped in developing trade routes and the connection of land mass. To keep expanding these connections, it is essential to have urban images of cities along the riverbanks and sea, which gives an idea of waterfront or riverfront developments (Jauhiainen, 1995). Waterfront developments are globally significant due to their multifaceted impact on urban life, economy, environment, and culture. They boost local economies through tourism, increase property values, and become vibrant business hubs. Modern projects emphasize sustainability and mixed-use spaces, enhancing urban vitality and quality of life. Environmentally, they aid in ecosystem restoration and climate resilience. Additionally, waterfronts serve as transportation hubs and showcase innovative technologies. Effective waterfront development requires integrated planning and community involvement, shaping resilient and dynamic urban environments (Üzümcüoğlu & Polay, 2022).

People in India worship the rivers as Goddesses and the living entity. They have a deep desire to frequently touch and feel water as one of the most precious five elements of earth, water, fire, air, and space (Bhat, 2022). It is crucial to provide exposure to river water by creating public spaces along riverbanks and shorelines. First and foremost, human engagement with water necessitates riverfront development. The current recognition of the intrinsic complexity of the environment opposes the previous tendency to oversimplify and isolate problems. Instead, there is a growing acknowledgement of the need to adopt an integrated approach to managing urban water systems. This approach involves considering all system components, promoting efficient water management involving conservation, varied fit-for-purpose water supplies, operations at different scales (central and decentralized), and establishing connections with other environmental cycles, such as energy and nutrients (Hoffmann, 2022).

In India, areas at more than 600 meters above sea level or with an average slope of 30° are considered hilly. This classification encompasses regions like the Himalayas, Central Highlands, Deccan Plateau, and northeastern hill ranges, constituting distinct geographical features in India. These regions present unique geo-environmental conditions and development resources (Kumar & Pushplata, 2015). Despite the challenges they presently face, hill regions are fascinating and demanding terrains for carrying out development work due to rugged terrains, steep gradients, complex geological structures, climate, and diverse flora (Kummu et al., 2016). Rapid population growth, substantial tourist influx, and improved living conditions have led to substantial environmental and visual changes in these hill towns (Kansal & Singh, 2022). The

urban expansion in these towns has far exceeded their original design and carrying capacity, converting lush green slopes into concrete-dominated areas.

The hilly areas observe many flash flood events and require protective measures. Flash floods can be triggered by natural events like cloudbursts, heavy rainfall leading to river and stream overflow, blocked drainage systems, volcanic eruptions, trapped thunderstorms, glacial lake outbursts, and tropical storms or cyclones. Additionally, anthropogenic factors such as dam failures, infrastructure breakdowns, climate change, wetland destruction, and deforestation can contribute to flash flood occurrences. These destructive events have several observable consequences, including the loss of human lives, property damage, and financial losses (Kansal et al., 2014). Vegetation in affected areas is often damaged or wholly uprooted, while animals, including pets, urban wildlife, and wild animals, may drown or perish. Flash floods also result in significant soil erosion, stripping away fertile topsoil from agricultural land and carrying pollutants and debris into rivers and seas through stormwater runoff. Furthermore, flash floods can destroy infrastructure like roads, buildings, bridges, and communication services, impacting residential and commercial areas and causing damage to valuable assets. Livestock are at risk of being killed, and farms can be devastated as well. Therefore, understanding and implementing protective measures against flash floods is essential to mitigate their adverse effects on both the environment and human society (Pandey & Vishwakarma, 2019).

Challenges in the development of hill towns stem from various factors, such as the absence, enforcement, or non-compliance of appropriate building regulations. Building regulations in hill towns encompass a set of rules designed to protect public health, safety, welfare, and the environment. They enable government or development authorities to regulate land use, buildings, and infrastructure, ensuring proper spatial organization and environmental protection (Dutta et al., 2018). These regulations provide essential frameworks and statutory guidelines for planning, designing, and constructing buildings and related structures. They also include provisions for ensuring the safety of hazardous buildings and lands and measures for the enforcement and approval of construction projects. By adhering to appropriate building regulations, hill towns can address and mitigate the challenges associated with haphazard development, leading to better urban planning and sustainable growth. The expansion of roads and industrialization led to factories and warehouses along riverbeds, polluting the once-pristine waters and causing factories to relocate to city centres. In the Indian context, urban riverfront evolution mirrored this pattern, influenced by socio-cultural and religious factors (Chakrabortty et al., 2022). Riverfronts hold immense value for architecture, settlements, and public spaces, exemplified by the Taj Mahal's iconic presence on the Yamuna River. Consequently, rivers and their developments are pivotal in shaping a city's essential imagery (Simons et al., 2023). Unfortunately, human intervention has negatively impacted riverfront areas, with indiscriminate raw waste and sewage dumping posing significant environmental challenges. Despite this, the past decade has witnessed substantial efforts to restore these waterfronts, rejuvenating their beauty and bringing them back to life. The Indian government is undertaking the extensive National Smart City Mission, a massive urban redevelopment initiative to improve citizens' quality of life. This ambitious project focuses on enhancing the livability and user-friendliness of various cities across India. Integral to this mission is the riverfront development project, which seeks to link linear waterfronts with public spaces, preserve natural riverfront development, and revive the city's identity (Vercruysse et al., 2022).

However, it has been a concern in the emerging cities in the hills, which are majorly along the upstream of rivers, which have exerted pressure on urban agglomeration, resulting in pollution and river health deterioration. This study aims to create a set of principles and criteria that will help create socially important locations along riverbanks. The idea of place identification, basic water infrastructure, public convenience, and recreational facilities is vital for its sustainable development. It is essential to focus on low-impact development while considering water and ecological sensitivity. To take care of extremes like floods, creating spongy areas to absorb and delay the flood routing is desirable. Further, it is crucial to use the river as a source of water supply for multiple purposes and return the wastewater as return flow, which should match its self-cleaning capacity. Keeping these in mind, this study focuses on identifying spaces for riverfront development in the holy city of Paonta Sahib on the banks of the river Yamuna. To cater to a mass of pilgrims (as floating population) and residents of Paonta Sahib, an attempt has been made to suggest the riverfront development. The development acts as a buffer between the city and the

river, considering issues such as wastewater treatment, stormwater collection, storage, and drainage systems. This effort can facilitate setting up the infrastructure related to the Sustainable Development Goal 6 - drinking water and sanitation for all.

2. The study area

Paonta Sahib is a town in India's Sirmaur district of Himachal Pradesh (Fig. 1). It is a fast-growing spiritual and industrial town. This town has state boundaries with four states of Himachal Pradesh, Haryana, Uttarakhand, and Uttar Pradesh. 40 years ago, it had a population of about 22 thousand and currently, it has a population of about 1 lakh with a much larger floating population as several thousand people cross the state border and assemble on the banks of river Yamuna during several festivals like *Makar Sankranti, Baishakhi, Ram Navami, Bhaiya Dooj, Krishna Janmashtami, and Deepawali*, etc (Development Plan – Paonta Sahib Special Area, 2017). Besides these, people perform the last rites of the deceased people, and there is a crematorium on the bank of the river Yamuna. Also, as it is an industrial hub with several pharmaceutical industries, there is immense pressure on the urban water infrastructure and utility services. Researchers and practitioners recognize the imperative significance of employing solutions with multiple benefits, engaging in interdisciplinary work, and adopting broad perspectives (Yereseme et al., 2022). Over time, water management in cities has evolved significantly, from merely securing water supplies to encompassing sanitation, flood protection, and realising a Water Cycle City.

River Yamuna is the largest tributary of the holy river in the Ganges in India. The river originates from the Yamunotri glacier, at the Bandarpunch peaks of the lower Himalayan range at a height of about 6320m above MSL in the Uttarakhand state of India. The river stretch is about 1500 kilometers, from Yamunotri glacier to Prayagraj, where the river confluences to river Ganga. The river traverses' multiple states, including Haryana, Uttar Pradesh, Uttarakhand, and Delhi. It meets several tributaries, including Tons, Chambal (its longest tributary with its own extensive basin), Sindh, Betwa, and Ken. At Paonta Sahib, the Yamuna forms the boundary between Himachal Pradesh, Uttarakhand, Haryana and Uttar Pradesh. Figure 2 shows the river Yamuna along with various important cities on its banks from its origin to its confluence at Prayagraj in Uttar Pradesh (Jain et al., 2007).

The total catchment area of the river for Himachal Pradesh is about 5799 sq.km, which is about 1.6% of the total catchment area of the river. The study area comes under the upper stretch of Yamuna which is in the Shivalik hill ranges. The upper Yamuna starts from Yamunotri to Okhla Barrage about 375 km and has reasonably good water quality. The river stretch enters the plains from Dak Pathar Barrage to Paonta Sahib, and further goes down to Hathnikund Barrage, which diverts the river into EJC – Eastern Yamuna Canal (Towards Uttar Pradesh) & WJC – Western Yamuna Canal (Towards Haryana). The course of the river in the study area is the stretch between Assan barrage and Hathnikund barrage which is about 33km. Paonta Sahib City is on the banks of a river stretch of about 6.5km. The slope here ranges from 0.2 m/km to 0.3m/km, with Calcareous Seirozemic soil deposits in this region. According to CPCB, 2006, the land use pattern for Himachal Pradesh under Yamuna catchment is 25% non-arable land, 59.4% forest area, 15.6% cultivable land out of which 14.2% is cultivated, and 1.6% of land is for habitational. The river has extremes of dry as well as flood events, due to low discharges, it is not suitable for navigation purposes but has the potential of development of recreational activities like tourist attraction as well as water sport facilities where discharges are more, especially near to barrages (CPCB, 2006).

Paonta Sahib, renowned for the Gurudwara dedicated to the 10th Sikh Guru Gobind Singh, serves as a gateway to Himachal Pradesh connected by NH 7 and NH 907. This religious town experienced significant population growth after the 1970s due to industrial development. The town's population has surged from 946 people in 1951 to 100,000 today. From GIS observations and physical surveys, most of the region does not show much variation in elevation, it represents a valley. The average elevation varies from 350 meters to 800 meters. The area also has a land slope varying from 0 to 30%. The region comprises the river Yamuna and the Doon valley, with the Himalayas in the north. These Dhars or ridges are delimited to the east by the Yamuna River. The entire area is near the Shivalik foothills and has a good slope from north-east to south-west. Most of the area has a slope of less than 8%, which reflects the flatness of the area. In the Paonta Sahib Special Area, the Himachal Pradesh Irrigation and Public Health Department has made drinking water available. Tube Wells are the primary source of water supply in the Paonta Sahib Special Area. To meet everyone's needs, the typical water supply is 70 litres per person per

day (Development Plan – Paonta Sahib Special Area, 2017). However, the only surface sources used for irrigation of land for agricultural reasons are the Rivers Yamuna and Giri. The water supply method is based on the time (intermittent water supply), which is two times a day. Sewage treatment plants are in three different zones of the Municipal Council area and serve only about 12,000 people.

Paonta Sahib experiences a cool and temperate climate, with temperatures ranging from approximately 10 to 25 ℃ throughout the year. The city receives moderate rainfall during the monsoon season, spanning from June to September. Winters are cool and comfortable, with temperatures possibly dropping to -5 ℃. The surrounding hills are adorned with diverse vegetation, including thick pine, oak, and rhododendron forests. (Fig. 3) Indicates the presence of existing water infrastructure in the municipal areas, such as 35 tube wells, 48 hand pumps, 3 overhead tanks, 4 bore wells and 2 existing STPs, and one proposed STP. These areas have great potential for natural groundwater recharge due to calcareous soil as well as the proximity of Yamuna River. There is observation of groundwater drawdown in the main settlement area of the city, marked in red on the above map. Huge groundwater dependencies need artificial recharge zones for the study area, and additional water supply and wastewater treatment infrastructure are needed for the growing city.

3. Riverfront development – issues and management strategies

Riverfront development offers growth opportunities but faces challenges like flash floods, ecological sensitivity, and the need for sustainable economic development. A balanced approach integrating environmental preservation, resilient infrastructure, and community engagement is essential for a thriving and sustainable riverfront. Outlined below are some issues and their management strategies to be considered.

3.1. Issues

Riverfront development faces diverse challenges, including flash floods driven by climate change and unsustainable practices, ecological sensitivity affecting biodiversity and local livelihoods, and the need for balanced economic growth. Addressing these issues requires integrated strategies such as sustainable urban planning, eco-friendly infrastructure, community engagement, and leveraging the area's strategic connectivity to promote recreation, pilgrimage, and environmental preservation.

3.1.1. Flash flood

Flash floods have become increasingly common worldwide, driven by factors like climate change, extreme weather events, and human activities such as unsustainable water management and deforestation. These floods can devastate the built and natural environment, posing serious threats to human life and livelihoods. As flash floods are often triggered by intense rainfall or sudden water release, preventive measures are essential to minimize their negative consequences (Zhou et al., 2019). Some of these measures include implementing efficient early warning systems for advance notice, improving urban planning with proper drainage and green spaces, promoting reforestation and green infrastructure to enhance soil absorption, constructing flood control infrastructure like dams and levees, adopting sustainable water management practices such as rainwater harvesting and groundwater recharge, and educating communities about flash flood risks and responsible water usage to encourage behaviors that contribute to flood prevention (Proverbs & Lamond, 2017).

3.1.2. Ecological sensitivity

Himachal Pradesh faces significant challenges due to climate change, including rising temperatures, unpredictable rainfall, and glacial retreat, affecting water resources, agriculture, and biodiversity. The state is also experiencing increased forest fires, landslides, and ecological shifts, putting its rich biodiversity and local communities at risk (Tewari et al., 2017). These changes impact livelihoods, tourism, and infrastructure, necessitating urgent adaptation and mitigation strategies. Sustainable practices, integrated water management, and community engagement are essential to address these issues and protect the state's environment and economy. Environmental risks associated with hillside developments evaluate key risks

such as soil erosion, landslides, and biodiversity loss, and assess their impact on local ecosystems and water resources. The study from Penang, Malaysia emphasizes the need for effective mitigation strategies, including engineering solutions, environmental management practices, and policy improvements. The paper highlights the best practices for balancing development with ecological preservation through case studies and findings, aiming to guide sustainable hillside development in Penang (Yahaya et al., 2013). The best practices include implementing effective drainage systems and retaining structures to prevent soil erosion and landslides (Yahaya et al., 2013). It advocates for soil stabilization techniques, reforestation, and adherence to sustainable land use planning and building codes.

3.1.3. Economic development

The connectivity in terms of the roadways, major cities nearby such as the NH 7 and NH 907 connecting the city to four major states of Haryana, Uttarakhand, Punjab and further connecting to the major city of Shimla in Himachal Pradesh. Transportation is usually a challenge in hilly areas, but here, there is a big advantage in connection with good infrastructure and strategic location. The waterway can't be used for navigation purposes due to the low discharge capacity of the river. In terms of Riverfront stability and geo-environmental conditions of the riverfront's land area (Duan et al., 2021) the area shows a great potential in creation of platforms and Ghats as well as land availability along the river banks, providing spaces for creation of green belt zones. The 16 km river stretch area can be utilized for pilgrimage purposes, recreational areas, and experimenting with nature-based wastewater treatment to reduce river water contamination.

3.2. Management strategies

Effective management strategies for riverfront development address critical challenges like flash flood risks, ecological sensitivity, and economic potential. By integrating sustainable practices such as Low Impact Development (LID), ecological assessments, and community engagement, these strategies ensure resilient infrastructure, biodiversity preservation, and long-term economic growth. Tailored approaches leverage natural resources and local contexts to create environmentally friendly and economically vibrant riverfronts.

3.2.1. Flashflood risk management

Some proposed potential measures to control flash flood problems which help provide resilient infrastructure as prevention and management measures for the project development are:

a. Utilization of parks, gardens, and rooftop gardens to absorb rainwater effectively, mitigating the risk of flash flooding.
b. Construction of embankments as part of a strategy to redirect water to open land areas during periods of heavy rainfall.
c. Flood plains and overflow zones along rivers and streams are established to facilitate controlled water overflow without causing damage.
d. Enhancement of urban drainage systems and regularly maintaining and unclogging drains to ensure efficient water flow.
e. Implementation of suitable practices for managing rainwater in urban areas.
f. Encouragement and construction mechanisms for rainwater harvesting to store and utilize precipitation efficiently, preventing flash floods.
g. Upgradation of flood warning systems and disaster management protocols to enhance overall preparedness.
h. Public awareness campaigns should be conducted to educate individuals on how to effectively handle situations related to flooding and heavy rainfall.

Riverfront development strategies using Low Impact Development (LID) represent powerful solutions for creating sustainable, resilient urban spaces along riverbanks. By incorporating LID practices such as green roofs, permeable pavements, rain gardens, and riparian buffer zones, help effectively manage stormwater runoff, protect water quality, and enhance biodiversity. These LID features contribute to the ecological health of the river and its surroundings and create attractive public spaces for the community to enjoy (Wadhwa et al., 2023). Additionally, adopting sustainable drainage systems, considering floodplains, and integrating LID elements in riverfront parks and open spaces demonstrate the commitment to

responsible water management and environmental conservation. Public participation and awareness are key to the success of riverfront development projects, as they foster a sense of ownership and responsibility among the local community.

Another development method is the ‘Sponge City’ concept, which involves the critical role of topography in urban sponge construction and provides a framework for integrating these factors into the planning process. By tailoring green infrastructure to the unique characteristics of mountainous terrains, cities can achieve more effective water management and reduce the risks associated with urban flooding (Chen et al., 2024). To enhance the effectiveness of sponge city measures in mountainous regions, implementing terracing on steep slopes to reduce water runoff and erosion, using natural depressions as water storage basins, applying permeable surfaces like pavements and green roofs to increase water retention, and selecting slope-specific vegetation to improve water absorption and filtration. Hydrogeological conditions both constrain and facilitate the development of urban water management strategies to enhance a city’s resilience to flooding and water scarcity (Lancia et al., 2020). Rapid urbanization and complex geological features reduce natural infiltration, increasing runoff and flood risks, while overextraction has led to declining groundwater levels. However, diverse soil types, existing natural waterways, and urban green spaces offer opportunities for localized infiltration and enhanced water retention and its management. Growing public awareness and government support further encourage sustainable sponge city initiatives.

3.2.2. Ecological sensitivity assessment

Assessment of the ecological sensitivity of riverfront areas is a complex process that involves multiple approaches. It typically begins with on-site ecological surveys to identify and characterize critical habitats, species, and nearby ecosystems. Geographic Information Systems (GIS) and remote sensing technologies are then employed to analyze land cover, vegetation types, and other environmental factors, helping to map out sensitive areas. Habitat suitability modeling further refines the assessment by predicting the suitability of the environment for specific species. Additionally, ecosystem services assessments quantify the area's benefits, such as water purification and flood regulation (Yadav & Kansal, 2023). Environmental Impact Assessments (EIAs) are often conducted as part of development planning to identify potential ecological impacts and propose mitigation measures (Dewi et al., 2021). Hydrological studies, stakeholder engagement, historical data analysis, and consultation with ecological experts further contribute to a comprehensive understanding of the riverfront's ecological sensitivity, guiding responsible development practices that protect the environment while supporting economic growth.

Some measures we take in this process are proximity of the riverfront to natural reserves, protected zones and identifying certain rare species that can be a part of biodiversity protection by the government (Duan et al., 2021). The other measure is to understand the role of the river in flood mitigation and flood storage areas, by creating sponge areas for LID. Another measure that sees the available areas' zoning according to their use and understanding the aquatic life and habitats provides proper health and breeding grounds for their growth. In assessing ecological sensitivity along riverfronts, it's essential to account for both local and global considerations. Global analysis shows that forests and grasslands are significant sources of natural infrastructure for cities. However, when adjusting for population, densely populated regions like China and India rely on agricultural areas for water, hence agricultural areas are also natural infrastructure. This highlights the need for tailored conservation strategies. For example, New York City's forested watershed serves as a model for forest-dominated areas, but cities like Beijing, with cropland-rich watersheds, require different approaches (Wen et al., 2019). Identifying the primary land cover in a city's watershed source is key to selecting appropriate natural infrastructure measures, benefiting mayors, utility managers, and citizens in making informed water resource management and preservation decisions.

3.2.3. Potential assessment for economic development

Assessment of potential economic development opportunities in riverfront development for a small city like Paonta Sahib involves considering various factors, including the city's unique characteristics, its current economic situation, and the resources available for development. Paonta Sahib, located in the Indian state of Himachal Pradesh, is known for its religious and historical significance, making it a potential tourist destination. Assessing economic development opportunities for Paonta Sahib's riverfront involves recognizing its tourism potential, learning from neighboring projects, improving infrastructure and accessibility, adhering to environmental regulations, engaging the local community, encouraging tourism-

related businesses, prioritizing sustainability, securing funding sources, implementing effective marketing, and maintaining infrastructure to ensure long-term economic growth. By combining these elements strategically, Paonta Sahib can create a thriving riverfront destination that attracts visitors and benefits the local economy and environment.

4. Materials and methods

4.1. Materials

The data for this study were collected from various sources to support the analysis, design, and assessment of the riverfront site. ArcGIS (ESRI, version 10.8) was used to map topography, land use, and ecological features, while AutoCAD (version 2021, Autodesk) supported architectural drafting. Photoshop (version CC 2017, Adobe) enhanced hand-drawn sketches, and Google Earth Pro (2023, Maxar) was used for spatial mapping. Historical maps, zoning regulations, environmental assessments, water infrastructure, and municipal boundary data were sourced from the Municipal Corporation Office of Paonta Sahib, Himachal Pradesh (https://hpsirmaur.nic.in/public-utility/municipal-committee-paonta-sahib/), along with the Central Ground Water Board's annual report (*CGWB,Sirmaur*,2013) (https://www.cgwb.gov.in/old_website/District_Profile/HP/Sirmaur.pdf). Water quality metrics (pH, turbidity, TDS, temperature) and meteorological data (soil type, flood levels, water levels, rainfall, flood peaks, discharge rates) were obtained from the Central Water Commission's (CWC), India local office at Paonta Sahib (https://cwc.gov.in/ybo/home). Demographic data was accessed from the 2011 Census (https://censusindia.gov.in), and economic feasibility data came from local contractor estimates and commercial revenue studies. These diverse sources provided a robust foundation for the study region's comprehensive site analysis and design.

4.2. Proposed methodology for riverfront development

The methodology for riverfront development in hilly terrains focuses on addressing environmental, social, and economic challenges while ensuring sustainable urban growth. It begins with an extensive literature review of successful riverfront development projects to identify the best practices and strategies. To understand region-specific challenges, this is followed by a detailed analysis of the study area's physical and socio-economic characteristics, such as flood risks, ecological sensitivity, and urban drainage issues. Employing a mixed methodology involving qualitative and quantitative methods, the study aims to address missing points in environmental research by focusing on policy recommendations, social and economic dimensions, and longitudinal studies. Through data collection from the sources and content analysis of existing studies, the research will establish linkages between environmental impacts and secondary attributes of riverfront development (Simons et al., 2023). With a holistic approach that integrates social, economic, and policy aspects, the methodology (Fig. 4) aims to provide a comprehensive analysis that guides policymakers and stakeholders toward more sustainable and impactful riverfront development, emphasizing ecological preservation and social well-being for a better and more sustainable future (Majumdar et al., 2023).

The implementation of proposed overall methodology as shown in Fig. 4 will help planners and designers develop sustainable infrastructure in hilly terrain concerning urban planning and riverfront development. The approach for the overall methodology includes case studies of national and international successful riverfront development, analysis of the on-ground reality of the study area, identification of the requirement. This will identify the best practices, then analysis of SWOT (Strength, Weakness, Opportunity and Threat), a development framework relevant to the context is made, which leads to assessment of its feasibility in aspects of the circular economy practices.

Nestled amidst the picturesque landscapes of the Indian state of Himachal Pradesh, Paonta Sahib stands as a testament to both natural beauty and cultural heritage. With its hilly terrain and the meandering presence of rivers, Paonta Sahib offers a unique canvas for urban development and riverfront enhancement. Crafting a thoughtful framework for zoning regulation and riverfront development in this scenic city becomes paramount to harmonize growth with environmental conservation. This framework recognizes the challenges posed by the rugged topography and envisions a sustainable future where the city's hills and riverbanks coexist harmoniously with vibrant communities and responsible development. In this endeavor, the city

seeks to engage stakeholders, uphold ecological values, and foster a resilient and prosperous urban landscape. Based on this understanding, the strategic framework development phase identifies the key objectives and principles for development. This framework integrates zoning, planning, and conceptualization strategies tailored to the unique challenges of hilly terrains. It emphasizes circular economy practices, sustainable resource utilization, and alignment with Sustainable Development Goals (SDGs), ensuring that urban growth complements ecological preservation. Key strategies involve fostering connections between the riverfront and the city through pedestrian and vehicular access, linking major attractions and public spaces while clearly segregating public and private areas (Anzevino, 2010). Emphasizing water-sensitive approaches, especially in areas with existing water infrastructure, and encouraging water-dependent and water-enhanced uses are essential. This framework is particularly pertinent for riverbank projects in hilly regions as shown in (Fig. 5).

A SWOT analysis (Strengths, Weaknesses, Opportunities, and Threats) for riverfront development can help assess the potential of such a project. The assessment is conducted subsequently to evaluate the study area's strengths, weaknesses, opportunities, and threats. Table 1 elaborates on strengths such as natural resources and existing infrastructure are identified, alongside weaknesses like ecological fragility, opportunities for economic growth, and threats from urban sprawl and environmental degradation. This analysis further refines the strategic framework to address specific vulnerabilities and leverage potential opportunities. Techno-economic feasibility assessments are then carried out to evaluate the proposed strategies' environmental, social, and economic impacts.

Table 1
Conditions assessment for riverfront development (SWOT Analysis)

Category	Description
Strengths	• Proximity to the Yamuna River, with abundant streams ensuring a reliable water supply. • Increasing public awareness about water conservation and the adoption of water-sensitive practices. • Local government initiatives such as rainwater harvesting systems and comprehensive water management plans to enhance water sustainability.
Weaknesses	• Inefficient management of water resources leading to significant wastage. • Poor enforcement of existing water conservation regulations. • Low public participation and awareness regarding water conservation efforts. • Lack of active engagement in adopting sustainable practices.
Opportunities	• Potential to position Paonta Sahib as a sustainable and eco-conscious tourist destination, leveraging its natural water resources and scenic beauty. • Opportunities for economic growth through enhanced tourism, creating jobs, and supporting local businesses. • Collaboration between businesses and the government to implement water-sensitive practices such as recycling and eco-friendly initiatives. • Public education and outreach programs to promote sustainable water usage and long-term ecological health.
Threats	• Climate change impacts, including altered precipitation patterns and rising temperatures, threatening water availability. • Unsustainable groundwater extraction causing aquifer depletion and reduced water quality. • Rapid industrialization leading to water pollution from industrial effluents, endangering ecosystems and public health. • Risk of overexploitation of natural resources, potentially damaging the region's ecological balance.

Longitudinal studies provide insights into long-term changes, guiding adaptable and resilient planning. The subsequent sections focus on the study area’s proposals, detailing techno-economic feasibility and circular economic strategies. These

include resource interdependence, spatial optimization, activity integration, fostering sustainable growth and a distinct urban identity. The findings culminate in actionable recommendations for balanced development and ecological preservation.

4.3. Regularizing zones for riverfront development

The zoning process for a hilly riverfront area involves delineating land use zones and regulations that account for the unique topographical and environmental characteristics. In a hilly riverfront, considerations must include strict restrictions on construction near riverbanks to prevent erosion, buffer zones to protect the riparian ecosystem, and height limitations to preserve the scenic beauty of the hills (Kumar & Pushplata, 2015). Zoning should encourage sustainable, flood-resistant construction practices while promoting mixed-use developments incorporating public access, recreation, and cultural spaces along the river. Overall, the zoning process aims to balance development needs with environmental preservation and the safety of hilly terrain (Chen et al., 2024).

Land is classified into built (includes artificial riverfront) and natural environments, with zones based on tourism and religious significance. Design considers factors like carbon footprint and biodiversity for carbon credits, aiming for environmentally sensitive and climate-resilient infrastructure (Mariana Sarmiento, 2023). Biodiversity conservation and climate change management require distinct crediting systems. Carbon credits offset emissions annually, while biodiversity credits (bio credits) address species loss and habitat preservation. A new framework is needed for bio credits, that ensures measurable ecological outcomes, long-term predictability for investors, and tradability. Global ecosystems vary in recovery rates, with some regenerating rapidly (e.g., tropical forests) and others taking decades (e.g., boreal forests). Discussions on voluntary biodiversity crediting systems must consider this diversity and address reliability and governance concerns.

Development in such zoning (Fig. 6) follows the existing infrastructure of the place. Significant activities are controlled through these proposals for development from the spiritual and other tourists' points of view. Some more proposals have been added to consider the increase in footfall and creation of economic opportunities through tourism. Stretches of development also focus on providing proper infrastructure for urban drainage, considering the settlement zones and passage or proposed road outlines that make planning and management more effortless.

4.4. Techno-economic feasibility assessment

The choice between conventional construction and vernacular techniques for riverfront development involves considering various factors such as site conditions, environmental impact, cultural context, and economic feasibility. It should be based on a holistic economic, environmental, cultural, and social analysis. Integrating elements of both approaches to achieve a sustainable and culturally sensitive riverfront development is often beneficial.

Conducting a feasibility study for riverfront development at Paonta Sahib involves careful assessment across multiple dimensions. Initial cost estimation encompasses land acquisition and construction breakdown, factoring in infrastructure, landscaping, and a contingency fund for unforeseen expenses. Operational and maintenance costs must be estimated, covering salaries, utilities, and security. With corresponding income projections, revenue streams such as entrance fees, commercial leasing, and sponsorships should be identified. Net Present Value (NPV), Return on Investment (ROI), and Payback Period calculations gauge financial viability, while Internal Rate of Return (IRR) assesses attractiveness. Sensitivity analysis identifies key variables impacting feasibility, and risk analysis quantifies potential risks and their impact. Social benefit-cost ratio evaluates the project's societal impact, considering factors like community engagement and cultural preservation (McKinney, 2011). Environmental impact and regulatory compliance costs must be factored in, and qualitative community and stakeholder input considered. A concise summary of these considerations informs the ultimate decision on the project's financial, social, and environmental feasibility.

Specification of some criteria and equations for a quantified comparison between conventional construction and vernacular techniques in the context of riverfront development:

4.4.1. Considerations for evaluating sustainable construction

Cost efficiency, environmental impacts, and cultural preservation are critical aspects of sustainable construction. *Cost Efficiency* is measured using the metric Cost per Square Meter, calculated as total cost divided by the constructed area. *Environmental Impacts* are assessed through metrics such as *Embodied Energy* (the sum of each material's quantity multiplied by its production energy) and *Carbon Footprint* (material quantity multiplied by per-unit carbon emissions), with higher values indicating greater impacts. *Cultural Preservation* evaluates alignment with local heritage and architecture using the *Cultural Compatibility Index*, balancing vernacular styles with cultural heritage. These metrics support holistic evaluations of construction projects (Dixit et al., 2012).

4.4.2. Economic Analysis

The cost required for different components of riverfront development are:

- Construction cost of bathing sites, crematorium, greenbelt development, and basic amenities.
- Environmental Management Plan.
- Environmental Monitoring Programme
- Operation and Maintenance Aspects

These are crucial in assessing the present worth cost and benefit analysis for the development project for a period of at least 35 years, starting from the year 2025–2060. The economic assessment is carried out using present worth of costs considering project life span of 35 years. Time value of the money is assessed through the capital recovery factor, present worth factor, and the series worth factors as mentioned below:

$$\text{Present Worth Factor } = \frac{\mathrm{P}}{\mathrm{F}},\ \mathrm{i}\%,\ \mathrm{n}\ ; \mathrm{P} = \frac{1}{(1+i)^n} \quad \text{Eq. 1}$$

$$\text{Capital Recovery Factor } = \frac{\mathrm{A}}{\mathrm{P}},\ \mathrm{i}\%,\ \mathrm{n}\ ; \mathrm{A} = \frac{\mathrm{i}(1+\mathrm{i})^{\mathrm{n}}}{(1+i)^n-1} \quad \text{Eq. 2}$$

$$\text{Series Present Worth Factor } = \frac{\mathrm{P}}{\mathrm{A}},\ \mathrm{i}\%,\ \mathrm{n}\ ; \mathrm{P} = \frac{(1+i)^n-1}{i(1+i)^n} \quad \text{Eq. 3}$$

Further the analysis has been done using the discount factor in section 5.2. under results.

5. Results

Based on the best practices suggested in the previous section, the riverfront development proposal for the Paonta Sahib is suggested. It aims to revitalize the Yamuna River while preserving its natural beauty and heritage. The project envisions a 16 km stretch of development, focusing on three precincts: ecological, cultural heritage, and socio-economic. The key elements include the extension of Yamuna Ghat, crematorium, green belt development along the riverbank, and pedestrian and vehicular path development. The proposal has been developed considering the methodological approaches discussed in the previous section. The zoning regulations in the hilly terrain and aim to balance development with environmental preservation prove vital. By integrating these elements, the proposal seeks to enhance the city’s urban image, promote spiritual tourism, and fosters a sustainable and resilient water management system through this riverfront development proposal.

5.1. The proposal

Riverfront development at Paonta Sahib is an ambitious and transformative urban project aimed at revitalizing the region's riverfront areas, particularly along the banks of the Yamuna River. The project typically includes components such as creating pedestrian-friendly promenades, green spaces, recreational areas, and cultural centers. It also involves infrastructure improvements, environmental conservation measures, and efforts to maintain the ecological balance of the river ecosystem. Riverfront development at Paonta Sahib aims to strike a balance between modernization and preserving the town's natural beauty and heritage. Further, existing infrastructure and possibilities to improvise and develop the proposal along the bank of Yamuna were looked at.

Addressable issues and challenges in a hilly terrain necessitate a thorough collaborative initiative involving multiple stakeholders, including the government, local communities, industries, and environmental organizations. Implementing sustainable water management practices, promoting water conservation, and adopting eco-friendly approaches in industrial processes are all vital steps towards safeguarding Paonta Sahib's water resources in the face of climate change and growing human activities. A more resilient and sustainable water future for the town and its residents can be ensured by immediate actions. To revive the ancient culture and healthy traditions, the involvement of local bodies and citizens is essential, and they named an organization together as “Hari Yamuna Sehyog Samiti”. This visualizes a holy and environmental centric movement of general masses aims at:

1. Protection and improvement of the environment - massive afforestation alongside the banks of the river.
2. Preservation of the rich heritage of the composite culture - rehabilitating the spiritual centers functioning along the banks of river Yamuna; By beautifying the areas alongside the banks with Shri Hari Krishna Leela’s/ Bhagwat katha/sculptors’/paintings.
3. Promotion of harmony and the spirit of common brotherhood
4. Promotion of spiritual tourism alongside the banks of the river Yamuna.
5. Creating mass awareness.
6. Advocacy and garner support from national and international governments and NGOs to achieve the above goals.

To achieve these goals or objectives a riverfront development has been proposed for overall image development of the city and managing the drained water and supplied water for the city, this initiative is essential. The proposal development is through these salient features, as observed in the physical survey below.

- Max. Flood Expected at Yamuna bridge is about 15000 cumec derived from Dicken’s flood peak discharge formula mention as (Q=C $\mathrm{A}^{\frac{3}{4}}$ Eq $\mathrm{Q} = \mathrm{C}\,\mathrm{A}^{\frac{3}{4}}$ Eq).

$$Q = C\,A^{\frac{3}{4}} \text{ Eq. 4}$$

Taking the C values as 14 for valleys and watershed area of Paonta sahib upstream river Yamuna as A = 10966 sq. km.; HFL corresponding to this flood is about 386 m.

- The existing riverbed is about 380 m and bridge level is about 393 m, meaning thereby a difference of about 13 m. The watershed area of Hathnikund Barrage for river Yamuna is 11391 sq. km.
- The expected scour depth near the Yamuna Ghat (where Guru Govind Singhji used to meditate) is between 10 to 15 (average 12 m).
- The Yamuna bank from the Bridge to existing steps is about 400 m, which is being scoured by the outflow from the powerhouse and the tributary of river Giri. This bank is in danger and needs strengthening.
- It is proposed to extend the Existing Yamuna Ghats on Upstream (about 700 m) (400 m till bridge and about 300 m upstream of existing bridge till Ram Janaki Temple); and downstream by about 100 m from the existing crematorium located downstream of the Gated structure.
- From the crematorium, it is proposed that a walkable path to the Kalesar temple be made and the existing solid waste dumping along the river Yamuna be removed. Further, along the proposed path, a forest should be created with various trees like Kadamb, Jamun, Mango, etc., and various grasses for grazing and soil conservation.
- The wastewater should be treated and checked along the proposed path at different levels on the right bank through natural means and phytoremediation. There can be a drain with different chambers that can check the wastewater from different villages along the river Yamuna, and the naturally treated water can be used for agriculture/ recharging. Still, it may not be mixed directly with the river Yamuna.

Some proposals (Fig. 7, Fig. 8, Fig. 8, Fig. 10) made as Architectural conceptual interpretation for transforming the observed spaces near the city bank of Yamuna till now. It covers the stretch of Paonta Sahib central city with a main riverfront

development stretch of 1.1km. It connects other sites such as Bahral village, Kalesar forest zone, and Kalesar Mahadev Temple, Haryana. The whole stretch of model development for Riverfront design is about 16 km, and the frontage stops about 4 km before the Hathnikund Barrage comes upstream from Yamuna to downstream Yamuna.

It is essential to develop the concepts from whole to part for riverfront development. Imagine the scale from a larger perspective, then come down to more minor details on a smaller scale. While designing the riverfront development, it was considered a valley surrounded by hills and picturesque views. Though the city does not have much gradient, it is an advantage for its development and connectivity. Considering its natural and cultural background, the main elements provided for developing a vibrant urban image are the provision of Ghats, cremation, bathing facilities, spiritual pathways, and vehicular and pedestrian path segregation. Some other elements such as construction of Idol Island and recreational islands have been provided, along with recreation parks and seating with other street infrastructure. Other aspects seen while developing the urban image is the provision of proper sewage treatment along with the urban drainage infrastructure.

The Paonta Sahib City Revitalization Project, inspired by the World Bank's Inclusive Heritage-based City Development Program (IHCDP) and National Mission for Clean Ganga (NMCG) by Jal Shakti Ministry aimed to address different challenges, including proper sanitation, and drinking water supply, within the city's boundaries. The comprehensive project focused on rejuvenating the 16 km river segment coursing through the urban area towards Hathnikund Barrage, Haryana. It divided the project into three distinct precincts, each aligned with the river's physical characteristics: An Ecological precinct, a Heritage & Cultural precinct, and a Socio-economic precinct.

The government's proactive investment in the city’s sewage treatment plants, and proactive involvement of the citizens and municipal corporation in cleaning sites near the riverbanks, signaled a significant step toward reducing pollution in the city's river. This move promised to substantially improve the river's ecological health by treating sewage to the required standards. Moreover, the project envisaged enhancing the aesthetics of the riverfront through physical interventions and infrastructure development (Bach et al., 2014). However, despite these efforts, the city's riverfront areas remain less than welcoming due to the presence of unintended uses and activities like sand mining, irresponsible waste handling. To fully realize the project's goals, ensuring the timely installation of several sewage treatment plants and effectively managing wastewater is imperative. Additionally, the longstanding tradition of creating vegetative bands or bioswale along the riverfront, a pilgrimage path development, continues to be an integral part of the city's heritage and should be considered in revitalization efforts (Lancia et al., 2020).

5.2. Economic analysis

In this study, an annual discount factor of **6%** is considered. The present worth and annual recovery factor has been calculated using the equations from section 4.4.2 The cashflow diagram is shown in Fig. 11.

Table 2 shows the details of the economic analysis, the project's present worth, and the annual capital recovery factor.

Table 2
Economic Assessment criteria for development of riverfront project.

Cost criteria	Description	PW of Cost (Million INR)
Fixed Cost (Base year 2025)		
1. Construction components	Riverfront & Ghat Development	269.7
	Crematorium Development	118.7
	Beautification & Green Belt Development	221.4
	Basic Infrastructure & Amenities	10.0
5. Environmental Management Plan	Design & Development plan, construction, labour, operation	1.3
6. Environmental Monitoring Plan	Air Quality Monitoring, Water Quality Monitoring, Noise Level Monitoring	3.1
Grand total (1 + 2 + 3)		**624.2**
O & M Cost		
7. Operation & Maintenance Cost (Annual)	3% of fixed cost (18.8 million per year)	**272.8**
Replacement Cost		
8. PW of Replacement Cost (after 12 years (2037), and 24 years (2049)	15% of PW of the Fix cost in 2037, 93.6 M	**46.6**
	30% of PW of the Fix cost in 2049, 187.3 M	**46.3**
Total Present Worth of the Project		**989.9**
Capital Recovery Factor (Annual)		**68.3**

The riverfront development is justified as it will fulfil the long-pending demand of at least two religions to provide facilities for spiritual pilgrimage to more than 0.3 million people every year. Also, it will provide employment and livelihood opportunities to the permanent residents of the Paonta Sahib. Integrating pilgrimage tourism, eco-tourism, and cultural activities with parks, walkways, and commercial zones can enhance property values by 15–20% and promote public well-being, as seen in similar projects (NIUA, 2022). Environmental restoration and flood management will also ensure ecological sustainability, making the riverfront a regional economic and social asset. It is felt that the developed infrastructure will result in an improved Human Development Index (HDI) and the holistic development of the area.

6. Discussion and recommendations

Cities and rivers share a symbiotic relationship, where urban development and sustainability often hinge on effective river management strategies. Within this context, the concept of urban river management takes centre stage, encompassing a wide scope and spectrum of activities to maintain the health and vitality of urban waterways. One crucial aspect of urban river management is river-centric planning, which involves mainstreaming 'River-Thinking' into a city's long-term vision (Bach et al., 2014). By integrating the river into the city's development plans, cities can harness the potential of these natural assets for the benefit of both residents and the environment. Understanding riverfront developments is equally important. This involves examining their historical significance, evolving functions, and the drivers that propel transformative changes along riverbanks (Wuijts et al., 2022). By learning from the past and recognizing current trends, cities can make informed decisions about their riverfronts.

The riverfront development in a hilly city offers scenic beauty and recreational potential but requires attention to erosion control, sustainability, and ecological conservation. Leveraging the hilly terrain for terraced design, hiking trails, and cultural

integration can enhance the riverfront's appeal (Kumar & Pushplata, 2015). Ensuring accessibility, mixed-use development, and public safety are essential, as are community engagement and conservation efforts. A riverfront should be developed with a focus on resilience, sustainable infrastructure, and the preservation of the city's unique natural environment and cultural heritage. There is a need to analyze the economic factor for at least 30 years for development, but the infrastructure built must cater to generations hence, at least 100 years can be assumed.

Elements of river management include the preservation of urban wetlands and water bodies, the enhancement and conservation of urban biodiversity, and effective measures for urban river pollution control. Additionally, it emphasizes the significance of enriching and maintaining the riparian buffer zones, which act as a protective barrier for riverside ecosystems. Understanding the economics of sustainable urban river management is also crucial, as it highlights the potential for economic growth while maintaining environmental sustainability (Yadav et al., 2024). Addressing urban extensions on floodplains is a challenging but vital aspect of river management (Pattacini, 2021). Developing design considerations for a barrier-free environment along riverfronts promotes accessibility, inclusivity, and safety.

Urban river governance, centered on river health and community participation, forms the backbone of effective management. Community engagement in the care and stewardship of their rivers fosters a sense of ownership and responsibility. The future field of urban river management is poised for innovation. Innovative monitoring techniques will play a pivotal role in urban rivers health assessment (Yahaya et al., 2013), enabling cities to take timely actions. Additionally, future considerations must account for changing environmental dynamics and emerging challenges, emphasis on the need for forward-thinking and sustainable practices in managing this vital urban resource. (Table 3) indicates that by recognizing the symbiotic relationship between cities and rivers and adopting comprehensive urban river management strategies, cities can thrive while preserving their waterways' natural beauty and ecological health.

Table 3
Circular Economy and riverfront development.

S.No	Factors	Issues & challenges	Design considerations / Remediations
1.	**Socio-Cultural** [This focuses on the social impacts such as the gatherings, activities and cultural activities related to the spirituality of the place. It also focuses om the political and crowd involvement in the city and riverfront.]	1. The involvement of 2 religions primarily Sikh and Hindu. 2. Sharing of common spaces between the 2 groups and similar activity sequence. 3. Politically acknowledges due to sharing borders with 4 states but no proper city planning boundaries. 4. Crowd generation through tourism as well as managing. 5. Festivities and conglomeration spaces along with recreational & green spaces are not provided.	1. Provision of Pilgrimage Path for both religions along the river stretch. 2. Creation of segregated spots for religious pilgrimage for both religions, sharing till certain points but segregation of religious spots. 3. Creation of riverfront along with different recreational activities alongside it. Provisions include Ghats, bathing, boating, common grounds, and recreational water activities.
2.	**Environmental** [This focuses on the environmental aspects such as the landmass, river course, the flora and fauna of the place and the topography of the place.]	1. Green spaces and reserve forests not maintained and bounded. 2. River having effluents discharged directly from STPs and pharmaceutical industries. 3. River health can be at risk with growing development & population. 4. Risk of disasters due to hilly regions such as landslides, flash floods, earthquakes, etc.	1. Provision of Green Corridors, Nature-based bioswales, and wastewater treatment to reduce river pollution and health. 2. Create planned urban drainage pipelines and flow measures and plan the city for different activity zones. 3. Flood risk resilient infrastructure and erosion protection by weirs, guide bunds and launching apron provisions. 4. Segregation & waste management with proper sanitation infrastructure.
3.	**Technical Intervention** [This focuses on the construction intervention, the planning aspect for the development, and understanding of the river-engaged activities for planning the drainage pattern of the place.]	1. Zoning regularization and intervention spots. 2. Infrastructure planning & materials in accordance with hilly conditions. 3. Riverbank scouring problem due to varying river discharges. 4. River engaged activities creation and provision of required infrastructure. 5. Urban drainage and river water quality control in accordance with additional infrastructure and growth.	1. Considering the environmental and social factors, the riverfront planning will require intervention spots according to build environment and natural environment. 2. Flood resilient: Launching aprons and cover blocks in riverfront encroached areas and providing vegetation to control scouring and erosion problems. 3. Using the river sediments for creation of platforms and ghats taking into consideration vernacular and resource utilization factors. Taking Urban Drainage & river health into consideration.
4.	**Socio – Economic** [This focuses on the project's financial, social wellbeing and tourism aspects. This also sees about the investment and return aspect.]	1. Generation of tourist spots and infrastructure for attracting tourism and revenue generation. 2. Involvement of stakeholders & plan	1. Riverfront development for an Urban Image of the city and revenue generation through its model. 2. Bringing on board institutions like NIUA, NMCG, IHCDP can help in creation of the visionary project.

S.No	Factors	Issues & challenges	Design considerations / Remediations
		implementation bodies. Maintenance and operation for the project implementation. 3. Revenue procurement for project implementation.	3. This project could serve as a model for circular economy through rivers. End-users need to be responsible citizens.

The strategies developed for the Paonta Sahib Riverfront project proposal provide valuable insights for addressing global urbanization and sustainable riverfront development challenges. The approach integrates ecological restoration with urban development (Dewi et al., 2021), can be adapted to similar projects across diverse settings, such as Brazil's urban rivers and Russia's vast waterways. These methods align with global best practices and support international objectives like the United Nations Sustainable Development Goals, focusing on SDG Goal 6 – Drinking Water and Sanitation for all. Furthermore, the findings demonstrate the importance of community collaboration and environmentally conscious design, offering a blueprint that can be applied to riverfront projects worldwide. This is especially relevant for regions like Uruguay, with similar socio-economic and environmental contexts. The success of the Paonta Sahib project, evidenced by increased tourism, improved public health, and strengthened community ties, illustrates the framework's broader applicability and benefits. In summary, the Paonta Sahib riverfront development model contributes to the global discourse on sustainable urban planning, offering a replicable approach for creating resilient and inclusive riverfronts globally.

In summary, the framework for riverfront development at Paonta Sahib envisions a resilient and prosperous future for the city, where the natural beauty of the hills and the region's cultural heritage coexist with vibrant communities and responsible development. By embracing this framework, Paonta Sahib can achieve sustainable growth, preserve its environmental treasures, and create a model for riverfront development in hilly regions worldwide. In the context of the circular economy (Fig. 12).

7. Conclusions

The proposed framework for riverfront development at Paonta Sahib presents a holistic approach to addressing the city's unique challenges and opportunities in the Himalayan foothills. Situated along the Yamuna River, the city offers immense potential for tourism and cultural preservation, driven by its strategic location and religious significance. The framework prioritizes sustainable practices, public engagement, and circular economy principles, focusing on efficient resource utilization, flood resilience, and ecological sensitivity.

Key elements include ghat development for recreation and rituals, green belts acting as sponge areas, nature-based wastewater treatment, rainwater harvesting, and proper drainage systems to reduce pollution and ensure water conservation. Zoning regulations tailored to the hilly terrain emphasize flood-resistant mixed-use developments, balancing urban growth with environmental preservation. This approach aligns with global standards for sustainable urban planning, emphasizing adaptability to diverse cultural and geographical contexts.

An annual capital recovery factor of INR supports the project's economic viability. 68 million over a projected period of 35 years. While the study provides urban aesthetics, zoning, and basic technical insights, further exploration into drainage systems, hydraulic analysis, and water quality monitoring are recommended. These studies can inform targeted development zones and integrated water management systems, ensuring the framework's scalability and relevance for diverse urban contexts.

Declarations

Compliance with Ethical Standards:

Ethical Approval:

Not Applicable.

Consent to Participate:

Not Applicable, as this study did not involve any human subjects.

Consent to Publish:

All authors of this manuscript agree to its publication.

Competing Interests:

The authors have no relevant financial or non-financial interests to disclose.

Conflict of Interest:

The authors declare that they have no known conflict of interest that could have appeared to influence the work reported in this paper.

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Authors Contributions:

All contributors played a role in shaping the study's conception and design. **Adyasha Jena**: Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing, Visualization. **Mitthan Lal Kansal**: Supervision, Methodology, Conceptualization, Writing – review & editing. Each author actively participated in the refinement process, and consensus was reached on the final manuscript, which all authors read and approved.

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Data Availability Statement

The information about the data used is in section 4.1 Materials of the manuscript. Additional data will be made available on request.

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Figures

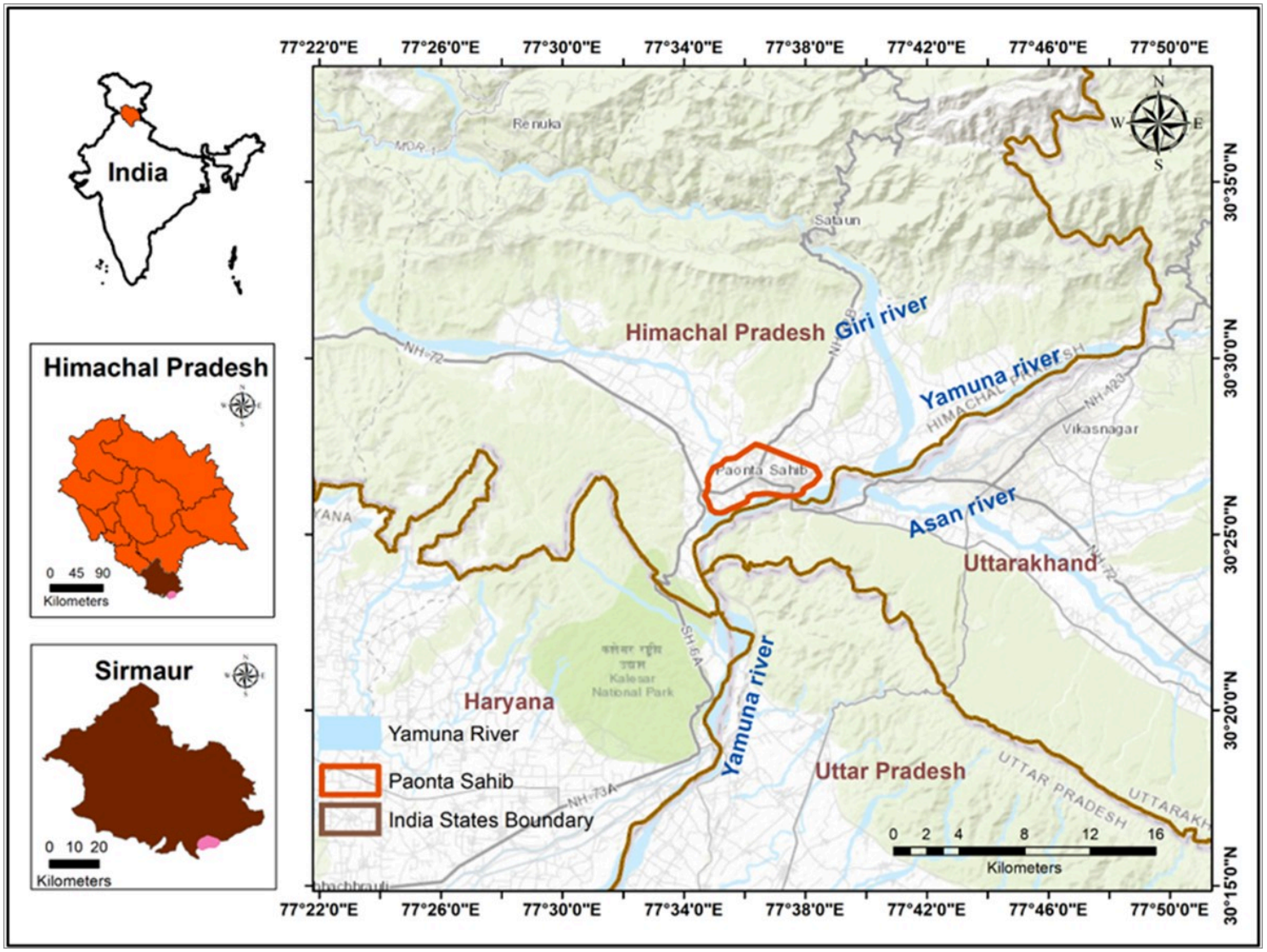

Figure 1

Locational map of Paonta Sahib, Himachal Pradesh, India.

(Source: Image generated from satellite image through ArcMap10.8.2 ©2023 Maxar)

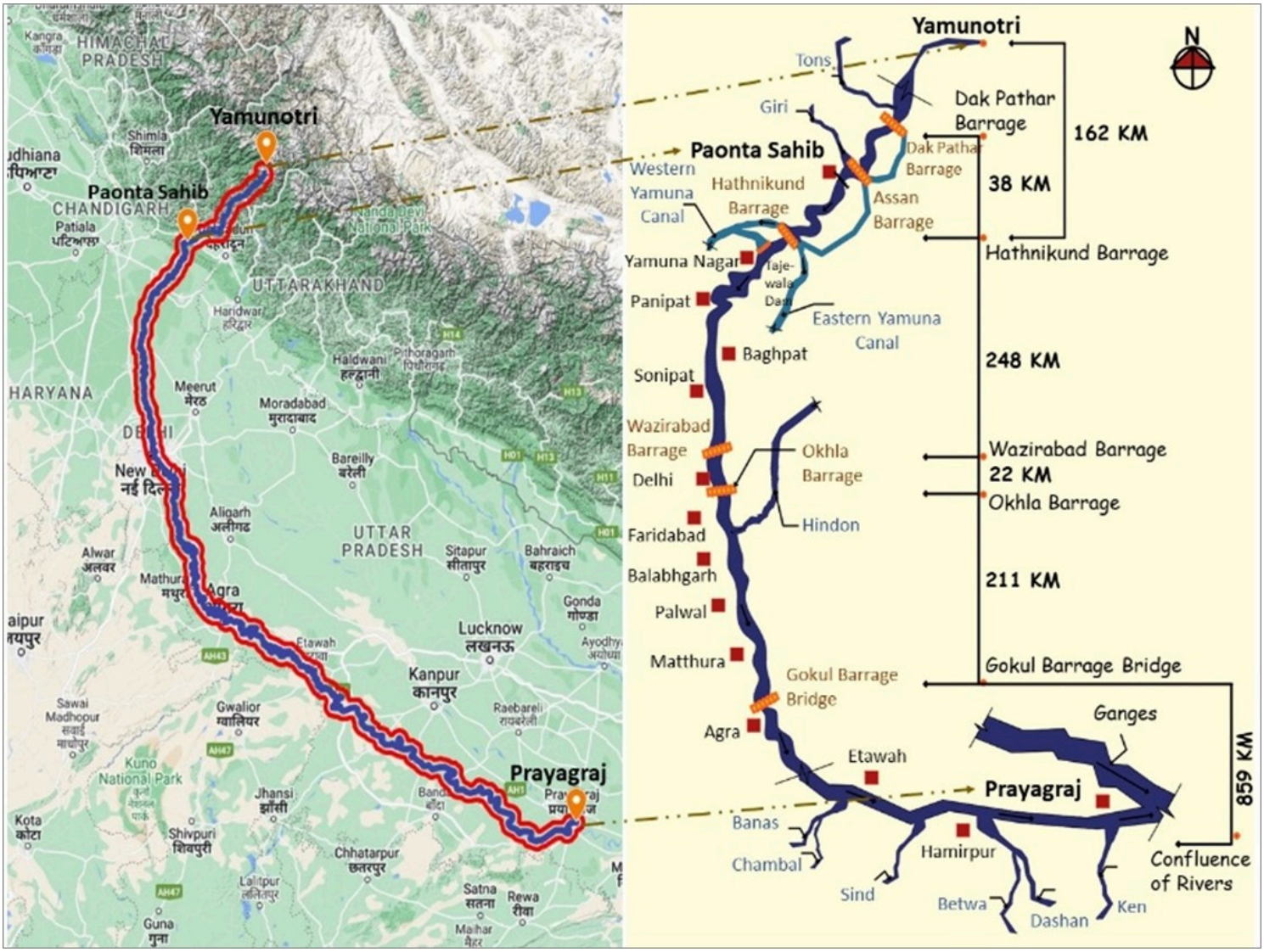

Figure 2

Schematic diagram of River Yamuna along with important cities.

(Source: Image generated from satellite image through Google Map ©2023 Maxar)

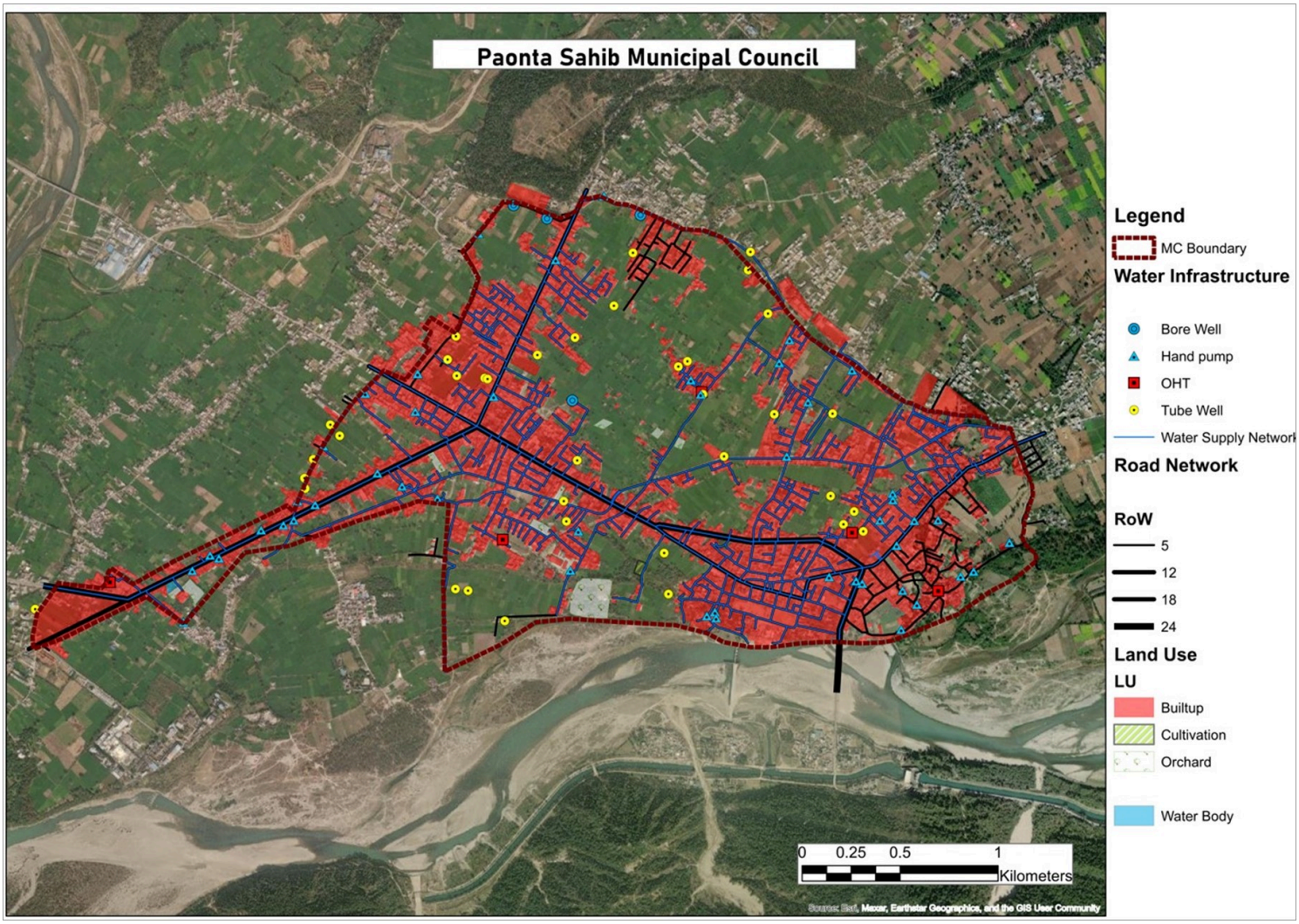

Figure 3

Land use and other water infrastructure in the Paonta Sahib town.

(Source: Image generated from satellite image through ArcMap10.8.2 ©2023 Maxar)

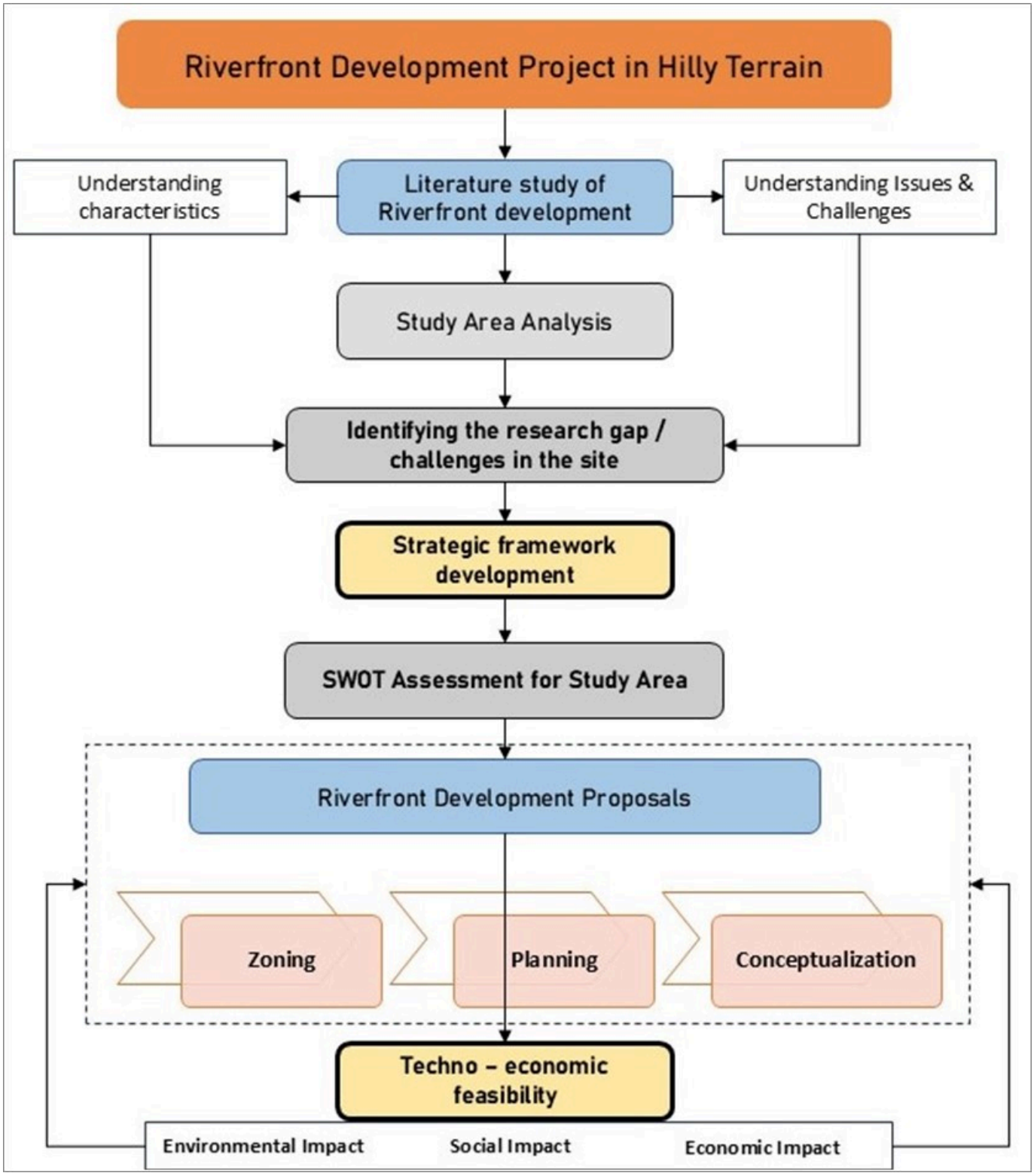

Figure 4

Proposed methodology for riverfront development

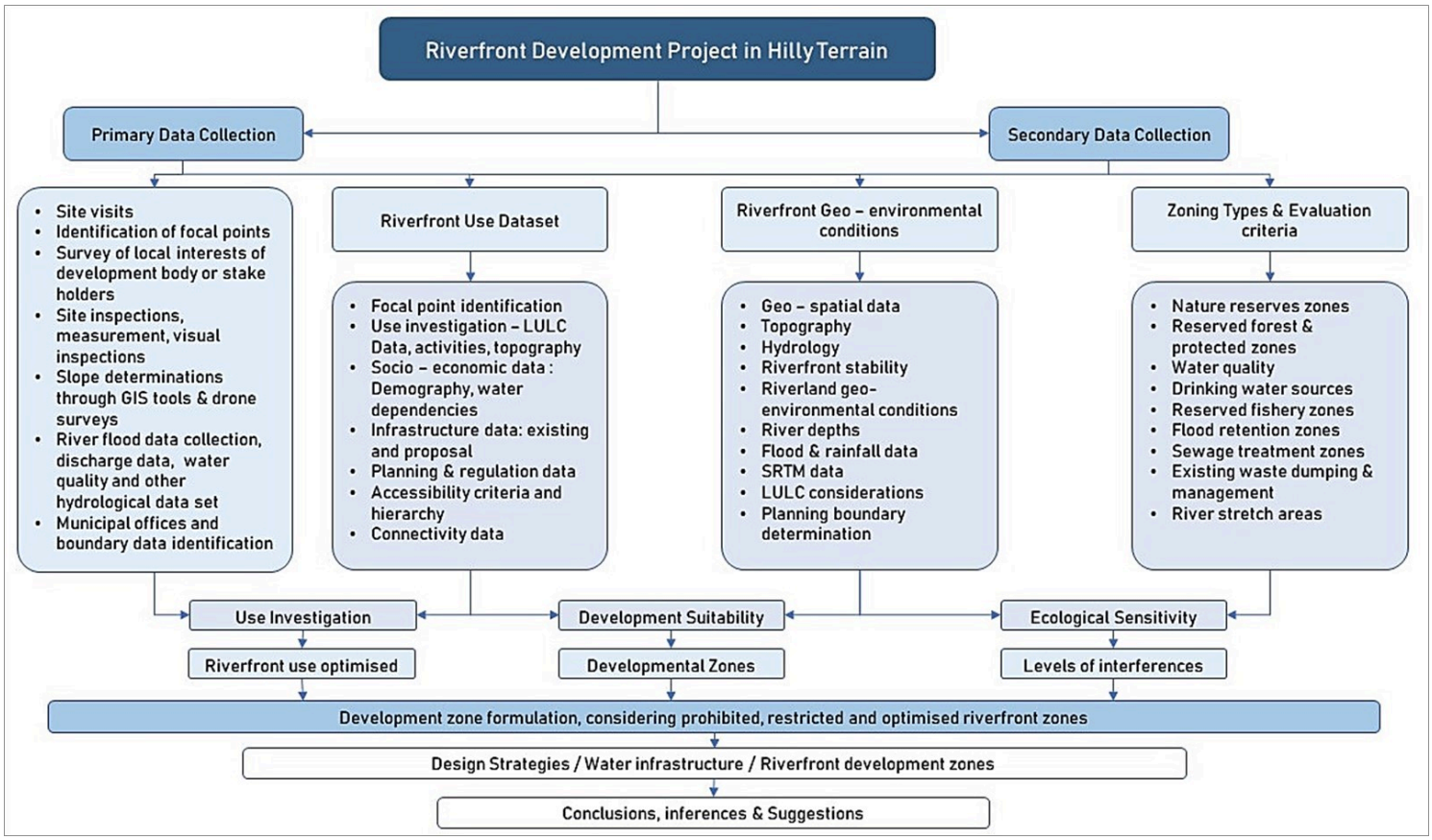

Figure 5

Strategic framework for riverfront development in hilly terrain.

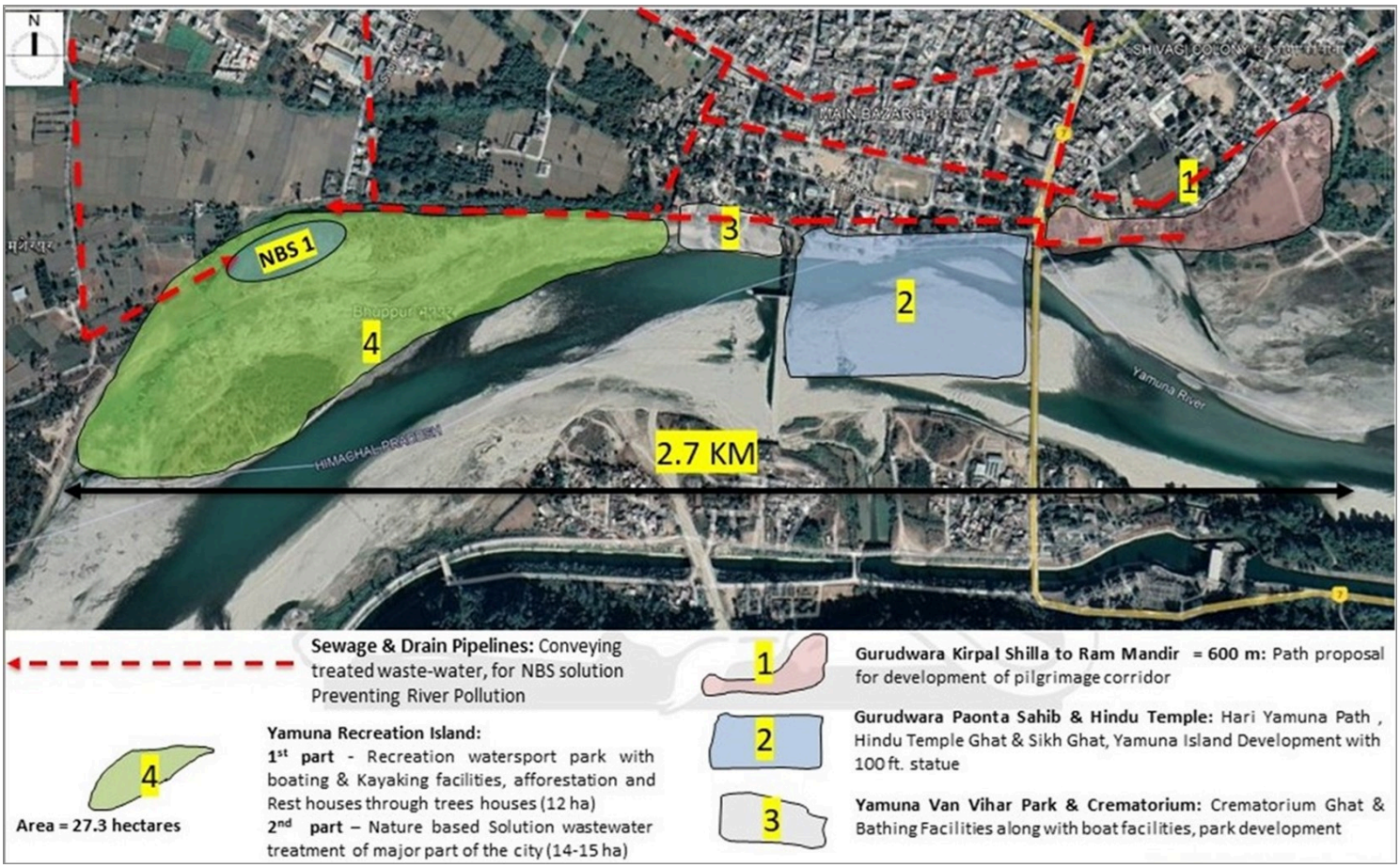

Figure 6

The zoning for the riverfront development using integrated activity zones.

(Source: Image generated from satellite image through Google Earth ©2023 Maxar)

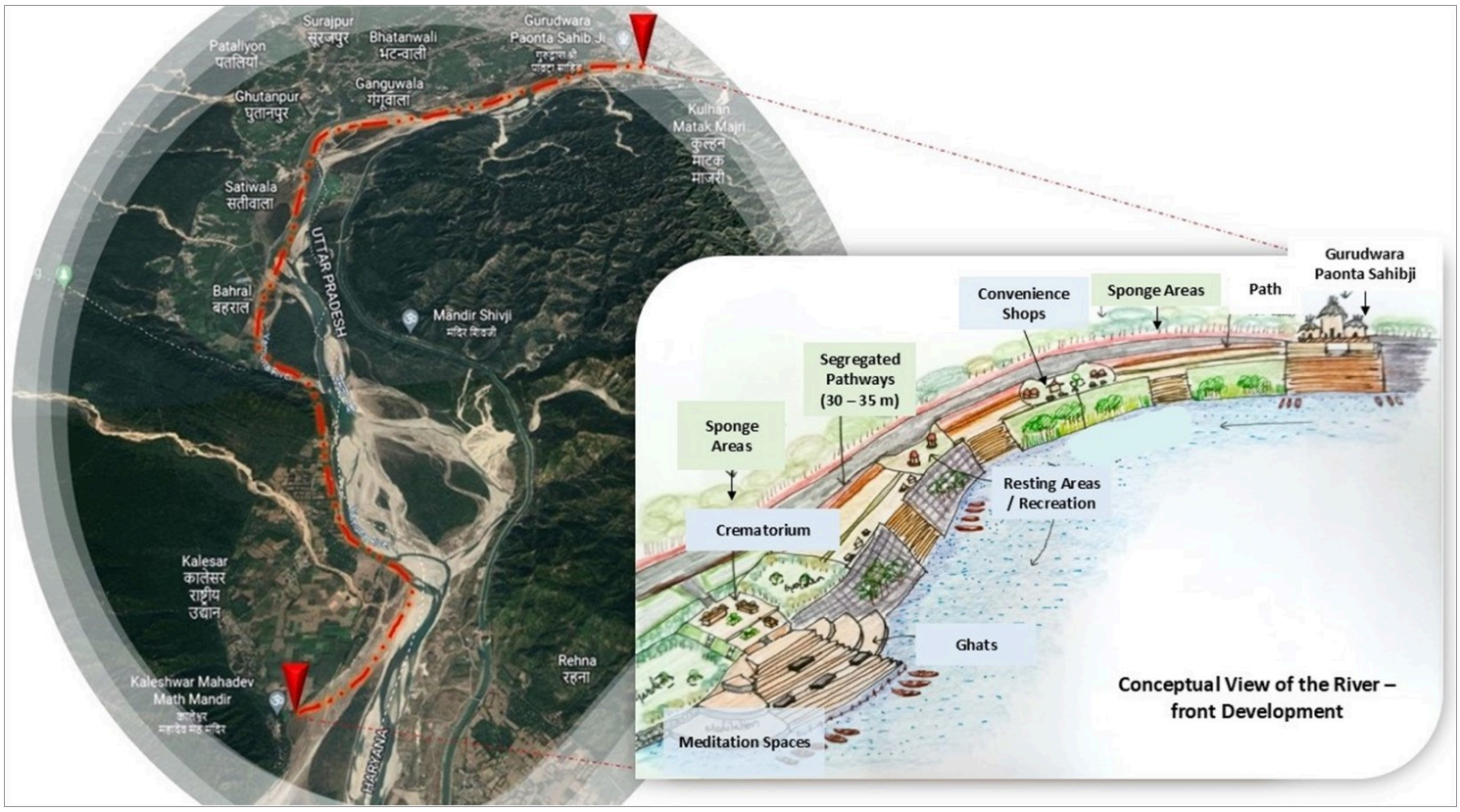

Figure 7

Yamuna River reaches from the Paonta Sahib to Kalesar Temple along with proposed riverfront.

(Source: Image generated from satellite image through Google Earth ©2023 Maxar)

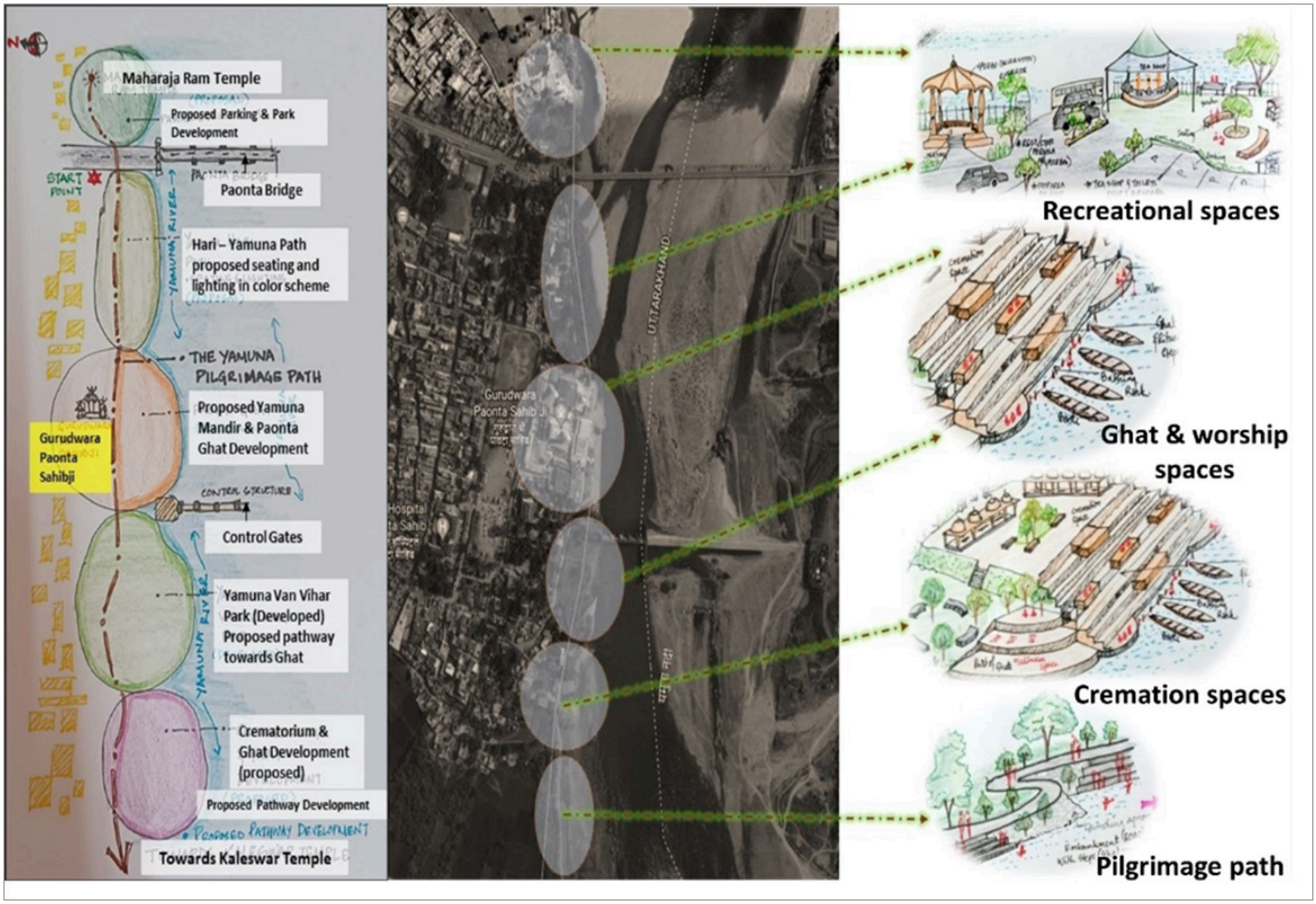

Figure 8

Conceptual idea for Riverfront Development.

(Source: Image generated from satellite image through Google Earth ©2023 Maxar)

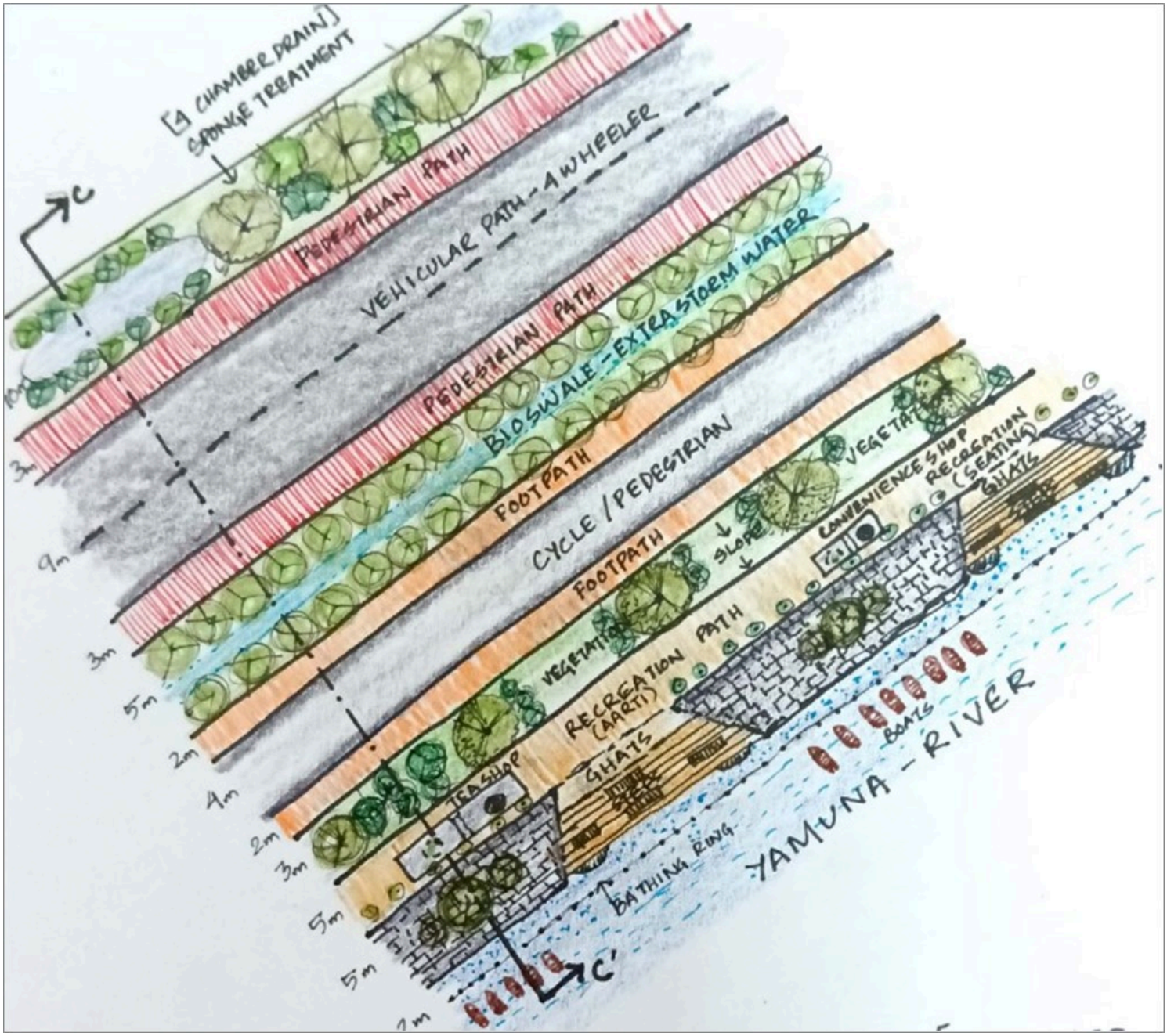

Figure 9

Conceptual details of the riverfront development corridor.

Figure 10

Riverfront development proposal in aerial view.

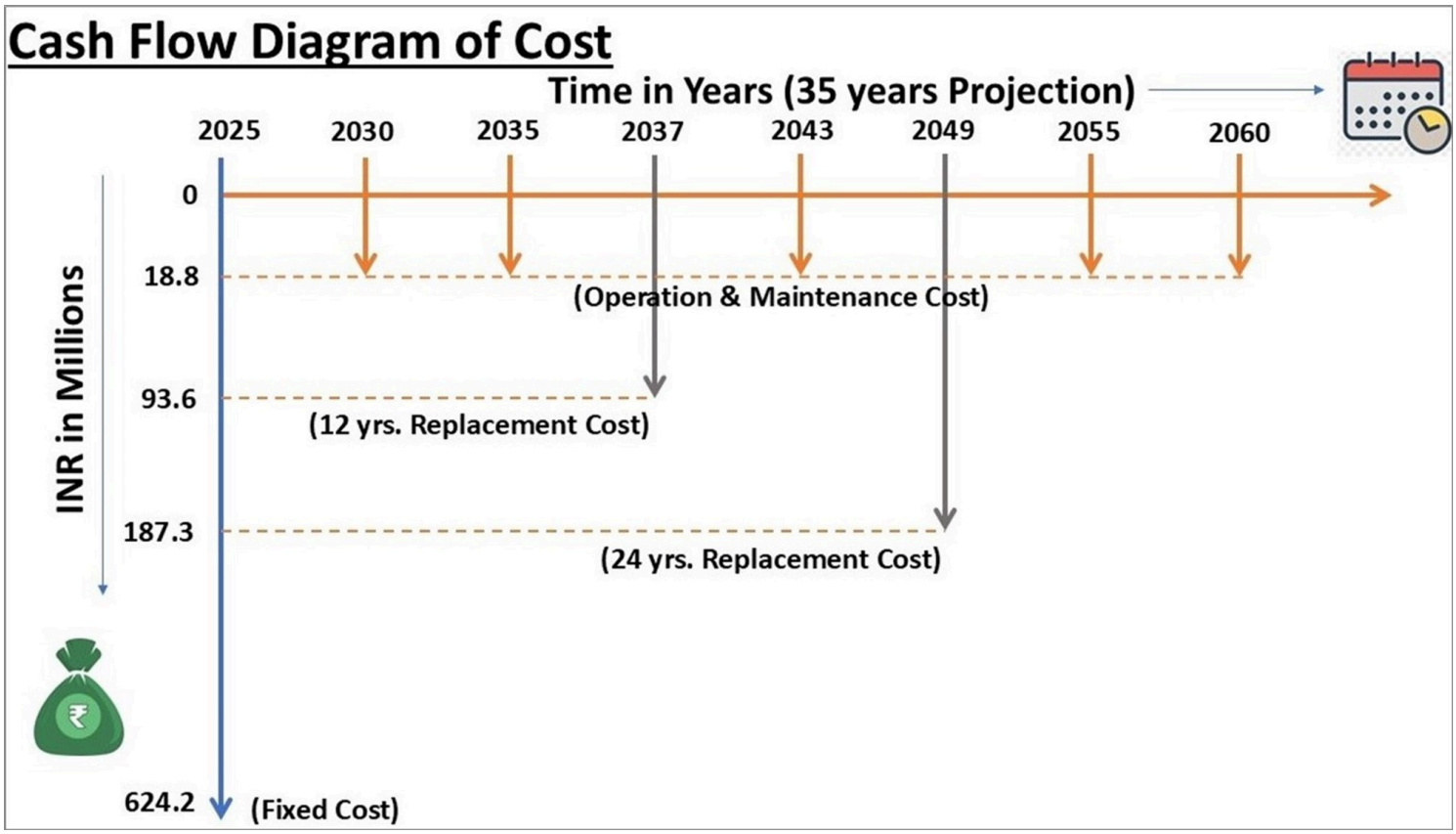

Figure 11

Cashflow diagram of cost for Riverfront development

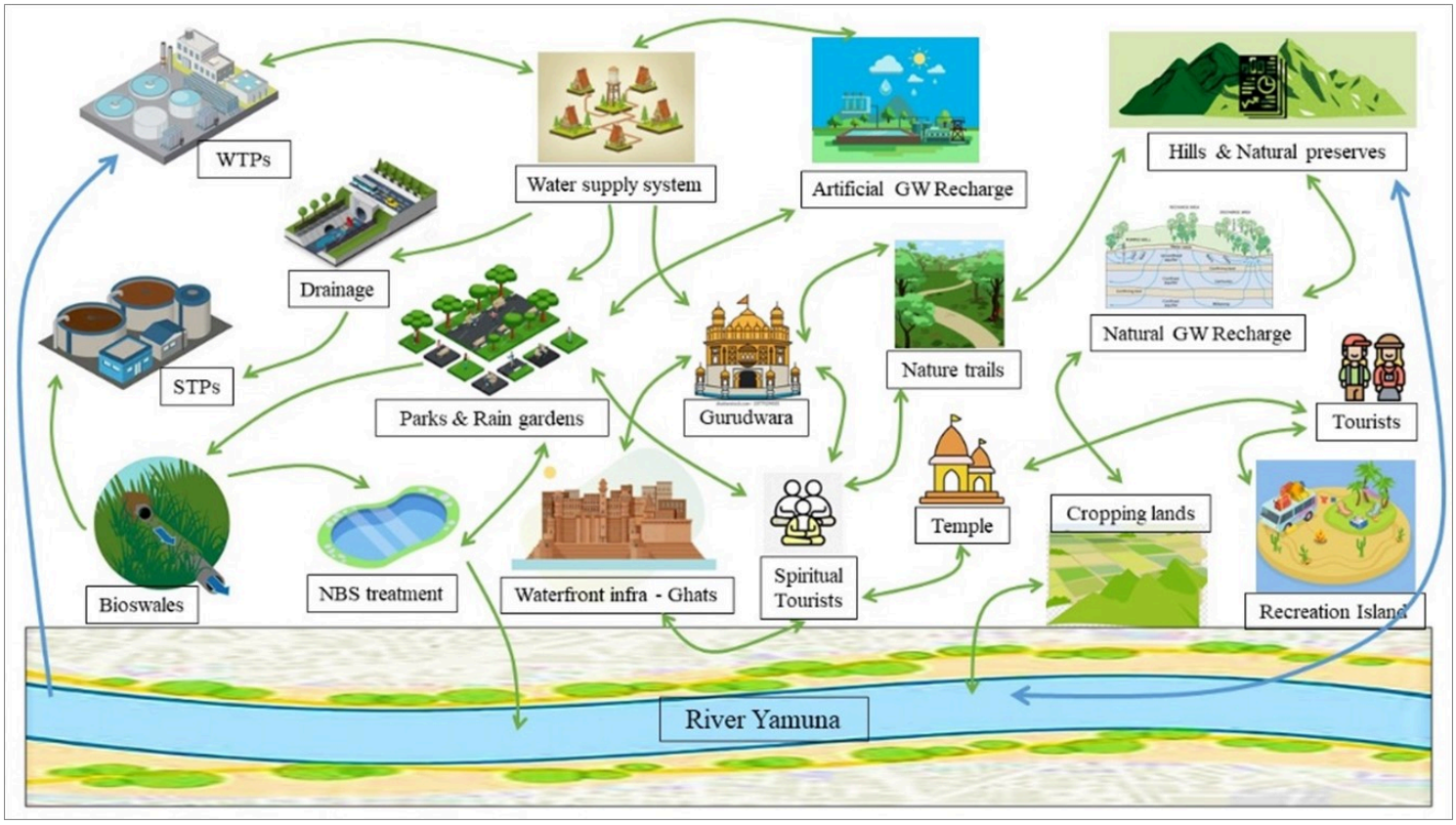

Figure 12

Circular Economy through Proper infrastructure planning and riverfront development.