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Rainwater Harvesting as a Sustainable Water Security Strategy for Vision 2030 Urban Development Projects

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Abstract- Urban development projects under Vision 2030 are transforming cities through giga-projects, tourist attractions, industrial areas, and urban infrastructure upgrades in one of the most climate water-stressed regions where desalination, aquifers' safeguarding, and treated wastewater use are crucial yet not sufficient alone. This literature review investigates rainwater harvesting (RWH) as a water security strategy for urban developments under the Vision 2030 program in Saudi Arabia. Based on a review of literature from 2020 to 2025, government publications, and case studies in the arid region, the paper aims to analyze the potential contribution of RWH technologies including rooftop systems, public-space cisterns, SUDS, wadis, aquifer recharge facilities, and intelligent monitoring to potable water savings, prevention of sudden floods, and aquifers' safeguarding. A structured narrative approach will be applied in this study focusing on four key questions about relevance of RWH to urbanization in Saudi Arabia, applicable technologies to arid cities, assessment criteria, and governance model for implementation of these solutions. The findings suggest that RWH should not be considered a minor green element for cities. The highest contribution of this technique can be expected from integrated portfolios combining distributed RWH, district detention, purification, recharge of the underground aquifer, and reuse of harvested water for irrigation, air conditioning, street sweeping, and construction needs. This paper develops an urban Vision 2030 RWH framework including site location, engineering design, water quality management, cost-effectiveness analysis, and community engagement.

Keywords- Rainwater Harvesting, Sustainable Urban Drainage, Saudi Arabia, Vision 2030, Water Security, Arid Cities, Managed Aquifer Recharge.

I. INTRODUCTION

Water security is increasingly recognized as a foundation for sustainable urban development rather than a separate utility concern. The attached Springer model paper frames Sustainable Development Goal 6 as a global water security agenda, emphasizing safe water access, water-use efficiency, integrated water resources management and community participation as mutually reinforcing targets (Arora and Mishra, 2022). This framing is highly relevant to Saudi Arabia, where new urban districts, tourism corridors and industrial cities are being designed at unprecedented speed while the natural freshwater base remains limited. The Saudi National Water Strategy 2030 describes a sustainable water sector that safeguards natural resources and the environment while delivering cost-effective, high-quality services, and it specifically prioritizes continuous safe supply, demand management, efficient services and optimization of water resources (MEWA, 2018). RWH belongs within this national logic because it turns short, intense and often disruptive rainfall events into planned urban water assets.

The case for RWH in Saudi Arabia is not based on replacing desalination. Desalinated water will continue to be the backbone of municipal supply, especially in coastal and inland cities connected to strategic transmission systems. The strategic issue is instead diversification. Urban water resilience improves when cities reduce unnecessary potable use, slow storm water peaks, retain water within landscapes and recharge shallow aquifers where hydrogeology allows. Recent work on water conservation in Saudi Arabia notes that the National Water Strategy combines supply reliability with demand-side management and resource protection, which means that decentralized and nature-based solutions need to be evaluated alongside conventional infrastructure (Almulhim, 2023). In the same period, international SDG 6 reporting has continued to warn that progress on water and sanitation targets is too slow and that water stress requires integrated, locally appropriate action (UN-Water, 2021).

Urban development intensifies both sides of the water problem. Impervious surfaces increase runoff, while higher densities, parks, cooling needs and construction activities increase demand. In arid cities, rainfall may be episodic, but when it arrives it can cause damaging water logging and flash flooding. A study of Riyadh flood risk using weighted overlay analysis demonstrates that arid urban areas still require serious storm water planning because landform, drainage density, soil, slope and urban expansion interact to create flood-prone zones (Alharbi, 2024). Regional evidence from Bahrain further shows that domestic RWH tanks can reduce storm water depth and extent while providing usable non-potable water, especially when sizing reflects household demand and rainfall variability (Hdeib et al., 2023). These findings support a Saudi approach in which RWH is designed as both water supply augmentation and flood mitigation.

This review argues that RWH should be embedded early in Vision 2030 project master planning. The aim is to evaluate RWH as a strategic layer within Saudi urban water security, not as a stand-alone sustainability symbol. The objectives are: first, to identify the technical and policy drivers that make RWH relevant for Saudi urban development; second, to compare suitable RWH and sustainable urban drainage options for arid urban contexts; third, to propose performance indicators for water saving, flood reduction, recharge and social value; and fourth, to develop an implementation framework aligned with Vision 2030, SDG 6 and the National Water Strategy 2030.

II. REVIEW METHODOLOGY

This paper applies a structured narrative review methodology appropriate for an emerging policy-engineering topic where evidence is distributed across journal articles, official strategies, SDG reports and arid-region case studies. The method follows four stages. The first stage defined the scope as urban RWH systems relevant to Saudi cities and Vision 2030 development projects, including rooftop harvesting, public-realm storage, sustainable urban drainage systems, green infrastructure, wadi retention, detention basins, recharge wells, smart monitoring and water quality controls. The second stage identified recent literature published between 2020 and 2025 using keywords such as rainwater harvesting, sustainable urban drainage systems, storm water management, arid cities, Saudi Arabia, water security, managed aquifer recharge and Vision 2030. Studies before 2020 were used only where they provided Saudi baseline context that is still widely cited.

The third stage screened material for relevance to urban water security rather than agriculture-only harvesting. Priority was given to peer-reviewed studies, official Saudi or UN policy documents and recent reviews in water, sustainability and environmental engineering journals. The review drew on global evidence where it addressed transferable design principles, but interpretation was filtered through Saudi conditions: low average rainfall, high temporal variability, intense storm events, dependence on desalination, high cooling and landscape water demand, rapid urban growth and the need for institutional coordination. The fourth stage organized evidence into a synthesis matrix covering drivers, technologies, benefits, risks and implementation requirements. This produced two outputs: a comparative technology table and a practical decision framework.

The methodology is intentionally review-based rather than empirical because the objective is to support research paper development, policy discussion and project concept design. However, the review avoids a purely descriptive approach by using analytical criteria. Each technology is assessed according to water yield potential, flood-mitigation contribution, water quality risk, maintenance complexity, suitability for arid urban form and alignment with Vision 2030 objectives. The review also considers co-benefits, such as reduced heat stress, public-realm quality and ecosystem support. This approach is consistent with recent urban storm water reviews, which recommend integrated assessment of hydraulic performance, environmental outcomes, governance barriers and long-term maintenance rather than narrow sizing calculations alone (Rentachintala et al., 2022; Monachese et al., 2024).

III. SAUDI WATER SECURITY FRAMEWORK WITH REFERENCE TO VISION 2030

There are several dimensions to the problem of water security in Saudi Arabia, related to structural issues, climate conditions and urban development challenges. Firstly, there is a scarcity of renewable fresh water resources within the kingdom, which means that the country is dependent on seawater desalination, pumping of groundwater and utilization of treated wastewater. Secondly, there is a high cost of production and supply in terms of expenses and negative impact on the environment, making it necessary to lower the level of consumption and protect water resources (MEWA, 2018). In addition, according to a recent economic overview, the country seeks to decrease daily per capita consumption from 263 to 150 liters by 2030 while total water needs already amount to 15.98 billion cubic meters (USSBC, 2022). These statistics demonstrate the importance of any measures aimed at reducing consumption, regardless of their individual impact. Finally, Vision 2030 is important in addressing water security since urban projects require facilities capable of remaining resilient in the face of climate uncertainty. This is where rainwater harvesting can play its part. First, this approach can significantly reduce the need for potable water where such a quality is unnecessary, such as in irrigation, flushing, cleaning of streets and other types of construction. Second, rainwater harvesting reduces pressure on the drainage network by collecting or recharging runoff close to the point of generation. Lastly, this approach fosters the cultural shift needed in water demand management. By harvesting rainwater, it becomes clear to people that water is a managed resource, not an unlimited one. The climate-related argument becomes stronger when considered against the background of rainfall distribution in the region. Namely, rainfall in Saudi Arabia tends to be distributed unevenly across space and time and is more intensive in the southwestern highlands. Moreover, there have been episodic rainfall events in the western and central urban basins. A study on the potential of rainwater harvesting in Saudi Arabia found that even arid basins could benefit from rainwater harvesting as long as rainfall concentration and appropriate structure location were taken into account (Almazroui et al., 2017). More recently, spatial analysis conducted in Asir showed the importance of GIS in choosing appropriate locations for indigenous rainwater harvesting structures (Alzghoul and Al-husban, 2021). While rainfall amounts may not allow substituting potable water on a massive scale in most areas, they may contribute to storage, recharge and runoff reduction. The attached reference article stresses the interrelation between SDG 6 and other dimensions of sustainable development, such as water quality, water-use efficiency, integrated management, ecosystem protection and participation, not just water availability (Arora and Mishra, 2022). This is relevant to urban RWH projects in Saudi Arabia since this technology touches on all these aspects of sustainable development. Inefficient harvesting practices may create water quality risks or maintenance problems. However, managed effectively, rainwater harvesting can reduce runoff pollution, recharge aquifers, increase infiltration and provide water for green spaces.

IV. TECHNOLOGIES AND DESIGN OPTIONS FOR URBAN RWH

Figure 1. Rainwater harvesting value chain for Vision 2030 urban projects (Apple-inspired minimalist design).

There is a broad spectrum of urban RWH options from building-level to district-level blue-green infrastructure. Rooftop harvesters are the most recognizable of them. They intercept the roof runoff with gutters, first flush diverters, filters, and storage tanks. Such roof-harvesting technologies can be effectively applied in Saudi cities for villas, schools, mosques, shopping malls, warehouses, hospitals, and public buildings with large roof surfaces. Advantages of these harvesting systems consist of controllability – roof runoff is typically less contaminated than road runoff and harvesting systems can be integrated with water reuse channels (for instance, irrigation and toilet flushing). Disadvantages are related to seasonality: tank size should not be excessively large to avoid high costs, given the low frequency of rainfall events; therefore, modular tanks and hybrid supplies should be prioritized to avoid fully independent systems. Public realm RWH consists of plazas, parks, street spaces, and transportation corridors optimized for slowing down and reusing runoff. Sustainable urban drainage systems (SuDS) refer to such practices as biowall design, rain gardens, permeable paving, infiltration trenches, detention basins, green roofs, constructed wetlands, and retention ponds. Recently conducted reviews confirm that SuDS reduce peak runoff rates, improve water quality, increase infiltration rates, and have amenity values, but the degree of efficiency is highly variable depending on the soil type, slope, maintenance practices, and local governance mechanisms (Monachese et al., 2024). In the case of Saudi urbanization, there is a need to adapt SuDS to arid landscapes by selecting appropriate native plants, designing shaded planting zones, forebays for sediment removal, and accessibility for maintenance. Harvesting in wadies is specific to Saudi Arabia, as many urban centers interact with natural drainage pathways. Traditionally, wadies are characterized by fast-moving and highly energetic streams, which, when urbanized, can cause flooding. To prevent this adverse effect, urban planners should preserve the free movement of water along wadi pathways while providing protection and control measures for reducing flood risk: detention basins, check dams, recharge areas, and landscape storage if there is no threat to life. The purpose of this practice is to work with wadies as an integral hydrological system rather than to urbanize them; therefore, GIS and remote sensing can help identify suitable areas, similarly to the contemporary approaches to selecting the areas for RWH (Al-Hasani et al., 2024; Shams, 2025). Another strategy worth noting is managed aquifer recharge. After preliminary sediment separation and quality treatment, captured storm water can be delivered to recharge basins or artificial recharge wells if aquifers are exhausted and hydrogeological features support recharge processes. The use of MWR systems implies stricter regulation since contamination can seriously impact underground reservoirs. Hydrocarbon contamination of roads and industry-related pollutants are typical examples of the reasons to use separators and sedimentation units. According to the international guidelines on water resource management, contaminated runoff requires quality treatment as well as regular monitoring due to risks to health and ecosystems (UNEP, 2021). Therefore, Saudi harvesting should differentiate among direct reuse, landscape infiltration, and MWR, establishing respective quality standards. The use of ICT technologies allows improving performance of RWH projects. Automated valves, weather forecasts, sensors, and digital dashboards provide means for proactive tank emptying before rainfalls and ensuring water quality during reuse. Information and communication technologies are recognized as necessary to achieve the goals of the SDG 6 acceleration roadmap, including monitoring of water resources availability and consumption, weather forecasts, and distribution (UN-Water, 2021). Therefore, in Saudi urban centers which embrace the concept of smart infrastructure in the framework of Vision 2030, RWH should be integrated with building, municipal, and city-wide ICT systems.

V. PERFORMANCE BENEFITS AND RISKS

The main benefit of RWH in relation to Saudi cities is offsetting drinking water needs. The best applications include irrigation of public lands, toilet flushing in big buildings, cooling when feasible, street cleaning, fire fighting supplies, and building construction. These applications are more compatible with intermittent rain than full-scale domestic substitution. The economic value of RWH water must be estimated on the basis of offset costs of desalinated water, pumping/transmission savings, and storm water infrastructure release. In view of the energy-intensive nature of desalination, any partial substitution is beneficial environmentally. The second benefit is storm water flood risk mitigation. In arid regions with rare but intense storm water events, rapid runoff through roads, roofs and public plazas causes low-lying urban districts to flood, despite relatively little annual rainfall. RWH mitigates the problem by distributing the storage throughout the city. Modeling of rainfall events in the arid context of Bahrain demonstrates that domestic household rainwater harvesting system reduces flooding in combination with tank capacity and rainfall event demand (Hdeib et al., 2023). In Riyadh and other Saudi Arabian cities, the implication is that RWH must be used in conjunction with drainage plan, flood hazard mapping, and flood preparedness strategies. RWH provides ecological benefits, including groundwater recharge, erosion reduction, urban cooling, and improvement of green infrastructure. Integrated green-blue solutions can retain moisture in soils and help sustain indigenous vegetation without irrigation requirements. Freshwater ecosystem studies have pointed out wetlands' importance to regulation of water table recharge, pollution abatement and flood protection (Vári et al., 2022). This same role can potentially be performed in Saudi Arabian urban projects by restored wadis, urban infiltration lands and man-made wetlands powered by rainwater and recycled wastewater. The key issue would be the balance between the project scope, available water, possible evaporation, and maintenance capabilities. There are also social and institutional benefits. They consist in creating visibility for water conservation at schools, mosques, parks and municipal buildings. In the light of the SDG6 framework, community participation in water management represents one of the targets. According to Arora and Mishra (2022), local community-based institutions react fast because they are intimately acquainted with the local ecology. Rainwater harvesting demonstrations could be useful in raising awareness of public water needs in Saudi cities, where there are demand management initiatives. However, social acceptance is contingent on hygiene, water quality and maintenance. All risks have to be accounted for. First of all, the quality of harvested water is critical because it may contain dust particles, bird excrement, roof materials, oil products, tyres and metal particles. Systems must incorporate a first-flush diversion, filtration, possible disinfection, adequate storage, regular cleaning and separation of usage. Standing water and mosquito larvae breeding pose problems if tanks are exposed or there are stagnated drains. Structural risks include additional weight imposed by tanks and difficulties accessing underground systems. Finally, economic risks emerge if projects build visually impressive systems that require maintenance but lack funds for it. Therefore, a research program in Scopus/Q1 must discuss both anticipated benefits and responsibilities.

VI. COMPARATIVE SYNTHESIS FOR VISION 2030 PROJECTS

The literature suggests that no single RWH option is universally best. Building-level systems provide direct demand offset and are easy to replicate through codes. District-scale systems provide stronger flood reduction and landscape benefits. Wadi and recharge systems provide long-term resource value but require detailed hydrological and water quality assessment. Smart systems improve operation but depend on data integration and trained maintenance teams. Table 1 summarises the comparative suitability of key options for Saudi urban development projects.

Table 1. Comparative suitability of RWH options for Saudi urban development projects

RWH option	Best Saudi urban use	Main benefits	Key risks / controls
Rooftop tanks	Villas, schools, malls, mosques, warehouses	Non-potable demand offset; clean catchment; easy replication	First-flush diversion, covered tanks, structural loading checks
Permeable pavements	Parking areas, promenades, low-speed streets	Runoff reduction; heat and amenity benefits	Clogging from dust; requires vacuum cleaning and sediment traps

Bioswales and rain gardens	Parks, medians, pedestrian streets	Peak attenuation, filtration, native landscape support	Plant survival, salinity, mosquito control and irrigation backup
Detention / retention basins	District parks, public realm, downstream flood nodes	Flood storage, recreation, sediment capture	Safety fencing, sediment removal, water quality monitoring
Wadi retention and check dams	Natural drainage corridors, peri-urban catchments	Hydrological continuity, recharge potential, erosion control	Avoid blocking flood paths; require catchment modeling
Managed aquifer recharge	Suitable geologic zones after treatment	Long-term resource support and drought resilience	Groundwater contamination risk; needs permits and testing
Smart controlled storage	Large buildings and smart districts	Forecast-based emptying, KPI reporting, predictive maintenance	Sensor reliability, cyber/data integration and staff training

Source: Author synthesis based on Arora and Mishra (2022), Hdeib et al. (2023), Monachese et al. (2024), and Saudi National Water Strategy priorities.

6.1 Integrated implementation logic

The strongest strategy is portfolio design. A new district should not select either rooftop tanks or drainage basins; it should combine both according to catchment hierarchy. At the plot scale, roofs and podiums can collect relatively clean water. At the street scale, permeable pavements and bioswales can slow runoff and filter sediment. At the neighbourhood scale, parks and detention basins can store larger volumes. At the city scale, wadis and recharge zones can protect downstream areas and enhance groundwater where suitable. This hierarchy turns every surface into part of a water-sensitive urban system.

Performance indicators should be selected before construction. The most useful indicators include annual non-potable water supplied, percentage reduction in peak runoff, storage volume per hectare, number of flood-prone points mitigated, groundwater recharge volume, water quality compliance, avoided potable water cost, avoided carbon emissions from desalinated water substitution, maintenance response time and public satisfaction. These indicators allow project owners to compare RWH with conventional drainage and supply alternatives. Table 2 proposes a KPI structure for Vision 2030 projects.

Table 2. Proposed KPIs for Vision 2030 RWH project evaluation

KPI group	Indicator	Why it matters for Vision 2030 projects
Water efficiency	Annual harvested water reused (m3/year)	Quantifies potable demand offset for irrigation, cleaning and flushing
Storm water resilience	Peak runoff reduction (%) and storage volume per hectare	Shows flood mitigation value and drainage network relief
Resource protection	Recharge volume and groundwater quality compliance	Links RWH to aquifer protection and safe managed recharge
Environmental co-benefits	Green area supported, soil moisture stability, heat reduction proxies	Connects water infrastructure with livability and urban cooling
Economic performance	Life-cycle cost per m3 and avoided desalinated water cost	Supports investment comparison and PPP business cases

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Operational reliability	Inspection completion, sediment removal and filter replacement rates	Prevents decline in system performance after handover
Social value	User satisfaction, public awareness activities and community reporting	Reflects SDG 6 participation and behavioural change
Digital governance	Sensor uptime, dashboard reporting and incident response time	Supports smart city integration and accountability

Source: Author synthesis for Vision 2030 urban RWH monitoring and evaluation.

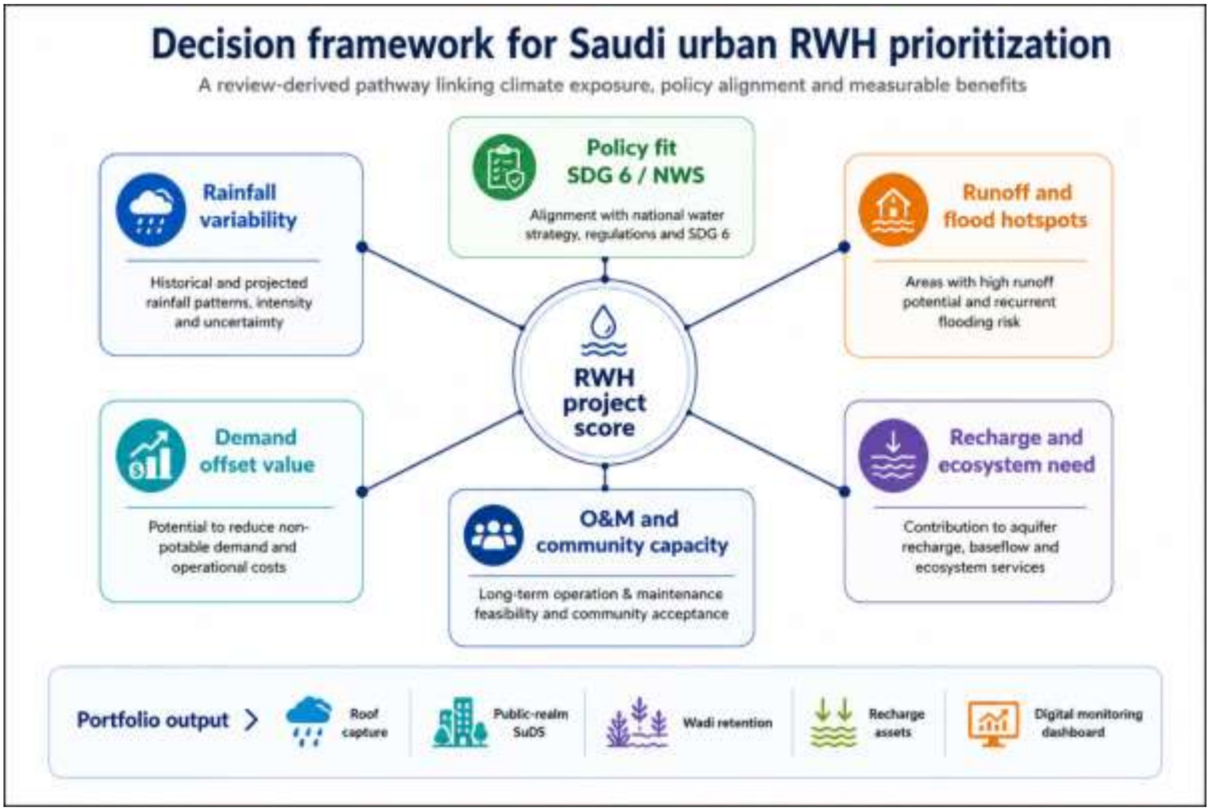

Figure 2. Decision framework for Saudi urban RWH prioritization (Apple-inspired minimalist design).

VII. GOVERNANCE, POLICY AND DELIVERY

Model Implementation of RWH involves much more than engineering design. Firstly, RWH needs to be embedded within planning approval and building regulation processes. Large roofs, public buildings, car parks, schools, mosques, shopping centers, sporting venues and industrial buildings can be assessed for harvesting potential at the conceptual phase. Local laws and planning regulations can call for feasibility assessments for rainwater harvesting above certain thresholds of roof size or plot area. Exceptions for low rain, building structure and poor water quality should be allowed. More international policy documents emphasize the need for legislation for urban rainwater harvesting, green roofs, infiltration and rain gardens because voluntary approach is too slow (Interreg Europe, 2025). Secondly, RWH requires cross-organizational coordination because harvesting interacts with municipal drainage system, municipal water supply company, environmental protection, building control office, developers and citizens. A project may collapse if one organization approves the architecture, a second manages the drainage and the third controls the reuse without coordination. A unique feature of giga-proiects in Saudi Arabia can be used to address this challenge – setting up integrated water design authorities at project level. These authorities can develop common assumptions for design rainfall, determine permissible end uses, establish common water quality standards, connect RWH facilities to

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digital platforms and assign responsibility for maintenance. Thirdly, RWH benefits multiple stakeholders. Developers pay for harvesting structures, municipalities save on reducing floods, and utilities save on demand reduction. Hence, it makes sense to incorporate avoided cost for infrastructure, added resilience value and environmental value into the business case for RWH, apart from the cost of harvested water. Public-private partnership can facilitate district-scale storage systems for RWH. Green Building Certification schemes can encourage developers to adopt RWH. Saudi water sector has moved towards more extensive private involvement in infrastructure development, and therefore, RWH can be promoted as part of resilient infrastructure investment (USSBC, 2022). Fourthly, O&M of RWH systems is critical to its success. Internationally, many rainwater systems have proved ineffective in the long term due to neglect and lack of maintenance planning. In addition, dust, sedimentation and high evaporation rate increase the maintenance workload in Saudi Arabia. Agreements about who will clear the gutters and filters, remove sedimentation, test water quality, replace filters, operate pumps and monitor sensors via digital platforms are needed. For the sake of transparency, digital maintenance logs should be created. For facilities in public areas, the system should be visible rather than hidden to allow easy inspection. Lastly, RWH implementation requires capacity building. Engineers, architects, landscaping designers, facility managers and municipal inspectors all need common guidance. Universities and professional organizations can assist in organizing relevant courses for RWH in arid climates, water quality risk assessment, use of GIS for optimal site selection and life cycle cost analysis. All of these aspects are covered by Target 6A of Sustainable Development Goal 6 on capacity building for water harvesting, desalination, water use efficiency, wastewater recycling and reuse (UN-Water, 2021). A national guide on RWH for urban projects could help to standardize terminology, design calculations, water quality controls and monitoring.

VIII. DISCUSSION: STRATEGIC ALIGNMENT WITH VISION 2030

Vision 2030 is not only a program of physical construction; it is a transformation of economic, environmental and social systems. RWH aligns with this transformation because it encourages efficient resource use, local innovation, climate adaptation and livable urban design. For Riyadh, Jeddah, Makkah, Madinah and emerging destinations, the main value is resilience under uncertainty. Climate models and recent extreme events across the region show that cities must prepare for both scarcity and sudden excess water. RWH is one of the few strategies that addresses both conditions simultaneously.

The review also shows that Saudi RWH should be evidence-led. Imported designs from humid regions may fail if they assume frequent rainfall, low sediment load or easy infiltration. Saudi projects need local rainfall intensity-duration-frequency data, catchment modeling, soil infiltration testing, evaporation estimates, water quality sampling and realistic O&M budgeting. GIS-based suitability mapping should become a standard front-end tool, especially for large master plans. Recent geospatial RWH studies demonstrate how multi-criteria analysis can identify sites by combining hydrology, terrain and land-use data (Al-Hasani et al., 2024; Fariz-Salinas et al., 2025). This approach can support Saudi decision-makers in selecting high-impact sites rather than distributing systems randomly.

A second discussion point is the relationship between RWH and desalination. Some stakeholders may dismiss RWH because desalination provides predictable volumes. This is a false comparison. RWH is not a national bulk supply substitute; it is a decentralized resilience and efficiency measure. Its value is highest where local runoff causes damage, where non-potable demand is near the point of capture, where storage can be integrated into public realm and where recharge can protect aquifers. Measured against these benefits, RWH can be economically and environmentally justified even if annual water yield is lower than desalinated supply.

A third point is equity. High-end districts may install attractive water features while older neighborhoods remain flood-prone. Vision 2030 RWH policy should avoid this imbalance by prioritizing schools, mosques, municipal parks, hospitals and flood-risk communities as demonstration sites. Public projects can show that water-sensitive design improves everyday urban life, not only premium developments. This supports the SDG principle that water security is connected to dignity, health and prosperity.

IX. PROPOSED FRAMEWORK

The proposed framework has six steps. Step one is diagnostic mapping, using rainfall, drainage, slope, land use, soil, flood complaints, groundwater vulnerability and demand centres. Step two is option selection, matching roof capture, SuDS, wadi detention, storage tanks and recharge to site conditions. Step three is design integration, ensuring that architects, civil engineers, landscape teams and utility planners work from the same water balance. Step four is risk control, with first-flush diversion, treatment, safe storage, end-use separation and monitoring. Step five is performance contracting, where maintenance, KPI reporting and asset ownership are defined. Step six is learning, where monitored performance from completed projects is fed back into national guidelines.

This framework turns RWH into a repeatable urban infrastructure practice. It also creates research opportunities. Future Saudi studies should develop local runoff coefficients for new urban surfaces, compare tank sizing under different climate scenarios, quantify desalinated water substitution, measure public acceptance, test smart control algorithms and evaluate the recharge quality of different treatment trains. Such work would contribute to Scopus and Web of Science research because it connects arid hydrology, urban design, digital infrastructure and policy implementation.

X. CONCLUSION

Rainwater harvesting is a practical and strategically relevant water security measure for Saudi Arabia's Vision 2030 urban development projects. Its strongest contribution is not replacing desalination, but diversifying the urban water portfolio, reducing non-potable demand, mitigating flash flooding, supporting green infrastructure and protecting groundwater where recharge is safe. The review shows that RWH must be designed as an integrated system: roof capture at building scale, SuDS in streets and parks, detention and wadi protection at district scale, managed recharge where hydrogeology permits, and smart monitoring across the asset life cycle.

For Saudi Arabia, success depends on early integration into master planning, realistic arid-region design assumptions, enforceable quality standards and clear maintenance responsibilities. RWH should be included in building codes, municipal drainage plans, green infrastructure standards and digital water dashboards. It should also be linked to education and community participation so that water conservation becomes visible in everyday urban life. When implemented through this integrated approach, RWH can support the National Water Strategy 2030, SDG 6 and Vision 2030 by turning episodic rainfall from a hazard into a managed resource for resilient, livable and sustainable Saudi cities.

Scope note

The current review intentionally considers harvested rainwater as a strategic urban resource, rather than merely a decorative element of sustainable development initiatives. Hence, it focuses its recommendations on effective measures in terms of measurable storage, controlled reuse, infiltration control, clear asset maintenance, performance monitoring, reporting and iterative learning throughout Saudi Arabia in such a way that each pilot becomes an example for improved implementation in consideration of the local climate conditions, soil type, health risks, landscape context, affordability, institutional capabilities and long-term asset management. In terms of practical realization, the first projects should target easily noticeable places where it will be possible to measure benefits of harvesting, namely schools with large roof area, mosques with routine maintenance crews, district parks in need of irrigation, car parks with high runoff, and storm prone underpasses for detention purposes. Such places will allow showcasing crucial features like easy filter access, secured tanks, sediment forebay, safe overflow channels, informative placards, and connection to non-potable demand points. At the same time, there will be chances to monitor various performance indicators, such as total volume of captured rainfall, turbidity, storage level draw down, pump power consumption, maintenance expense, end-user acceptance, and amount of saved desalinated or tanker water. Later on, this experience can contribute to creating standardized details for roofs, landscapes, roads, recharge basins and intelligent control systems. It can also assist in comparing various alternatives for implementation by developers in the course of value engineering without compromising water security aspect. The learning-by-doing approach seems appropriate for Vision 2030 as it combines innovative solutions with rigorous execution. Additionally, climate resilience cannot be reached using only one big facility. Instead, multiple smaller structures, which are properly maintained and interconnected, will enable keeping rain closer to where it lands, protecting vulnerable drainage lines and reducing urban growth dependence on energy-consuming supply infrastructure expansion. Thus, RWH technology is both an engineering solution and governance tool. Successful implementation will require proper design, but also ownership, inspection, public relations and further learning each year during the season of rains. This principle should be applied to academic publications too. Well-rounded review paper about Saudi Arabian cities will explicitly state its assumptions, differentiate between global evidence and local suitability, identify knowledge gaps and not exaggerate water production potential. This balanced approach increases likelihood of approval by academic reviewers since it presents RWH as a viable resilience strategy that is supported by policies, scientific evidence and proper asset management. Subsequent empirical studies should explore cost-effectiveness, water quality and end-user acceptability in Saudi cities.

REFERENCES

[1] Alharbi, T. (2024). A weighted overlay analysis for assessing urban flood risks in arid lands: A case study of Riyadh, Saudi Arabia. Water, 16(3), 397. https://doi.org/10.3390/w16030397

[2] Al-Hasani, B., Al-Ansari, N., & Knutsson, S. (2024). Integrated geospatial approach for adaptive rainwater harvesting site selection under historical and future scenarios. Stochastic Environmental Research and Risk Assessment. https://doi.org/10.1007/s00477-023-02611-0

[3] Almazroui, M., Islam, M. N., Balkhair, K. S., Şen, Z., & Masood, A. (2017). Rainwater harvesting possibility under climate change: A basin-scale case study over western province of Saudi Arabia. Atmospheric Research, 189, 11-23. https://doi.org/10.1016/j.atmosres.2017.01.004

[4] Almulhim, A. I. (2023). Developing a sustainable water conservation strategy for Saudi Arabia. Sustainable Futures, 6, 100127. https://doi.org/10.1016/j.sftr.2023.100127

[5] Alodah, A. (2023). Towards sustainable water resources management in Saudi Arabia: A review of policy, demand and reuse pathways. Sustainability, 15(20), 14674. https://doi.org/10.3390/su152014674

[6] Alzghoul, M., & Al-husban, Y. (2021). Rainwater harvesting and storage in Asir, Kingdom of Saudi Arabia, using spatial modeling and geographic information systems. Desalination and Water Treatment, 233, 19-29. https://doi.org/10.5004/dwt.2021.27531

[7] Arora, N. K., & Mishra, I. (2022). Sustainable development goal 6: Global water security. Environmental Sustainability, 5, 271-275. https://doi.org/10.1007/s42398-022-00246-5

[8] ESCWA. (2024). Arab Sustainable Development Report 2024: SDG 6, clean water and sanitation. United Nations Economic and Social Commission for Western Asia.

[9] Fariz-Salinas, E. A., et al. (2025). Definition of potential sites to implement urban rainwater harvesting systems using GIS and analytic hierarchy process. Sustainable Cities and Society.

[10] Food and Agriculture Organization & UN-Water. (2021). Progress on change in water-use efficiency: Global status and acceleration needs for SDG indicator 6.4.1. FAO.

[11] Hdeib, R., et al. (2023). An urban flood risk mitigation measure in arid areas: Assessing rainwater harvesting systems for stormwater retention. Water Science and Engineering. https://doi.org/10.1016/j.wse.2023.04.004

[12] Interreg Europe. (2025). Sustainable urban drainage systems and water harvesting: Expert support report. European Union Interreg Europe Programme.

[13] Menéndez, P., Losada, I. J., Torres-Ortega, S., Narayan, S., & Beck, M. W. (2020). The global flood protection benefits of mangroves. Scientific Reports, 10, 4404. https://doi.org/10.1038/s41598-020-61136-6

[14] MEWA. (2018). National Water Strategy 2030. Ministry of Environment, Water and Agriculture, Kingdom of Saudi Arabia.

[15] Monachese, A. P., et al. (2024). Challenges and innovations in urban drainage systems: A review of sustainable urban drainage systems. Water, 17(1), 76. https://doi.org/10.3390/w17010076

[16] Piemontese, L., Castelli, G., Fetzer, I., Barron, J., Liniger, H., Harari, N., Bresci, E., & Jaramillo, F. (2020). Estimating the global potential of water harvesting from successful case studies. Global Environmental Change, 63, 102121. https://doi.org/10.1016/j.gloenvcha.2020.102121

[17] Rentachintala, L. R. N. P., Reddy, M. J., & Mohan, S. (2022). Urban stormwater management for sustainable and resilient measures and practices: A review. Water Science and Technology, 85(4), 1120-1140.

[18] Saudi Green Initiative. (2023). Climate and environmental action progress in the Kingdom of Saudi Arabia. Saudi Green Initiative.

[19] Saudi Water Authority. (2025). Water security management and integrated infrastructure planning for Saudi Vision 2030. Saudi Water Authority.

[20] Shams, E. M. M. (2025). Optimal sites for rainwater harvesting and proposed dams in an arid zone of Saudi Arabia. Journal of Arid Environments / ScienceDirect article record.

[21] UN Department of Economic and Social Affairs. (2023). Saudi Arabia voluntary national review and SDG implementation documents. United Nations.

[22] UN Environment Programme. (2021). Progress on ambient water quality: Tracking SDG indicator 6.3.2. UNEP.

[23] UN Environment Programme. (2021). Progress on integrated water resources management: Tracking SDG indicator 6.5.1. UNEP.

[24] UN Environment Programme. (2021). Progress on water-related ecosystems: Tracking SDG indicator 6.6.1. UNEP.

[25] UN-Water. (2021). Summary progress update 2021: SDG 6 - water and sanitation for all. United Nations.

[26] UN-Water. (2021). Progress on level of water stress: Global status and acceleration needs for SDG indicator 6.4.2. United Nations.

[27] UN-Water. (2021). SDG 6 global acceleration framework. United Nations.

[28] USSBC. (2022). Saudi Arabia's water sector: Economic brief. U.S.-Saudi Business Council.

[29] Vári, Á., Podschun, S. A., Erős, T., Hein, T., Pataki, B., & Iojă, I. C. (2022). Freshwater systems and ecosystem services: Challenges and chances for cross-fertilization of disciplines. Ambio, 51, 135-151. https://doi.org/10.1007/s13280-021-01556-4

[30] World Resources Institute. (2023). Aqueduct water risk atlas and global water stress data. World Resources Institute.