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Original Research Article

Sustainable Urban Drainage and Rainwater Harvesting Solutions for Climate-Resilient Infrastructure in Saudi Arabia

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Abstract: Urban development and climate conditions in Saudi Arabia will need to take account of arid conditions, increasing rainfall variability and fast urbanization in future infrastructure. In this regard, sustainable urban drainage systems, rainwater harvesting and blue-green infrastructure may provide an integrated solution to these challenges in terms of being protective and water productive simultaneously. This review article focuses on sustainable urban drainage systems, rainwater harvesting and blue-green infrastructure, as an integral package for climate resilience of Saudi Arabian cities. It uses a structured review format similar to Springer review practice, combining review of terminology, benefits, evidence on implementation and applicability to other regions before proposing Saudi-specific application framework. Literature review of sustainable urban drainage, stormwater management, rainwater harvesting, blue-green infrastructure, urban flooding, water stress and climate adaptation for Saudi Arabia was conducted between 2020 and 2025 years. Results demonstrate that Saudi Arabian applications will be inappropriate if they just copy the solutions designed for more humid climatic zones; they will require hot-arid design decisions taking into account first-flush treatment, sediment management, evaporation prevention, managed aquifer recharge, non-potable reuse, smart monitoring and low-maintenance design principles for the public realm. Contribution includes a practical typology of solutions for Saudi municipalities and mega-development projects, implementation table and illustrative graphs.

Keywords: Sustainable Urban Drainage Systems, Rainwater Harvesting, Blue-Green Infrastructure, Stormwater, Climate Resilience, Saudi Arabia, Vision 2030.

1. INTRODUCTION

Urban infrastructure in Saudi Arabia is now developing due to demographic changes, new economic areas, tourism hubs and giant urban projects that are required to function sustainably under climatically challenging conditions. Traditionally, drainage engineering assumed that rainfall should be quickly conveyed out of the streets to avoid damages. However, in an arid climate, stormwater is a precious episodic resource. This means that modern climate-resistant solutions should address two goals at once: prevent pluvial flooding due to heavy rainfall and recover the water for subsequent non-potable reuse. Recent reviews on blue-green infrastructure emphasize that climate-resilient urban development depends more and more on systems that restore infiltration, detention, evapotranspiration and managed flow release in urbanized watersheds rather than grey end-of-pipe solutions (Almaaitah *et al*., 2021; Przestrzelska *et al*., 2024). Climate of Saudi Arabia makes it very relevant for the above consideration because its cities have low rainfall amounts, short-term heavy rainfall, high proportion of impervious surfaces, heat stress, landscape irrigation, dust reduction and public cooling needs. Different combinations of flooding risks are presented by cities along the Red Sea Coast, cities in valleys such as Jeddah or Dammam, and the emerging coastal urban clusters such as Neom. Consequently, sustainable urban drainage must be catchment specific instead of relying merely on particular drainage products. Permeable pavements, bioswales, detention basins, rain gardens, underground cisterns and green-blue roofs are useful only if they are properly matched to soil conditions, rainfall depth, sediment load, maintenance capacity and water reuse needs. Review paper recently published in Springer demonstrates why it should not present blue-green infrastructure as a monolithic approach or a single technology. Firstly, it includes analysis of nomenclature and benefits; secondly, it analyzes how international experience in the field is implemented in particular contexts. Thirdly, one important issue that is emphasized is that some water-stressed climatic regions remain understudied in blue-green infrastructure literature despite the fact that there is a great need in adaptation to changing conditions in them (Przestrzelska *et al*., 2024). Following this reasoning, this paper considers Saudi Arabia as a water-stressed country in need of sustainable urban drainage solutions. How can rainwater harvesting and drainage contribute to climate-resilient infrastructure in this country?

2. AIM AND OBJECTIVES OF THE STUDY

This review aims at developing a Saudi Arabian application scenario of sustainable urban drainage and rainwater harvesting to reduce flood risk, provide for non-potable water use and implement climate-resilient public infrastructure under the Vision 2030 and Saudi Green Initiative. Unlike general SuDS review papers, this paper pays particular attention to climatic characteristics of Saudi Arabia, intermittent character of rainfall, sediment loads, high evaporation rates, cost-effectiveness of reuse options, and inter-institutional coordination between urban planning, municipal engineering, water companies and real estate projects. Four research objectives were formulated for the current study. Firstly, this paper defines the terminology related to sustainable drainage, LID, WSUD, BGI, stormwater management and rainwater harvesting. Secondly, it analyzes the potential of these solutions to address the problems of Saudi Arabian cities in view of water stress. Thirdly, it presents the design framework that combines multiple SuDS strategies including source control, conveyance, storage, treatment, reuse and monitoring of urban drainage network. Finally, it proposes research priorities for Saudi cities and municipalities, and implementation priorities for project managers and facility engineers seeking for Scopus-level scientific support for climate-resilient drainage designs.

3. METHODOLOGY

For the purpose of the current study, an applied structured narrative review methodology was adopted, since the evidence base for drainage practices is interdisciplinary in nature and includes climatic and socioeconomic aspects beyond mere technical data. Review methodology was derived from recent review practice on blue-green infrastructure that employs a standard approach of database searching, title-screening, abstract screening, full-text analysis and thematic synthesis (Przestrzelska *et al.,* 2024). Themes for literature review included sustainable urban drainage systems, rainwater harvesting, blue-green infrastructure, nature-based solutions, urban flooding, arid cities, Saudi Arabia, stormwater reuse, managed aquifer recharge, climate-resilient infrastructure and Vision 2030. Articles published between 2020 and 2025 were prioritized, while older publications providing key definitions were only used as supportive material. The criterion of inclusion involved peer-reviewed journals, international reviews, Saudi or Gulf region urban water studies and official documents addressing topics of drainage, stormwater management or climate adaptation in cities. The articles addressing agricultural rainwater harvesting, traditional hydraulic pipe-based systems or climate change adaptation unrelated to stormwater management and reuse were not included in the review process. The extracted information was categorized into five categories, namely terminology, technical components, performance benefits, hot-arid climatic challenges and Saudi application scenarios.

4. Conceptual Background

While SuDS and rainwater harvesting are normally considered separately, climate-resilient infrastructure in Saudi Arabia requires these two concepts to be integrated. SuDS aim at mimicking natural runoff and managing it by slowing down, promoting infiltration, filtration and flow regulation. Rainwater harvesting refers to the collection and subsequent storage of rainfall from roofs and impervious surfaces for reuse. Blue-green infrastructure adds the component of spatial and ecological connectivity to the above concepts through vegetation, soils, water and public open spaces. This paper discusses SuDS as a drainage philosophy, rainwater harvesting as a function of water recovery and blue-green infrastructure as a tool for multifunctionality. Terminology may sometimes confuse people who are looking for drainage solutions. Low Impact Development is used widely in North America, WSUD is popular in Australia, SuDS is common for the United Kingdom, sponge city approaches are prevalent in China, and stormwater control measures are widely known throughout engineering community. What is essential in all of these is that rainwater management is performed locally and close to the source. The most appropriate term for Saudi Arabia would not be the name but the desired performance of the drainage network: reduced peak flows, better water quality, protected conveyance routes, improved water retention and non-potable reuse wherever needed.

5. Saudi Climate and Urban Drainage Context

Arid climate of Saudi Arabia gives rise to challenges in designing sustainable drainage infrastructure, although it is accompanied by certain opportunities as well. Arid and semi-arid climates have long dry periods and rare instances of heavy rainfall. These features combined result in sudden occurrence of stormwater runoff because dry ground with impervious surfaces and steep catchment areas are capable of producing extremely quick flows. Moreover, urbanization intensifies surface runoff, thus posing threat of damage even from small rainfall amounts. The climate change studies prove that rainfall is becoming increasingly non-stationary in these climatic zones (Asif *et al*., 2023; Rashed, 2025). Nevertheless, Saudi Arabia also offers opportunities. Since rainfall is scarce and precious, captured water can replace potable supply for purposes of irrigation, street washing, cooling green spaces, construction works, toilet flushing in large facilities, or aquifer recharge where necessary. Green areas can be created in Riyadh city, Red Sea Coast, vic…

6. Technical Solution Typology

A Saudi SuDS and rainwater harvesting portfolio should start with source control. Roof runoff from villas, schools, malls, warehouses and stations can be routed through first-flush diverters and storage tanks. Blue-green roofs may have selective value in dense districts where structural capacity, irrigation demand and maintenance are secured. Permeable pavements can reduce runoff from parking areas and low-speed streets, but they require careful sub-base design, sediment pretreatment and maintenance to prevent clogging under dusty conditions. Tree pits and rain gardens can capture local runoff while improving microclimate, but plant palettes must use drought-tolerant native or adapted species.

The second layer is conveyance and detention. Vegetated swales, dry channels, linear parks and wadis can carry storm water safely while providing public amenities during dry periods. Detention basins and retention ponds should be designed as multi-use spaces rather than isolated fenced depressions where possible. In hot-arid cities, open water storage must account for evaporation and safety; therefore, covered tanks, shaded basins, underground modular crates and managed release may be preferable for many sites. The third layer is treatment and reuse, including sediment forebays, bioretention media, constructed wetlands where water is available, disinfection for selected reuse applications and smart controls that release water before predicted storms.

7. Benefits for Climate-Resilient Infrastructure

The first benefit is flood-risk reduction. Distributed SuDS elements reduce runoff volume and delay peak discharge, lowering pressure on conventional storm drains. This is particularly important in areas where pipe upgrades are expensive, road corridors are congested or historical development has blocked natural drainage routes. International modelling literature shows that SuDS decision-support systems are moving from simplified runoff calculations toward integrated hydraulic, water-quality and planning tools (Ferrans *et al*., 2022). Saudi municipalities can use this direction to test combinations of swales, basins, permeable surfaces and tanks before construction.

The second benefit is water productivity. Urban rainwater utilization reviews show that rainwater can be managed through source collection, conveyance, storage, treatment and final reuse, with benefits for both pollution control and flood mitigation (Xu *et al*., 2023). For Saudi Arabia, reuse is most practical when the demand is close to the source. A school can irrigate shaded courtyards, a mosque can support landscape cleaning, a logistics park can reuse tanked water for dust suppression, and a residential compound can combine roof harvesting with greywater and treated sewage effluent strategies. This reduces pressure on desalinated potable water and supports circular water management.

The third benefit is urban liveability. Blue-green drainage corridors can reduce heat stress, improve walkability, enhance biodiversity and create public spaces that align with quality-of-life objectives. The benefit is not only aesthetic. Heat, flooding and water scarcity interact: shaded landscapes reduce outdoor thermal stress, planted areas increase infiltration, and harvested water helps sustain vegetation during dry periods. However, poorly designed green infrastructure can also increase water demand. Saudi projects should therefore use water-budgeted planting, smart irrigation, soil moisture sensors and reuse targets to avoid creating landscapes that depend on additional potable water.

8. Design Framework for Saudi Applications

The proposed framework follows five linked steps. The first is catchment diagnosis, including rainfall intensity, flood pathways, wadi connectivity, soil infiltration, groundwater constraints, imperviousness, asset exposure and social vulnerability. The second is solution selection, where measures are matched to local conditions rather than selected from a generic catalogue. The third is performance modelling, using hydrologic and hydraulic tools to estimate runoff reduction, storage volume, bypass flows and exceedance pathways under climate-adjusted events. The fourth is delivery governance, including standards, approvals, procurement, construction quality and operation responsibilities. The fifth is monitoring and learning through sensors, inspections and post-storm reporting.

This framework supports a shift from project-by-project drainage to networked urban water resilience. In a new district, every parcel can have a runoff target; streets can function as safe conveyance corridors; parks can store exceedance flows; and district tanks can supply irrigation. In existing neighborhoods, retrofitting can begin with schools, mosques, municipal buildings, medians and parking lots because these spaces are visible, publicly controlled and repeatable. In giga-projects, SuDS and rainwater harvesting can be integrated with digital twins, building information modelling and environmental performance dashboards from the earliest master-planning stages.

9. Governance and Policy Integration

Technical design alone will not deliver climate resilience. Saudi implementation requires coordination among municipalities, water authorities, road agencies, real-estate developers, landscape architects, facility managers and emergency services. A common barrier in global SuDS practice is fragmented responsibility: one entity builds the system, another maintains the landscape, and a third manages flood risk. This fragmentation creates uncertainty about budgets, inspection standards and performance accountability. Therefore, every Saudi SuDS project should have a maintenance owner, an asset register, inspection frequency, sediment disposal protocol and performance indicators linked to municipal approvals.

Policy alignment is strong. Vision 2030 emphasizes sustainable cities, quality of life, environmental protection and efficient resource use. The Saudi Green Initiative supports greener urban landscapes, while giga-projects require climate-conscious infrastructure that can attract investment and tourism. SuDS and rainwater harvesting can contribute directly to these goals when they are not treated as decorative extras. Planning codes can require on-site retention, maximum runoff discharge rates, water-quality pretreatment and non-potable reuse studies for large developments. Incentives can support retrofits in commercial districts and residential compounds, while public projects can demonstrate reliable designs before private-sector scaling.

10. Research Gaps and Innovation Agenda

The Saudi research agenda should move beyond proving that SuDS works in principle. The urgent need is location-specific evidence on design storms, sediment loading, infiltration rates, pollutant profiles, vegetation survival, lifecycle costs, maintenance frequency and social acceptance. Many international studies are based in humid or temperate contexts, while the Saudi environment includes dust storms, high solar radiation, saline groundwater in some areas and long dry periods that affect biological treatment processes. Pilot projects should therefore be monitored across multiple seasons, including dry weather, first flush, extreme rainfall and post-event recovery.

Innovation opportunities include smart rainwater tanks linked to weather forecasts, modular underground storage beneath parking and plaza spaces, bioswales using native planting, AI-assisted drainage inspection, satellite and drone mapping of flood pathways, permeable pavement clogging sensors, and district-scale digital twins for stormwater. Managed aquifer recharge may also become more relevant where harvested water can be pretreated and injected or infiltrated safely. However, recharge should be governed by hydrogeological assessment, water-quality protection and long-term monitoring. The most valuable Saudi innovation will be not a single device but a repeatable system that integrates hydrology, landscape, data and governance.

11. DISCUSSION

The review confirms that Saudi Arabia should treat sustainable urban drainage and rainwater harvesting as a combined resilience strategy rather than as separate environmental features. Blue-green infrastructure literature shows that solutions must be adapted to climate and socio-economic context; what works in Rotterdam, Copenhagen or Singapore will not automatically work in Riyadh, Jeddah or Tabuk. The attached Springer model also shows that water-stressed areas often have less documented implementation, making Saudi-focused evidence valuable for global scholarship as well as national planning (Przestrzelska *et al*., 2024).

A key design tension is between infiltration and storage. Infiltration is attractive because it restores natural hydrology, but it may be limited by soil permeability, contamination risk, groundwater conditions and subsurface utilities. Storage is controllable and supports reuse, but it requires space, capital cost and maintenance. Saudi projects should therefore use a hybrid logic. Infiltrate where safe and useful; store where reuse demand exists; detain where flood protection is the priority; and convey exceedance flows visibly and safely through wadis, parks and streets. This balanced approach is more realistic than promoting one universal solution.

Another tension is between landscape greening and water conservation. Blue-green infrastructure can reduce heat and improve urban quality, yet vegetation in arid climates can increase irrigation demand if species and soil design are poorly chosen. The solution is water-sensitive planting supported by harvested rainwater, treated wastewater where available, mulching, hydrozoning and smart irrigation. In this sense, rainwater harvesting is not merely a tank technology; it is the water budget that makes resilient landscapes credible. Projects should report annual irrigation demand, harvested contribution, treated-water contribution and potable-water avoidance as linked indicators.

12. CONCLUSION

Sustainable urban drainage and rainwater harvesting can become a practical foundation for climate-resilient Saudi infrastructure if they are designed as integrated urban systems. The review identified source control, conveyance, detention, treatment, reuse and monitoring as the main functional layers. It also showed that hot-arid adaptation requires sediment control, evaporation management, first-flush treatment, maintenance planning and realistic reuse demand. For Saudi cities, the strongest pathway is a hybrid network that combines grey drainage capacity with blue-green public spaces, underground storage, smart controls and catchment-scale exceedance planning.

The paper contributes a Saudi-specific review synthesis, a technical typology, a governance roadmap and two visual frameworks aligned with contemporary journal-style presentation. Future research should prioritize monitored demonstration projects in Riyadh, Jeddah, Makkah, Madinah, Dammam and new giga-project districts. Each pilot should quantify peak-flow reduction, harvested-water volume, pollutant removal, lifecycle cost, vegetation survival, heat-mitigation value and public acceptance. If these data are standardized, Saudi Arabia can build a national evidence base for resilient drainage that supports Vision 2030 while contributing new knowledge to arid-city stormwater scholarship.

13. Saudi City Typologies

Riyadh requires attention to wadi corridors, expanding road networks and heat-sensitive public spaces. Jeddah requires coastal drainage coordination, sea-facing infrastructure protection and retrofits in districts affected by historic flood exposure. Makkah and Madinah require crowd-sensitive drainage around holy sites, transport nodes and accommodation clusters, where even short disruptions can affect large numbers of residents and visitors. Eastern Province cities require integration between industrial drainage, coastal groundwater conditions and urban development. New destinations along the Red Sea and northwest regions can embed SuDS from master planning, avoiding the retrofit burden faced by older cities.

14. Water Quality Considerations

Urban stormwater in Saudi Arabia can contain dust, hydrocarbons, tire particles, construction sediment, nutrients from landscapes and litter accumulated during long dry periods. The first storm after a dry spell may therefore carry high pollutant loads, making first-flush management essential. Pretreatment should be simple, visible and maintainable: silt traps, sediment forebays, gross pollutant screens, oil separators where vehicle activity is intense, and planted filtration zones where water quality and irrigation needs can be balanced. Reuse applications should be matched to treatment level, with higher safeguards for public-contact uses and aquifer recharge.

15. Hydraulic Safety and Exceedance Planning

SuDS should never be presented as a replacement for safe flood routing. During storms that exceed design capacity, water will move through streets, wadis, underpasses and low-lying open spaces. Resilient design therefore identifies exceedance pathways before construction, protects critical buildings, avoids basement vulnerability, preserves culvert capacity and prevents informal blockage of natural channels. Roads can be graded to convey shallow flow safely, parks can accept temporary storage, and warning systems can close risky underpasses. This approach accepts that not every event can be contained, but every event can be routed with less damage.

16. Maintenance and Asset Management

The long-term success of Saudi SuDS depends on maintenance that is funded, assigned and audited. Dust accumulation can clog permeable surfaces, dead vegetation can reduce filtration, and blocked inlets can turn a designed basin into a failed asset. A practical asset-management plan should define inspection triggers after rainfall, routine cleaning intervals, spare parts, vegetation replacement, sediment disposal and digital records. Maintenance contracts should reward performance rather than only appearance. Public landscapes must remain attractive in dry weather, but hydraulic function should be tested through inlets, outlets, overflow structures and storage capacity.

17. Digital Monitoring and Decision Support

Smart infrastructure can make distributed drainage systems easier to manage. Low-cost sensors can record water level, soil moisture, tank volume, pump operation and overflow events. Weather forecasts can trigger controlled release from storage before storms, increasing available capacity. GIS dashboards can combine rainfall radar, citizen reports, road closures, maintenance history and asset condition. Digital twins are especially useful for giga-projects because they can test growth scenarios, climate-adjusted rainfall and emergency routing before physical networks are overloaded. However, digital systems should support field maintenance teams, not replace basic hydraulic design.

18. Economic and Social Value

A SuDS and rainwater harvesting project should be evaluated through avoided flood damage, deferred pipe enlargement, water savings, lower landscape irrigation cost, improved public space, biodiversity value and reduced heat exposure. Some benefits are direct and easy to price; others, such as public comfort and urban attractiveness, require broader appraisal. In Saudi Arabia, where public-realm quality is central to tourism, investment attraction and quality of life, these co-benefits matter. Community acceptance can be improved when residents understand that a rain garden, swale or detention park is functional infrastructure rather than unused land.

19. Recommended Research Design

Future Saudi studies should use mixed methods. Hydrological modelling can estimate design performance, while field sensors verify actual storage, infiltration, overflow and drawdown. Water-quality sampling should compare first-flush, mid-event and post-treatment conditions. Maintenance records should document cleaning frequency and failure points. Interviews with municipal engineers, facility managers and users can reveal operational barriers and acceptance. Publishing these results in a consistent format would allow meta-analysis across cities and climates. It would also help Saudi Arabia contribute original arid-region evidence to international SuDS and blue-green infrastructure literature.

20. Implementation Priorities

The most immediate priority is to develop national hot-arid SuDS guidance linked to municipal permitting. The second priority is to retrofit public assets that can demonstrate visible success, including schools, mosques, parks, universities, hospitals and transport hubs. The third priority is to require large private developments to meet runoff and reuse targets. The fourth priority is to protect wadi corridors and restore their role as safe ecological conveyance systems. The fifth priority is to build a national monitoring database so future standards are based on measured Saudi performance rather than imported assumptions. Together, these actions can convert stormwater from a periodic hazard into an infrastructure resource.

21. Design Standards and Procurement

Saudi drainage standards should move from minimum pipe capacity toward performance-based drainage outcomes. Tender documents can require bidders to state how each design reduces runoff, improves water quality, protects exceedance routes and lowers potable water demand. Procurement should also evaluate maintainability, because a lower-cost design that is difficult to clean may fail within a few seasons. Design-and-build contracts should include commissioning tests for tanks, pumps, inlets, permeable layers and overflow paths. Public-private partnerships can include performance clauses linked to availability of storage volume and response after storms.

22. Education and Institutional Capacity

Engineers, planners, landscape architects and facility teams need common training because SuDS sits between disciplines. A drainage engineer may focus on flow capacity, while a landscape designer may focus on planting and user comfort. Climate-resilient infrastructure needs both. Universities and professional bodies can create short courses on hot-arid stormwater design, water-quality sampling, digital monitoring and lifecycle costing. Municipal staff can use checklists during plan review and site inspection. Public communication is also important, because residents are more likely to protect and respect features when their flood-control and water-saving functions are clearly explained.

23. Equity and Public Safety

Climate-resilient drainage should protect vulnerable neighborhoods as well as premium developments. Flooding often harms lower-income communities more severely because roads, homes and services may have less redundancy. Saudi retrofit programs can use risk maps to prioritize schools, clinics, pedestrian routes and transport links in exposed districts. Public spaces designed for temporary detention must include safe slopes, visible edges, warning signs and rapid drainage after storms. Inclusive design also means shaded access, barrier-free paths and maintenance that keeps facilities clean, safe and usable during the long dry season.

24. Integration with Circular Water Systems

Rainwater harvesting should be planned with treated sewage effluent, greywater reuse and desalinated supply rather than as an isolated system. In some districts, harvested rainwater may be a small annual volume but a valuable seasonal supplement. In others, it can reduce peak drainage loads and support strategic landscaping. A circular water plan should rank end uses by treatment requirement, reliability need and public exposure. Irrigation, street cleaning and construction uses are often realistic early markets. Over time, combined storage and smart controls can improve the balance between flood protection and water conservation.

25. Journal Positioning

For an Elsevier, Springer or Emerald style submission, the paper should be positioned as a review with applied framework development rather than as an empirical modelling article. The introduction should justify Saudi relevance, the methodology should explain database screening and thematic coding, and the discussion should compare global evidence with local adaptation needs. Strong figures, concise tables and a transparent limitation section improve review credibility. A future manuscript could strengthen the contribution by adding a bibliometric search protocol, case-study interviews or preliminary hydrological simulations for one Saudi district.

26. Overall Contribution

The review demonstrates that Saudi stormwater resilience is not only a drainage engineering question. It is a combined urban policy, water management, landscape design, public safety and asset-governance challenge. Sustainable drainage can reduce flood peaks, but rainwater harvesting gives the captured water a productive role. Blue-green infrastructure then makes the system visible, accessible and valuable for residents. The strongest contribution for Saudi Arabia is therefore an integrated planning language that helps different agencies discuss the same catchment, the same storm event and the same public-space asset with shared performance indicators.

27. Closing Note for Practice

The next generation of Saudi drainage projects should begin with water-sensitive master planning, continue through evidence-based design review, and end with transparent post-storm learning. This cycle will help public authorities convert every significant rainfall event into data for safer and more efficient urban infrastructure.

Local validation will support practical standards, stronger asset governance, safer streets, water-conscious public landscapes and internationally publishable evidence for arid urban resilience.

Verified Saudi drainage evidence strengthens resilient infrastructure policy and supports practical implementation decisions for municipalities developers researchers and operators while improving transparent climate adaptation governance capacity.

Monitored assets produce reliable.

Tables and graphical representations.

Table 1: Sustainable urban drainage and rainwater harvesting solution typology for Saudi Arabia

Measure	Saudi climate-resilient function	Key design note
Roof rainwater harvesting	Captures clean runoff for irrigation, cleaning and toilet flushing in large buildings.	Use first-flush diversion, covered tanks, mosquito control and demand-based sizing.
Permeable pavement	Reduces runoff from parking areas, plazas and low-speed streets.	Include sediment pretreatment and scheduled vacuum sweeping to manage dust clogging.
Bioswales and dry channels	Conveys stormwater safely while filtering sediment and supporting streetscape cooling.	Use drought-tolerant plants, check dams and overflow paths for intense storms.
Detention basins and parks	Stores peak flows during storms and functions as open space in dry periods.	Design for public safety, fast drawdown and easy sediment removal.
Underground modular storage	Provides high-volume storage beneath plazas, roads and parking areas.	Connect to smart controls and reuse pumps where non-potable demand exists.
Constructed wetlands	Treats runoff and creates biodiversity where reliable inflow exists.	Apply selectively because evaporation and variable water supply limit performance.

Measure	Saudi climate-resilient function	Key design note
Managed aquifer recharge	Converts surplus stormwater into strategic groundwater storage.	Requires pretreatment, hydrogeological studies and water-quality safeguards.

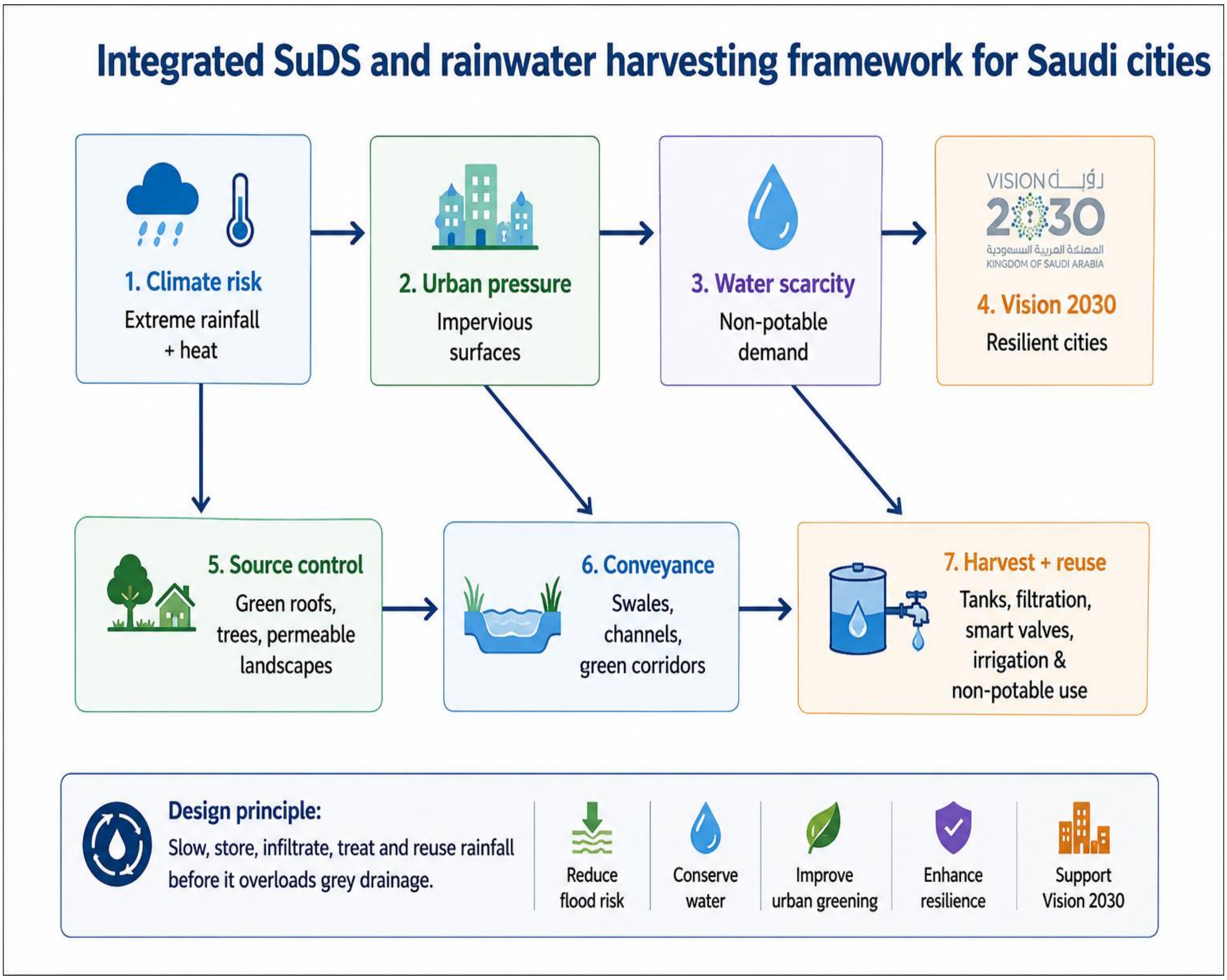

Figure 1: Integrated SuDS and rainwater harvesting framework for Saudi cities

Table 2: Phased implementation roadmap for climate-resilient Saudi urban drainage

Phase	Action	Outcome indicator
1. Diagnose	Map flood pathways, wadi corridors, impervious cover, soil conditions and public assets.	Catchment risk map and priority retrofit list.
2. Pilot	Install monitored systems in schools, mosques, parks, campuses and municipal buildings.	Measured runoff, water-quality and maintenance data.
3. Standardize	Create Saudi design guidance for hot-arid SuDS and rainwater harvesting.	Approval checklist, design storm assumptions and O&M templates.
4. Scale	Apply runoff targets and reuse studies to major developments and giga-project districts.	District-level storage, reuse and exceedance plans.
5. Audit	Review post-storm performance using sensors, inspections and public reports.	Annual resilience dashboard and code updates.

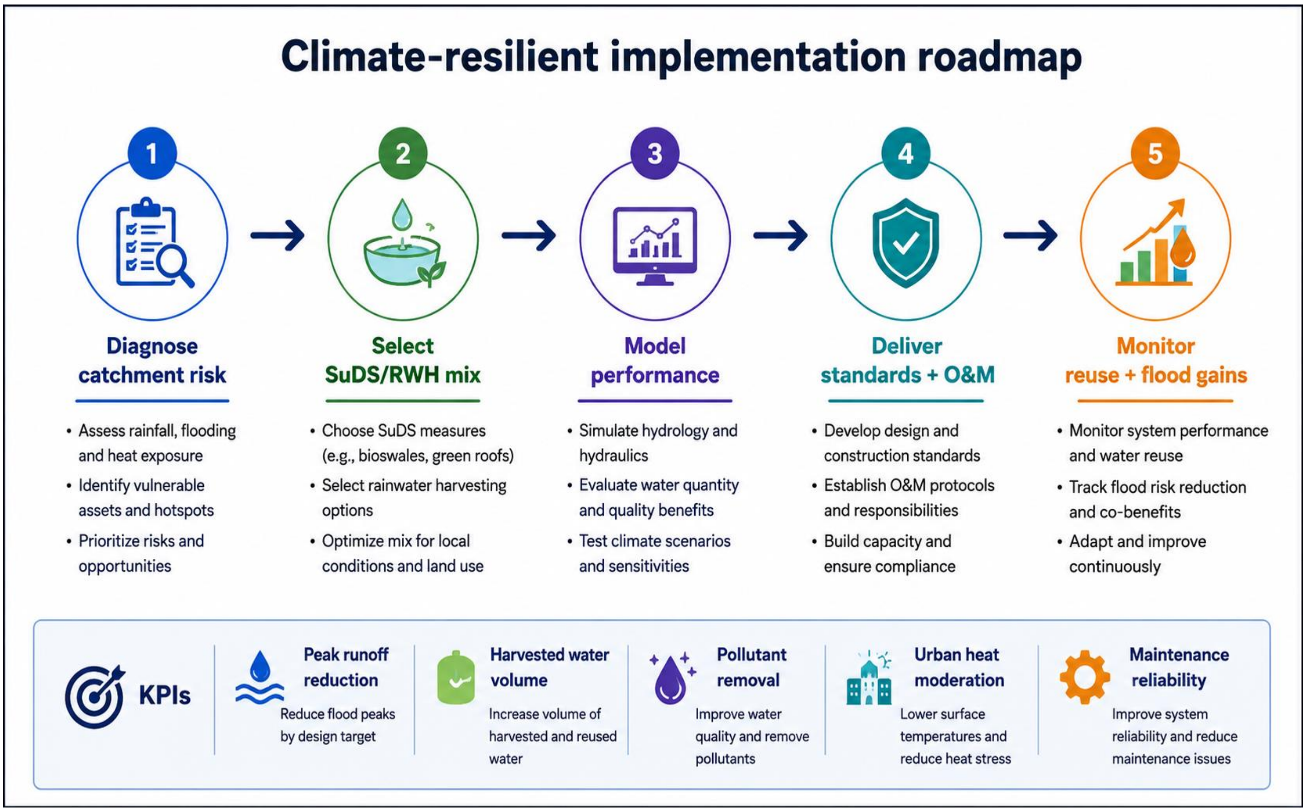

Figure 2: Climate-resilient implementation roadmap

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