MODERN METHODS AND ARTIFICIAL INTELLEGNCE IN STORMWATER HARVESTING AS SUSTAINABLE SOLUTIONS

Shuokr Qarani Aziz[1], Khalat Khalid Muhammed[1*]

[1]Department of Civil Engineering, College of Engineering, Salahaddin University-Erbil, Erbil, Kurdistan Region, Iraq

khalat.mohamedsalih@su.edu.krd[*]

https://doi.org/10.31972/iceit2024.053

Abstract

This study investigates stormwater harvesting's combination of contemporary techniques with artificial intelligence (AI) as a viable urban water management strategy. Rapid urbanization and climate change are increasing challenges for cities, making efficient stormwater management essential for reducing floods, improving water quality, and advancing environmental sustainability. The research emphasises the benefits of cutting-edge infrastructure, such as permeable pavements and green roofs, which greatly lower runoff and enhance water retention. Moreover, the research explores the use of AI and machine learning methods in stormwater modelling and management, showcasing their potential to improve water collection tactics, forecast water quality indicators, and enhance decision-making. Case studies from cities such as Philadelphia and Singapore demonstrate the successful implementation of these technologies and their effectiveness in addressing urban stormwater issues.

Keywords: Artificial intelligence, Harvesting, Stormwater, Sustainability.

1. Introduction

The most common sources of stormwater are precipitation and the melting of snow. Despite the fact that rainwater harvesting is an essential part of stormwater harvesting, there is a substantial difference in the quality of rainwater that is collected directly from roofs and that which is collected in rain tanks in addition to rainwater that was gathered in stormwater reservoirs. Rainwater collected from rooftops is less contaminated than rainwater collected from other sources (McCarthy et al., 2012). Stormwater, a byproduct of groundwater pollution, is more likely to contain chemical and microbiological contaminants than stormwater. Factors contributing to stormwater include precipitation, urban runoff, vehicle washes, and ground washing. Most collected stormwater comes from dry conditions. Groundwater contributes to stormwater flow, but its contribution is variable and difficult to quantify. Cross-contamination of rainwater and sewage is a concern due to aging infrastructure and poor execution (Sidhu et al., 2012). Population growth, increasing urbanization, and climate change have put pressure on traditional water supplies and deteriorated the environment. Urban stream syndrome is a phrase that was created to represent the complicated challenges that are associated with changes in land cover and stream flow. The effects of urbanization on natural hydrological systems has been examined in a series of review papers and recent studies (e.g.,. Stormwater capture and storage is the collection of rain water, mostly from urban areas, to be used at a later time. The method aims to limit pollution, mains water demand and flooding, with decisions made for water in a long term strategies. The water that is collected can then be used for irrigation, toilet flushing and in industries etc. (Akram et al., 2014). Stormwater runoff has been identified as a major source of pollution and flooding because of the increase in urban population growth as well as other impermeable surfaces. Persistent good research in the field of water resource management and sustainable urbanization is crucial to overcoming these challenges. In this research, some examples of historical and current stormwater management philosophy including sustainable drainage system (SuDS) / low impact development (LID) / water-sensitive urban design (WSUD) for a few cities with future needs for higher liveability were given (van Leeuwen et al., 2019). Stormwater harvesting has been established as a sustainable option and can offer the benefit of an alternative long term water supply, reduction of associated energy consumption, and limit negative impacts on natural water bodies by controlling distributed demands to avoid the need for new supply development whilst reducing treated wastewater discharge to sensitive surface waterways. On the other hand, there are also, as yet, possible disadvantages including irregular rainfall patterns, environmental effects of storage (such as mosquito breeding), health risks, and increased unit price relative to both the mains water and rainwater tanks. Successful stormwater harvesting systems must address public health and environmental issues, get support from key stakeholders, be cost-effective, and be sustainable (Akram et al., 2014). Sustainable stormwater management methods, such as rainwater collecting, are critical for lowering stormwater runoff peak and volume, minimising environmental impact, and cutting demand for potable water. The benefits of using stormwater as a resource and using decentralised stormwater harvesting systems include aquifer preservation, cost savings on potable water, reduced non-point pollution discharge, and the prevention of future flooding events. Sustainable stormwater management strategies can improve water resource management and help offset the effects of climate change on precipitation patterns (Vargas, 2009). Modern stormwater harvesting techniques include swales, biofilters, ponds, wetlands, and biofilters to improve urban stream health, water supply, and flow regimes. Storage capacity constraints may not hinder stormwater collection. Participatory evaluation is crucial for sustainable food production in arid and semi-arid regions (Mitchell et al., 2007).

2. Materials and Methods

2.1. Study Area

The capital of the Kurdistan Region in northern Iraq is Erbil, also referred to as Hawler, Figure 1. The province of Erbil spans 14,873.68 km^2, with 930,389 people living in the Centre district of Erbil, which is the studied region for this paper, and an area of 1131.44 km^2 in population as of 2015 (Mustafa et al., 2022). It is almost 350 km away from Iraq's capital, Baghdad. The Erbil Centre district connects Iraq to Turkey and Iran, while the northeast and east of the country are mostly hilly. The district is primarily flat. In addition, a lowland area south of the city is home to a rural population that lives in this agricultural zone (Mustafa et al., 2019). Hameed (2017) exhibited that The proportion of built-up and bare soil in the core district of Erbil increased by 53.26% and 52.72%, respectively, between 1984 and 2014. On the other hand, there was a 50.06% and 57.72% decline in vegetation and agricultural area, respectively. Regarding the sewage system, the city utilizes a combined drainage system that excludes grey water, instead collecting it from residential cesspools and sending it outside the city. Additionally, the system's exit connects to a river. Due to heavy rains, this region has experienced several flash floods in the last 10 years. The Erbil meteorological station, for instance, reports that the largest rainfall occurred on January 28, 2013, with a total of 71.8 mm in a 24-hour period. Other maximum rainfalls on April 22, 2011, December 31, 2015, January 27, 2014, March 28, 2016, and November 22, 2018 have been recorded. The Kurdistan Region has semi-arid weather. Erbil City has lengthy, balmy summers and chilly, wet winters. From June to September, there is either none at all or very little precipitation throughout the summer. But from October to the latter days of May, the rain begins to pour. January is also the wettest month of the year. This city has 7 °C to 47 °C temperature swings, with an average yearly temperature of 21°C. The annual average precipitation is around 400 mm, with dry years having 200 to 650 mm of precipitation, respectively (Hameed, 2017).

Aziz et al., (2023a) identify the causes and offer solutions to mitigate the damage caused by floods in Erbil City. Numerous site visits and data collection revealed that floods stem from various factors such as high rainfall, clogged culverts, sewers, and inlets, blockages in watersheds, and issues with technology and architecture. Some of the solutions include cleaning watersheds, maintaining storm sewers, creating new diversion channels, correctly designing storm sewers, culverts, and bridges, removing obstacles, and researching municipal master plans. The Erbil basin in Iraq has seen a significant reduction in groundwater resources due to overexploitation, uncontrolled groundwater removal, and unregulated activities. This predicament has had numerous negative effects on the environment, agriculture, clean water supply, and human settlement. The sustainable management of water resources, especially in arid and semi-arid environments, greatly benefits from runoff collection and artificial groundwater recharge (Al-Kakey et al., 2023).

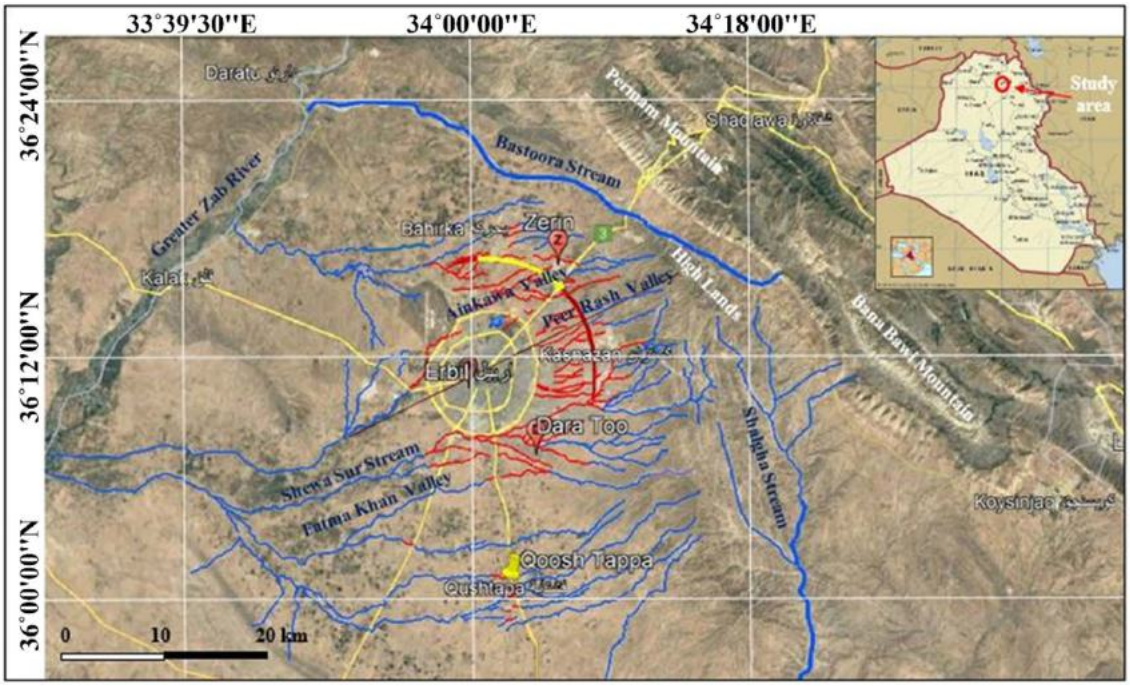

Fig. 1: The major wadis, streams and the city of Erbil are seen in the satellite picture. (K Sissakian et al., 2022).

2.2 Data Collection System

Data collection is vital for assessing, planning and better management Planning in Stormwater harvesting as well as any other work requires data for more accurate evaluation. To elucidate the flow of stormwater and provide better planning for its retention and use (Ochoa-Rodriguez et al., 2019). To manage stormwater correctly, you need both rain gauges and weather stations. It is, however a challenge to use rain gauges for the quantification of precipitation because they provide information only at isolated points and are extremely limited in the space. The real-time data, such as temperature, humidity, wind speed and precipitation from weather stations is informative for be wetland water balance but it presents limitations due to its high cost and maintenance needs (Rivera et al., 2023). Satellite photography allows for the collection of large volumes of data (satellite remote sensing) on precipitation and land surface conditions. This approach allows for remote monitoring of difficult-to-access distant places and provides large geographical coverage. Basic concerns include loss of temporal resolution and difficulties in processing and understanding data. (Sheffield et al., 2018). This information must then be filtered through a strong data management process to form the basis of any actionable intelligence. A good example is a combination of using local servers (where we have authority over how data protection is nested) and some parts in the cloud where it has proper scalability along with accessibility. Key to interpreting the information and delivering meaningful conclusions is the application of data processing technologies such as Geographic Information Systems (GIS) and hydrological modelling software. Integration with Decision Support Systems (DSS) at the same time allows better planning and management by using data collected to simulate different scenarios and optimise stormwater harvesting approaches (Di Luzio et al, 2004).

2.3. Stormwater Water Quality

In developed urban areas, rainwater collection is becoming more common. It entails gathering and processing rainwater for residential use, including drinking if properly treated. This method prevents floods and conserves water supplies, among other advantages (Mejía-Ferreyra et al., 2024). Rainwater initially contained very few contaminants, other than those that fell from the sky. However, gathering, storing, and using rainwater in residential settings may gradually degrade its quality. Of course, factors influencing the features of rainfall include the abundance of smoke from electric generators and automobiles, investment projects, the production of oil and gas, industrialization, changes in the area's land use and land cover, etc. Because it has varying qualities when gathered from different locations in different seasons within the same region, rainfall often has a complicated chemical makeup. Native substances from various regions and atmospheric components compose rainwater (Carroll, 1962). A number of things, including as leaves, bird droppings, and fluttering soil, may contaminate rainwater (Aziz et al., 2023a). Mejía-Ferreyra et al., (2024) recommended continuous rainwater monitoring for two years, incorporating sample analyses, to assess the impact of natural and human sources of contamination on ecosystems. It is feasible to use sensors to remotely monitor environmental conditions. Developing low-cost systems that use microcontrollers and sensors to monitor the physicochemical status of water in real-time. These gadgets incorporate big data and the internet of things. A low-cost sensor system in Parkville, Australia, exhibits dependability.. In Pretoria, South Africa, a sensor system was created and developed to detect physicochemical water quality parameters such conductivity, temperature, pH, flow rate, and oxidation-reduction potential. Every sensor data is instantly processed, analysed, and wirelessly sent via a Wi-Fi network. When water quality criteria are exceeded, the system informs the user instantly and sends out alarms (Mejía-Ferreyra et al., 2024).

3. Results and Discussions

In our discussion of stormwater management and harvesting, mention that in semiarid locations, it can reduce household runoff by up to 20%. In addition, emphasize the use of IoT technology in leak detection, smart farming, water treatment, other resource management and monitoring applications. Case studies of effective stormwater harvesting systems, such as those in Singapore and Philadelphia, are shown. Stormwater management system implementation is limited by high prices, uniform data, and potential cyber threats. The data show how important stormwater collection is in enhancing urban resilience to climate change effects.

3.1. Modern Methods and Techniques in Stormwater Harvesting

Stormwater control measures (SCMs) and green infrastructure are increasingly popular for managing urban hydrology and stormwater due to rising urban planning challenges. However, these systems require regular maintenance and inspections, often conducted by personnel with prior knowledge in stormwater management (Erickson et al., 2013). Regular inspections should be conducted at least once a year, and proper budgeting and allocation of responsibility are crucial. Additional maintenance may be necessary to maintain site-specific performance standards, such as erosion management, vegetation management, or water quality management (Erickson et al., 2013). Visual observations and extensive documentation are essential for routine inspections. Addressing issues such as excessive sedimentation, bank destabilization, erosion, invasive vegetation, or troublesome fauna can result in expensive maintenance costs. It is important to record any additional issues beyond typical watershed loading conditions (Erickson et al., 2018). Professionals in the field of stormwater management encounter new and emerging issues, establish guidelines for maintaining high-priority SCMs like media filtering methods, infiltration techniques, stormwater wet ponds, and permeable pavements, and attend to stormwater management requirements. The suggestions aim to enhance the existing assessment and maintenance guidelines, drawing from real-world experiences in the Northern Midwest region of the United States (Erickson et al., 2018).

3.1.1. Retention Ponds and Wetlands

During periods of heavy precipitation, retention ponds are developed basins that are primarily used for the purpose of reducing the peak flow. The construction of wetland areas is analogous to the practice of incorporating plants into wet retention ponds that are shallow in depth. In addition to its utility in reducing peak flows, wetland areas are also used for controlling the quality of stormwater (Jiang et al., 2015). The construction pond can not only take up the surplus water, bed load and the alluvial stored from these processes but it has also potential to reduce the risk of flooding by diverting excess water and bedload round the pond, thereby decreasing any likelyhood for flooding. Different kinds of materials are used in the construction of ponds, and they come with different water supply and drainage systems. These include controlled outlets, gravity outlets and drainable outlets which are all aimed at controlling water levels and reducing the risk of floods further downstream. Seepage fed ponds-seepage fed ponds are inherently at risk of water contamination. A more correct water source and a utilization process will be safer for the flooding and drought factors-Back to Up (Ferk et al., 2020).The conventional configuration of a wetland comprises an initial deep pond, referred to as a sediment forebay, that is used to slow the water velocity and represent the load of sediments going into the wetland. Following this deep pond will be shallow water (shallow wetland plants) and an outlet structure to provide the wetland with a hydraulic regime. To function well, the wetland should maintain a constant flow to provoke the growth of wetland plants, Figure 2. (Jiang et al., 2015). Stormwater ponds need to be designed with maintenance in mind, including routine and non-routine aspects, which can issue or consume between 2 % to 10 % of the total cost of construction. To be effective, the pond should be designed with a specific purpose and performance goals in mind. Ponds are capable of contributing to serving as carbon storage, biodiversity conservation, and an ecosystem as service (Erickson et al., 2018). Capturing stormwater can be advantageous in a multitude of ways, including improved conditions in urban streams or providing beneficial water source (Mitchell et al., 2007). Residents may anticipate using construction ponds for decorative or recreational reasons, which raises issues about the purity of the water and the presence of unsightly vegetation. Construction ponds have an influence on stormwater management methods since they serve as sacrificial water bodies with the objective of protecting waterways farther downstream (Anderson et al., 2002). It is possible that additional pretreatment, such as pretreatment sump pumps, may be required in order to address difficulties such as the development of algae. Additionally, stakeholders should have a say in the activities that are performed for maintenance. The residents often consider drainage ponds to be natural ecosystems, and as a result, they may be resistant to management attempts (Taguchi et al., 2022).

Fig. 2: The image depicts the well-known Felaw Pond, which is located in the Choman district (https://www.kurdistan24.net).

3.1.2. Blue-Green Infrastructure (BGI)

The term BGI refers to a network of landscape systems that are meant to deliver ecosystem services linked to stormwater by integrating natural and manmade materials (Liao et al., 2017). BGI saves water, reduces energy consumption because it requires less cooling, improves air quality, and sequesters carbon, Figure 3. These are just some of the advantages that come from lowering stormwater runoff. BGIs are a multifunctional approach to the control of urban flood risk because, in addition to reducing the danger of flooding, they contribute to other advantages. Because they are complementary to one another, the ideal technique is to combine the green, blue, and grey alternatives (Alves et al., 2019). In this case, compared to system's inherent ability to regulate the quantity and quality of the flowing stormwater, the BGI for stormwater management in urban ecosystems tries to detain, store, infiltrate, and bio-absorb polluting agents to a larger extent. To highlight the connection between the aquatic and the terrestrial ecosystems (Liao et al., 2017). Some of the co-benefits that arise from BGI includes water conservation, energy conservation, air quality improvement and carbon sequestration are some of the important factors in the management of urban flood risks from climate change (Alves et al., 2019). Thus, the municipal water system benefits that can be derived from the implementation of BGI techniques may include one or more of the following: better water quality, enhanced biological richness, and increased value of housing stock (Wilbers et al., 2022).

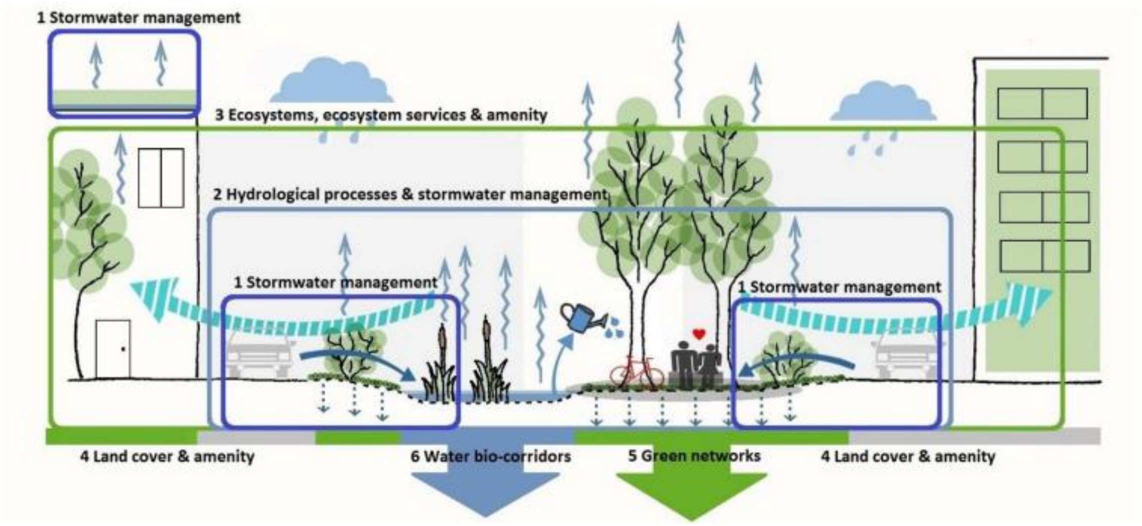

Fig. 3 : Schematic representation of BGI methods in the urban environment; illustration of the urban landscape (Kopp and Raška, 2017).

3.1.3.Green Roofs

Green roofs are a sort of stormwater harvesting approach that transform impermeable roof surfaces into multifunctional areas by using plants, growth medium, and specialised roofing materials, Figure 4. Green roofs are also known as green construction. Both widespread and intense systems are possible, with extensive systems being more frequent owing to the reduced costs and weight restrictions associated with them. Through the storage of precipitation in the growth medium and the facilitation of evaporation, transpiration, and interception functions, green roofs contribute to the management of stormwater by removing water from the surface of the roof (Carter and Butler, 2008). In comparison to impermeable roofs, green roofs have the potential to considerably decrease the amount of stormwater runoff as well as the timing of the runoff, particularly during the summer months. Rainfall is retained by vegetated roofs throughout the summer months to a greater extent than by medium-only roofs; however, the impact is contingent upon the magnitude of the rain event. Rainfall that occurs during the dry season may have an effect on the ability of green roofs to retain water. In urban drainage networks, green roofs are more successful than other methods for decreasing flow peak and volume during storms that occur often and are of a reduced size (Schroll et al., 2011). Green roofs retain more rainwater than traditional roofing systems, with research showing a thin-layer system holding 48% more rainfall than a gravel ballast roof. They are cost-effective and have a longer lifespan than traditional roofs. Although initially more expensive, green roofs offer economic advantages over time, including longer roof life, energy savings, and reduced stormwater fees, making them an excellent stormwater management method (Carter and Keeler, 2008).

Fig. 4 : Sonoma Academy's guild and commons building utilizes rooftop space for rainwater collection, featuring solar panels, a white reflecting stone ballasted roof, and a biodiverse green roof (Dvorak and Drennan, 2021).

3.1.4. Permeable Pavement

Permeable pavement systems reduce pavement runoff and contaminants, facilitating infiltration, storage, and distribution of rainwater, Figure 5. They enhance groundwater recharge and reduce surface runoff. Imran et al. (2013) illustrated that permeable pavement reduces surface runoff volume by 90% and 99.4%, with interlocking concrete pavers showing similar results. Enhancing the management of stormwater may be accomplished by integrating permeable pavement into the urban infrastructure that is already in place. The purpose of permeable pavements is to collect precipitation and runoff from storms, and they may be incorporated into traditional stormwater drainage systems so that they can be used as necessary (Harvey et al., 2017). Reduced floods, elimination of pollutants, decreased deicing, and elimination of water treatment expenses are some of the financial advantages that may be realised by the use of permeable pavement for stormwater harvesting. Infiltration of rainwater into the earth, as opposed to runoff water, is made possible by permeable pavements, which in turn leads to the recharging of subterranean water storage basins. If permeable pavements are used, it is possible to fully remove the expenditures that are involved with water treatment, which will result in huge financial savings (Antunes et al., 2020).

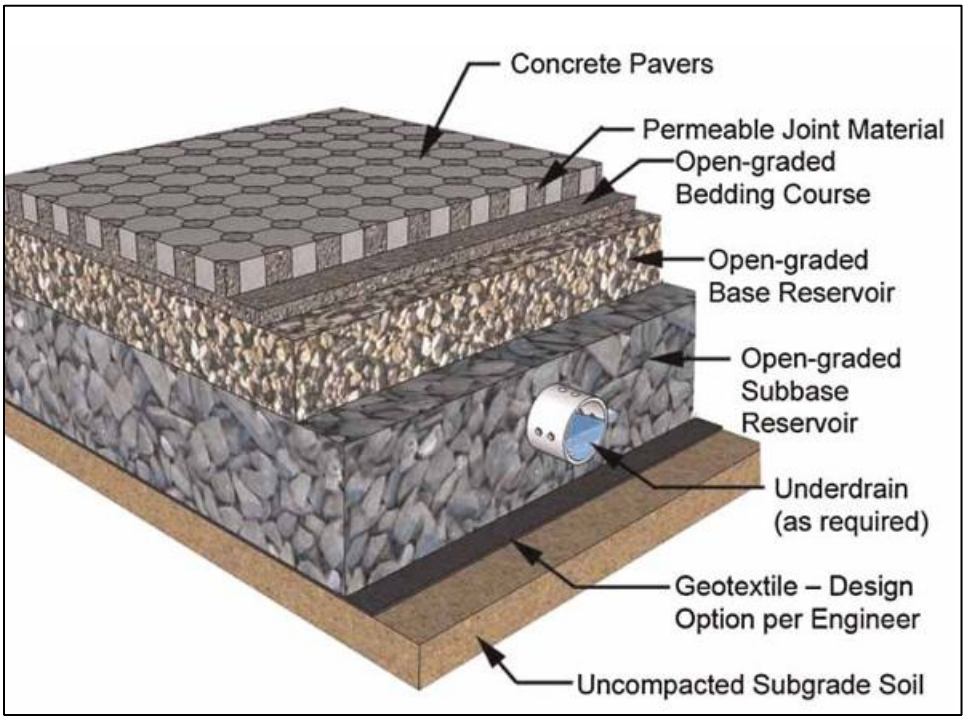

Fig. 5 : An illustration of a typical Permeable pavement cross-section is shown (photo courtesy of the Interlocking Concrete Pavement Institute) (Drake et al., 2013).

3.1.5. Rain Gardens

Rain gardens reduce water flow into rivers and streams during storms, offering an environmentally friendly and cost-effective solution for retrofitting existing stormwater management plans (Seymour, 2005). Rain gardens offer a comprehensive solution to urban environmental challenges, benefiting technology, operations, ecology, society, health, aesthetics, and cost savings, Figure 6. They collect stormwater runoff, recharge groundwater, remove pollutants, attract animals, improve biodiversity, promote human health, enhance aesthetics, reduce noise, improve air quality, capture carbon dioxide, and control global climate (Bąk and Barjenbruch, 2022). Rain gardens in Poland cost between 2,000 and 2,500 Polish Lei (PLN) per square meter, depending on factors such as size, soil conditions, location, design, installation time, plant types, and materials used. Investment, operations, maintenance, and land usage costs also contribute to these costs. However, reputable companies may present varying estimates for certain installations, highlighting the potential for variations in prices across different regions (Siwiec et al., 2018).

Fig. 6 : Kyoto Gakuen University's rain garden is located in Nishigyo Ward, Kyoto, Japan (Zhang et al., 2020).

3.1.6. Sponge Cities

A sponge city is also referred to as an ecological city which has been built sustainably in a way that it does not interfere with the water systems and natural habitats, prevents floods, preserves water and enhances the quality of the water in the region, Figure 7. It illustrates a city in which a water system is created in the manner that it collects, filter, stokes and releases rainwater for use in the future (Rui et al., 2018; Ahmed et al., 2024). Sponge city is the concept where urban structure is altered to be green to avoid floods and also to enhance the quality of water. This combines porous pavement, roof gardens, bio-infiltration swales, and retention basins to harvest, filter, and store stormwater. This way, the formed impervious cover is lowered, making the groundwater recharge enhanced, less strain placed on usual drainage systems, work towards more sustainable urban development as well as control of floods (Ahmed et al., 2024). It is worthy to note that the GI, LID and BMPs and BPPs that the US and Canada adopted influenced China more specifically the Chinese government's sponge city plan of 2014. Examples of systems adapted are; Integrated urban water management (IUWM) from the United Kingdom, France and other European countries the alternative methods (ATs), water-sensitive urban design (WSUD) from Australia and New Zealand, and sustainable drainage systems or sustainable urban drainage systems (Sus Drain/SUDSs). Based on sponge facilities, ecological treatment of contaminated water, non-point source emission reduction, and rainfall utilization, Li et al. (2017) proposed a fast assessment method for promoting sustainability and building livable societies. Thus, it exposes the fact that the assessment of the interconnection between the following aspects is paramount: Biodiversity Microclimate Sponge facilities. Sponge city building has a variety of benefits, including increased urban livability, improved water quality, and increased flood management. It fosters unconventional water sources, lessens pollution, boosts biodiversity, and improves drainage and protection infrastructure. It also creates green spaces (Li et al., 2018; Ahmed et al., 2024).

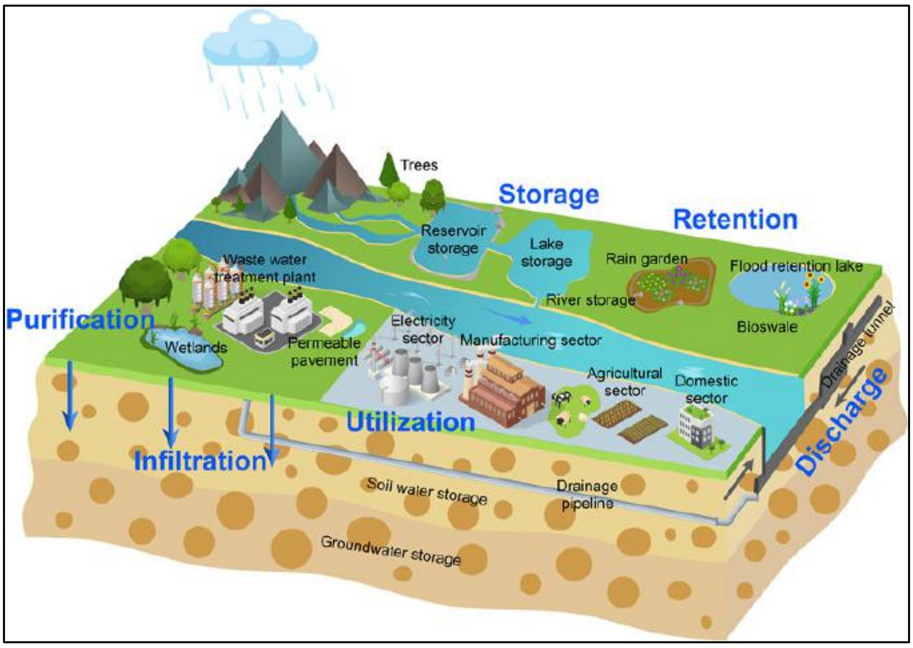

Fig. 7: The planning of sponge cities incorporates hydrological mechanisms (Liu et al., 2022).

3.2. Successful Stormwater Harvesting Projects

Successful implementation of stormwater harvesting programs requires overcoming obstacles such as system self-maintenance and expense. Cities like Austin have noted system self-maintenance as a potential barrier to pressurized systems. Cost often hampered program implementation and performance in the assessed cities. Local plans that include rainwater collection rules may also help ensure effective implementation (Fricano and Grass, 2014). Case studies from Barcelona and Stockholm emphasize the significance of small-scale public initiatives that combine irrigation with rainwater collection for drainage management, offering socioecological advantages in densely populated regions (Suleiman et al., 2020). The new

South Wales (NSW) Home Saver Payments Programme, for instance, offered payments to customers for climate-friendly equipment, including rainwater tanks. Sydney Water's Rainwater Tank Programme pays reimbursements to residents who install rainwater tanks to supplement their water usage (Imteaz and Moniruzzaman, 2018). Studies on the spatial variability of possible water savings from rainwater tanks in Sydney have shown significant variations in the yearly water savings across the city's various areas (Imteaz and Moniruzzaman, 2018). As part of its stormwater management plan, Singapore launched the Active Beautiful Clean (ABC) Waters Programme in 2006, emphasising low-impact development and water-sensitive urbanism techniques. The programme incorporates various ABC design elements, including built wetlands, rain gardens, green roofs, and canal restoration projects. Although the program has demonstrated effectiveness in eliminating particles, it has difficulty eliminating nutrients. A project's ongoing success depends on monitoring and assessment after completion (Lim and Lu, 2016). The ABC Waters Programme in Singapore has demonstrated success in enhancing both urban liveability and water quality through the use of canals and reservoirs. Individuals who own private homes certified by ABC Waters are prepared to pay more for elements included in ABC Waters designs. People's willingness to pay for ABC Waters initiatives has also grown as a result of using virtual reality apps. In general, the programme has shown positive effects on the environment and community (Iftekhar et al., 2019). Virtual reality-based Singapore's ABC Waters Programme has long-term effects on private housing, water quality, and urban liveability; however, its nutrient removal effectiveness is not without problems (Iftekhar et al., 2019).). To reach its 10-year target of greened acres, the City of Philadelphia's Green City, Clean Waters initiative has developed projects with success. Modifications are required, particularly in the execution of non-residential private and non-city public properties, in order to achieve the overall plan objective by 2036. The initiative has significantly improved volume and water quality, while also hybridizing the stormwater system with gray and green infrastructure (CITY and PLAN, 1991).

3.3. Implementation of Stormwater Harvesting Systems

Implementing stormwater harvesting systems in residential areas, especially in semiarid locations, results in a significant decrease in runoff volume and peak flow. These systems provide financial advantages and cost-effective management in residential areas, with both passive and active release mechanisms yielding significant reductions (Gee and Hunt, 2016).To successfully implement stormwater harvesting systems, it is essential to design and develop them in accordance with the site's specific requirements. Correct design of the control algorithm is necessary for active systems to outperform passive systems in terms of water supply and stormwater retention (Quinn et al., 2020). In this sense, active systems have been typically better off. There are three ways to improve stormwater management performance: new load demands, extension of passive and active structures, and an extension of the existing approach (Rahman et al., 2020). Stormwater harvesting planning is therefore based on potential sources, uses, performance goals, and sub-systems for collection, storage, treatment, distribution, and discharge. Current frameworks are not too heavy on modeling and design and never was applied to large scale scenarios. These may involve making site selection; making approach to the controllers; sourcing for funds; and the question of arts specific funding and community fund-raising (Dandy et al., 2019). Stormwater construction as well as domestic and industrial storage tanks and filtering systems are compulsory in the stormwater harvesting systems. More often than not, post-storage treatment techniques such as fine sediment filtering as well as disinfection are incorporated in these systems. Some of the strategies necessary for collection of stormwater consist of catchments, pipelines, tanks, filters, treatment of water and pumps. The materials that the roof is made of will determine the quality of water that is collected in case of rainwater harvesting (Sojka et al., 2016). In such areas such as Salisbury in South Australia, the objective of stormwater harvesting systems is for sustainable irrigation purposes. These technologies, which are being under development now all over the world, help to counter climate change by avoiding usage of water from energy-intensive sources (Velasco-Muñoz et al., 2019). It is therefore important to ensure that to guarantee the success of stormwater harvesting systems, they are properly maintained regularly. It can be due to factors such as proper maintenance that can convince users associated with the place and guarantee that the quality of the water is good. Just two aspects of technology and its management impact the quality of the collected rainwater and its usability (Campisano et al., 2017). The costs that are attributed to the management of stormwater harvesting systems vary from one type of system to another in the same category. To give but one example of a porous asphalt system, the total breakdown of maintenance loads for pavement vacuuming has been identified as having the lowest human hours and yearly costs out of all the options available (Houle et al., 2013). Although LID systems usually cost more in initial installation as compared to conventional pond systems, there is general agreement that annual maintenance costs are significantly lower with LID systems. It is succeeded by vegetated swales, subsurface gravel wetlands, and bioretention systems by means of the annualized cost of maintenance expressed as a percentage of capital expenditures. The table below shows that the least annualized maintenance cost is associated with the porous asphalt systems. Some of the costs include the vegetated swale at $2,280 per hectare per year and the wet pond at 7,830 $ per hectare per year (Kang et al., 2008). In the case of stormwater management systems, maintenance costs play a critical role throughout the design as well as the implementation process.

3.4. Challenges and Future Directions

Challenges toward the management of stormwater include inadequate funding and poor awareness of the stormwater system. For the control of stormwater runoff, (LID) is better and more cost-effective than the traditional grey infrastructure. To some extent, this type of work reduces the load created by rainwater on municipal sewers through the retention, and infiltration of rainwater through natural systems where rainfall happens (Copeland, 2016). Green infrastructure solutions are proving popular with decision-makers because the said conventional grey infrastructure technologies are expensive (Qiao et al., 2018). SMPs have responsibilities that cities can communicate to the public, enhance, and assume in watershed initiatives to enhance people's awareness of stormwater harvesting. As people's experience in water quality and their perceived responsibility for using rain gardens increases, their knowledge about the quality of water increases. Reducing the stormwater charges and propagating rain barrels are some ways that can also help people adopt stormwater harvesting practices. Outmoded regulation and privatization, lack of public awareness and motivation, willingness to resist change, deficiencies of performance and cost data, deficiency of design standards and maintenance instructions, lack of pollution fee and sufficient funds and revenues to support, deficiencies of effective incentive policies and programs, as well as unclear operation and maintenance roles can all make it challenging for regulatory barriers and permitting requirements for stormwater harvesting systems (Tian, 2011). To overcome these challenges, municipalities have to have comprehensive approaches to the management of watersheds, introduce green infrastructure concepts into regional policies on stormwater management, and require government support in the implementation of so-ordered measures based on licenses and court decisions (Tian, 2011). Prescribed education and awareness campaigns that seek to encourage stormwater harvesting systems may help convince people to change the status quo with a view of turning the suburbanites into on-site stormwater managers. Some of the ways true include webinars arising from stormwater management, labeling of products linked with stormwater, and clean water festivals. The Clean Water Act requires education efforts to be a part of municipal stormwater plans (Lieberherr and Green, 2018).

3.5. Problem and Solutions

The following succinctly describes Erbil City's issues with floods and environmental management:

Frequent Flooding Events: Numerous flooding incidents have occurred in Erbil City in recent years, especially in 2021 and 2022, which have caused serious damage to houses and infrastructure as well as fatalities. Because of the city's poor drainage infrastructure and high rainfall, flash floods are common (Aziz et al., 2023a).

Changes in Land Use and Urbanisation: Increased impermeable surfaces as a result of unplanned construction and rapid urbanization have decreased natural drainage and increased flood hazards. Natural hydrological processes have been hampered by the conversion of agricultural and green space into built-up region.

Poor Infrastructure for Drainage: Heavy rainfall often overwhelms the current drainage systems, which include storm sewers and culverts, causing obstructions and overflow. Water flow is further impeded by the many building waste and debris-filled drainage ditches (Aziz et al., 2023a).

Environmental Degradation: Natural landscapes are deteriorating, there are fewer green places, and there is less biodiversity as a result of urban growth. Local ecosystems and water quality have suffered as a result of contaminants and building debris being dumped into streams (Anuthaman et al., 2023).

Impacts of Climate Change: Increasing rainfall frequency and intensity due to climate change presents more difficulties for flood control. Flood occurrences are becoming harder to anticipate and plan for due to shifting climatic trends (Aziz et al., 2023a).

Lack of Comprehensive Flood Management Plans: Integrated flood control plans that take non-structural as well as structural measures into account are lacking. The intricacies of urban floods and environmental sustainability may not be sufficiently addressed by current strategies (Anuthaman et al., 2023).

3.6. Reduce Flooding, Erosion and Groundwater Recharge

Stormwater management also can potentially reduce flooding by drawing out some of the stored amounts before a rain event; increasing the flow rate of the river before the event and reducing the peak flow may help prevent flooding (Fisher-Jeffes et al., 2017). This reduces the peak and volume of flow of stormwater runoff, one of the ways stormwater harvesting assists in the avoidance of erosion. The above in turn leads to an improvement in the overall environmental impact as well as the requirement for potable water. Besides this, it reduces the degree of depletion of aquifers, the costs of potable water, non-point source pollutants, and the future risks of the occurrence of floods that may lead to damage to infrastructure (Vargas, 2009). It was also found that stormwater harvesting could improve soil stability through such measures as utilization of infiltration rates and prevention of erosion. However, improper management of stormwater harvesting causes soil compaction and nutrient leaching that acts negatively on the stability of the soil (Maliva and Maliva, 2020). Since the available recharging water is mostly from surface water from rivers, dams, etc., scarcity of the same hampers the availability of water to be used for this purpose. But to try to enhance or put more volume into the existing stock of groundwater, there is the managed aquifer recharge, or MAR, that can be used. Other sources include stormwater, and due to its reusable quality, its utilization in MAR is receiving increased attention (Song et al., 2019). Ways in which stormwater harvesting may aid in making groundwater resources more available include conveying rainfall runoff from roadways and then employing recharge wells to artificially recharge the water table. There is potential with this approach to be able to assist in the sustainability of the groundwater in areas such as Lahore, which can increase the level of the groundwater after each monsoon season (Hussain et al., 2019). This has the potential to lengthen the duration surface water bodies such as rivers and streams are charged as well as create perpetual streams, increase the yields of wells and boreholes, reduce the energy needed to pump water, vegetative cover, reduce erosions, and in the process improve the flora and fauna of the area. Increased agricultural produce, increased irrigated land, and reduced vulnerability and susceptibility to drought are some of the economic benefits (Gale et al., 2002). The quality of the stormwater might negatively affect the recharge of the groundwater by polluting the groundwater and reducing the infiltration system. Pollutants that are dumped in the stormwater may sometimes find their way into the groundwater source. Some of these pollutants include TSPs, organic matter nutrients, and metals, among others. Furthermore, pollution in stormwater involves physical, biological, and chemical blockage, and these have implications for the feasibility of recharge in urban stormwater (Song et al., 2019).

3.7. Providing Sustainable Water Source for Landscaping and Irrigation

Stormwater collection can provide alternatives to traditional drinking water sources by reducing reliance on them. Using rainwater for irrigation conserves drinking water and saves money on water supply concerns. (Dandy et al., 2019). In several countries, the absence of available water has continued to be an issue of growing concern. Drought-prone regions face erratic rainfall patterns and very high evaporation rates in the dry seasons, two factors that aggravate it (Haghtalab et al., 2013). Cities in regions with dry seasons face challenges like water scarcity and increased surface runoff. Rainy seasons cause massive runoff to flow through streets, causing a gradual decrease in groundwater supply (Zhang and Hu, 2014). Lack of water has several negative effects on human existence, both directly and indirectly. A water shortage has several significant implications, one of which is its influence on the urban environment, a crucial component in making a city habitable. In urban settings, there is a clear correlation between the urban landscape and the environmental, social, and physical quality of human existence. The built environment contains a significant amount and quality of urban green space (Seitz et al., 2014). Water resource management is crucial for creating green spaces in dry and semiarid environments. Developing sustainable water supply methods for irrigation is essential for maximizing benefits. Stormwater collecting systems and rainwater reuse improve landscape quality and environmental sustainability of irrigation techniques (Ghisi et al., 2009). In addition to supplying a fresh supply of water, the collection and utilization of rainfall for landscape irrigation results in infiltration, which in turn offers several advantages, including the preservation of nutrients in the soil, the elimination of pollutants, the replenishment of groundwater, and the provision of green space that is more conducive to health (Seymour, 2005). By using this win-win method in landscape design and management, it is possible to minimize the amount of potable water that is used for irrigation while simultaneously improving the quality of the water (Saeedi and Goodarzi, 2020).

3.8. AI Application

AI can enhance efficiency in water collection and delivery by way of smart water management techniques for different purposes like effective distribution, conservation, and maintenance of water quality standards (Krishnan et al., 2022). The deployment of AI models is employed in stormwater gathering data processing using sensors, which form part of dynamic management systems. Infrastructure components are optimized using deep learning algorithms that support effective water collection strategies. AI stormwater modeling tools enhance the management and quality of water by analyzing data, making informed choices, and predicting stormwater flows as well as their quality (Ramovha et al., 2024). Recent years have witnessed a lot of growth in the area of using AI, machine learning (ML), and satellite-based remote sensing techniques, among other things, to model water quantity and quality. By merging artificial neural networks (ANN) and support vector machines (SVM) with AI and ML techniques to get accurate estimates of the metrics for water quality (Meshram et al., 2020). By using modeling software, AI encompasses stormwater management on big data sets to predict stormwater volume and water quality, optimize Best Management Practices (BMPs), and support decision-making regarding the construction of stormwater management structures (Ramovha et al., 2024). It is possible for sensors that are powered by artificial intelligence to continually monitor water quality metrics, such as the concentration of pollutants, pH levels, and turbidity, to evaluate the efficiency of existing systems and locate regions that might need improvement (Ramovha et al., 2024).

Short-range water level forecasting employs different machine-learning methods than long-term streamflow forecasting (Mosavi et al., 2018). An effective water management strategy could benefit from the integration of IoT technology in leak detection, water treatment plants, smart farming, and monitoring of various water bodies. Through this innovation, it is possible to minimize energy and water losses while maximizing farm productivity. However, high costs, cyberattacks, and data consistency issues need to be addressed for their successful implementation. Besides, the use of intelligent water systems can enhance water resource management and alleviate global water scarcity (Gupta et al., 2020). The adoption of IoT technology impacts water conservation initiatives because it enables the use of precise DSS for water consumption, forecasts precipitation fluctuations, tracks groundwater depletion, and creates sustainable water indicators (Salam, 2024). Contemporary stormwater harvesting technologies reduce residential runoff by up to 20% in semiarid regions and less in higher rainfall areas. This benefits communities and individuals by providing an alternative water source and stormwater management strategy (Steffen et al., 2013). Prior studies have focused on disaster information and communication systems, including analog, digital, and mobile apps accessible via the web, have been the subject of prior study (Nasution et al., 2017). Using Ethernet as a web server and ultrasonic sensors to broadcast flood height data in real-time, one such system is the flood early warning system. Another system, the GSM-based disaster information system, uses a building-based GSM module as a prototype fire monitoring information system. Utilizing an Ethernet module as a web server and an Adriano microcontroller for water level processing, this system transmits flood height, rainfall, and temperature data over the internet (Poslad et al., 2015). ANN approaches have drawn more attention lately for their use in hydrological modelling. ANN and other data-driven models have been used to examine long-term discharge prediction and reported the results (Cheng et al., 2020). ANN be used to identify the link between rainfall and runoff for the rainfall-runoff modelling process. Learned connection inside a few layers of nonlinear transition functions to convert rainfall input into runoff output can be built. The ANN modeling technique is relatively easy and efficient because it learns without explicit physics inputs. The AI stormwater model considers the amount and quality of stormwater using three different methods: sub-watershed green infrastructure LID controls, drainage conduit network hydraulic modeling, and nonlinear reservoir overland flow routing. which determine the runoff from overland flow, the value of treating stormwater on-site, and the real-time model with sensor monitoring data modification for the operations of the hydraulic structure devices (Cheng et al., 2020). Table 1 illustrates some AI applications in stormwater harvesting.

Table 1: AI applications in stormwater harvesting

No.	Type	purpose	citation
1	Artificial neural networks (ANN)	ANN can improve stormwater harvesting by integrating performance assessment, considering water sources, and balancing social, environmental, and economic goals, but current frameworks are insufficient for comprehensive modeling.	Dandy et al. (2019)
2	Deep Learning(DL)	DL can improve stormwater harvesting and urban runoff by monitoring garbage accumulation. Using deep convolutional neural network models, high recall, precision, and accuracy rates were achieved, helping cities prioritize and assess garbage reduction efficacy, thereby meeting stormwater regulation requirements.	Fu et al. (2022)
3	Principle Component Analysis (PCA)	PCA, which gives a non-heuristic way to give weights to attributes and rank possible stormwater collection sites, may help with the process of picking stormwater collection sites. This method has shown strong agreement with the locations that water planners have chosen, making it a viable tool for choosing stormwater collection locations.	Pathak et al. (2017)
4	Bayesian Model	By improving reservoir operations and taking model selection uncertainty into account, BMA may enhance	Fang et al. (2018)

	Averaging (BMA)	stormwater harvesting. The BMA method worked better than other operating rules because it looked at the uncertainty of choosing specific models with different weights. This led to more hydropower output and better use of natural inflows.	
5	Random Forest (RF)	RF makes flood hazard rating prediction models that improve the accuracy of stormwater analysis by using two-dimensional numerical analysis to figure out inundation and flow velocity maps for model training. With debris considerations taken into account, the model can estimate flood danger ratings of grid units with up to 99.99% accuracy given the target region's total cumulative overflow.	Kim and Kim (2020)
6	Support vector machines (SVM)	SVM can handle uncertainties in stormwater harvesting data by reconstructing flooding patterns using satellite imagery data. SVM provides accurate classification with a small training set, combining data from different satellites for flood risk management.	Dhara et al. (2020)

4. Conclusions

This study highlights the potential for enhancing stormwater harvesting as a sustainable urban water management strategy through the application of AI and contemporary techniques. Successful case studies from Singapore and Philadelphia show how innovative infrastructure, such as green roofs, permeable pavements, and bioretention systems, may minimize urban runoff and enhance water quality. AI-driven technologies may improve stormwater system design and operation, increasing effectiveness and ensuring adherence to water quality regulations. The combination of AI and IoT technology enables smart water management systems to monitor water quality measurements and proactively identify problems, thereby enhancing system performance. However, issues such as high installation costs, cybersecurity concerns, and the need for standardized data standards hinder widespread use. To overcome current challenges and ensure the long-term success of stormwater management initiatives, it is crucial to continue investigations, involve stakeholders, and engage in collaborative efforts.

5. References

Ahmed, H.G., Aziz, S.Q., Wu, B., Ahmed, M.S., Jha, K., Wang, Z., Nie, Y. and Huang, T., 2024. Application of Sponge City for Controlling Surface Runoff Pollution. *Asian Journal of Environment & Ecology*, *23*(9), pp.1-23.

Akram, F., Rasul, M.G., Khan, M.M.K. and Amir, M.S.I.I., 2014. A review on stormwater harvesting and reuse. *International Journal of Environmental, Earth Science and Engineering*, *8*(3), pp.178-187.

Al-Kakey, O., Othman, A. and Merkel, B., 2023. Identifying potential sites for artificial groundwater recharge using GIS and AHP techniques: A case study of Erbil basin, Iraq. *Kuwait Journal of Science*, *50*(1B).

Alves, A., Gersonius, B., Kapelan, Z., Vojinovic, Z. and Sanchez, A., 2019. Assessing the Co-Benefits of green-blue-grey infrastructure for sustainable urban flood risk management. *Journal of environmental management*, *239*, pp.244-254.ANDERSON, B., WATT, W. & MARSALEK, J. 2002. Critical issues for stormwater ponds: learning from a decade of research. *Water Science and Technology,* 45**,** 277-283.

Antunes, L.N., Sydney, C., Ghisi, E., Phoenix, V.R., Thives, L.P., White, C. and Garcia, E.S.H., 2020. Reduction of environmental impacts due to using permeable pavements to harvest stormwater. *Water*, *12*(10), p.2840.

Anuthaman, S.N., Ramasamy, S., Ramasubbu, B. and Lakshminarayanan, B., 2023. Modelling and forecasting of urban flood under changing climate and land use land cover. *Journal of Water and Climate Change*, *14*(12), pp.4314-4335.

Aziz, S.Q., Saleh, S.M., Muhammad, S.H., Ismael, S.O. and Ahmed, B.M., 2023a. Flood Disaster in Erbil City: Problems and Solutions. *Environmental Protection Research*, pp.303-318.

Aziz, S.Q., Alrawi, R.A.A., Dizayee, K.K., Khalil, C., Shaheed, I.M. and Mustafa, J.S., 2023b. Investigation of Rainwater Quality in Erbil Province and the Feasibility of Various Uses. *Environmental Protection Research*, pp.240-262.

Bąk, J. and Barjenbruch, M., 2022. Benefits, inconveniences, and facilities of the application of rain gardens in urban spaces from the perspective of climate change—A review. *Water*, *14*(7), p.1153.

Campisano, A., Butler, D., Ward, S., Burns, M.J., Friedler, E., DeBusk, K., Fisher-Jeffes, L.N., Ghisi, E., Rahman, A., Furumai, H. and Han, M., 2017. Urban rainwater harvesting systems: Research, implementation and future perspectives. *Water research*, *115*, pp.195-209.

Carroll, D., 1962. Rainwater as a chemical agent of geologic processes: a review.

Carter, T. and Butler, C., 2008. Ecological impacts of replacing traditional roofs with green roofs in two urban areas. *Cities and the Environment (CATE)*, *1*(2), p.9.

Carter, T. and Keeler, A., 2008. Life-cycle cost–benefit analysis of extensive vegetated roof systems. *Journal of environmental management*, *87*(3), pp.350-363.

Cheng, J.Y., Xiang, C. and Ma, Y., 2020, July. AI application on LID stormwater management and urban planning in Guam, USA, and Southern China, PRC. In *International Low Impact Development Conference 2020* (pp. 188-200). Reston, VA: American Society of Civil Engineers.

CITY, G. and PLAN, C.W., 1991. Philadelphia's.

Copeland, C., 2016. Green infrastructure and issues in managing urban stormwater.

Dandy, G.C., Marchi, A., Maier, H.R., Kandulu, J., MacDonald, D.H. and Ganji, A., 2019. An integrated framework for selecting and evaluating the performance of stormwater harvesting options to supplement existing water supply systems. *Environmental Modelling & Software*, *122*, p.104554.

Di Luzio, M., Srinivasan, R. and Arnold, J.G., 2004. A GIS‐coupled hydrological model system for the watershed assessment of agricultural nonpoint and point sources of pollution. *Transactions in GIS*, *8*(1), pp.113-136.

Dhara, S., Dang, T., Parial, K. and Lu, X.X., 2020. Accounting for uncertainty and reconstruction of flooding patterns based on multi-satellite imagery and support vector machine technique: A case study of Can Tho City, Vietnam. *Water*, *12*(6), p.1543.

Drake, J.A., Bradford, A. and Marsalek, J., 2013. Review of environmental performance of permeable pavement systems: State of the knowledge. *Water Quality Research Journal of Canada*, *48*(3), pp.203-222.

Dvorak, B. and Drennan, P., 2021. Green roofs in California coastal ecoregions. *Ecoregional Green Roofs: Theory and Application in the Western USA and Canada*, pp.315-389.

Erickson, A.J., Taguchi, V.J. and Gulliver, J.S., 2018. The challenge of maintaining stormwater control measures: A synthesis of recent research and practitioner experience. *Sustainability*, *10*(10), p.3666.

Erickson, A.J., Weiss, P.T. and Gulliver, J.S., 2013. Optimizing stormwater treatment practices. *A Handbook of Assessment and Maintenance*, *1*(1), pp.1-337.

Fang, G., Guo, Y., Huang, X., Rutten, M. and Yuan, Y., 2018. Combining grey relational analysis and a bayesian model averaging method to derive monthly optimal operating rules for a hydropower reservoir. *Water*, *10*(8), p.1099.

Ferk, M., Komac, B. and Loczy, D., 2020. Management of small retention ponds and their impact on flood hazard prevention in the Slovenske Gorice Hills. *Acta geographica Slovenica*, *60*(1), pp.107-125.

Fisher-Jeffes, L., Carden, K., Armitage, N.P. and Winter, K., 2017. Stormwater harvesting: Improving water security in South Africa's urban areas. *South African Journal of Science*, *113*(1-2), pp.1-4.

Fricano, R.J. and Grass, A., 2014. Evaluating American rainwater harvesting policy: A case study of three US cities. *Journal of Sustainable Development*, *7*(6), p.133.

Fu, G., Jin, Y., Sun, S., Yuan, Z. and Butler, D., 2022. The role of deep learning in urban water management: A critical review. *Water Research*, *223*, p.118973.

Gale, I., Neumann, I., Calow, R. and Moench, M., 2002. The effectiveness of Artificial Recharge of groundwater: a review.

Gee, K.D. and Hunt, W.F., 2016. Enhancing stormwater management benefits of rainwater harvesting via innovative technologies. *Journal of Environmental Engineering*, *142*(8), p.04016039.

Ghisi, E., da Fonseca Tavares, D. and Rocha, V.L., 2009. Rainwater harvesting in petrol stations in Brasília: Potential for potable water savings and investment feasibility analysis. *Resources, Conservation and Recycling*, *54*(2), pp.79-85.

Gupta, A.D., Pandey, P., Feijóo, A., Yaseen, Z.M. and Bokde, N.D., 2020. Smart water technology for efficient water resource management: A review. *Energies*, *13*(23), p.6268.

Haghtalab, N., Goodarzi, M., HABIBI, N.M., Yavari, A.R. and Jafari, H.R., 2013. Climate modeling in Tehran & Mazandaran provinces by LARSWG and comparing changes in northern and southern central Alborz hillside.

Hameed, H.M., 2017. Estimating the effect of urban growth on annual runoff volume using GIS in the Erbil sub-basin of the Kurdistan region of Iraq. *Hydrology*, *4*(1), p.12.

Harvey, J., Shan, S., Li, H., Jones, D.J. and Wu, R., 2017. Fully permeable pavement for stormwater management: Progress and obstacles to implementation in California. *Airfield and Highway Pavements 2017*, pp.125-136.

Houle, J.J., Roseen, R.M., Ballestero, T.P., Puls, T.A. and Sherrard Jr, J., 2013. Comparison of maintenance cost, labor demands, and system performance for LID and conventional stormwater management. *Journal of environmental engineering*, *139*(7), pp.932-938.

Kurdistan24.net/Felaw-Pond-choman district, (2024). https://www.kurdistan24.net/en) [Accessed on 24 July 2024]

Hussain, F., Hussain, R., Wu, R.S. and Abbas, T., 2019. Rainwater harvesting potential and utilization for artificial recharge of groundwater using recharge wells. *Processes*, *7*(9), p.623.

Iftekhar, M.S., Buurman, J., Lee, T.K., He, Q. and Chen, E., 2019. Non-market value of Singapore's ABC Waters Program. *Water research*, *157*, pp.310-320.

Imran, H.M., Akib, S. and Karim, M.R., 2013. Permeable pavement and stormwater management systems: a review. *Environmental technology*, *34*(18), pp.2649-2656.

Imteaz, M.A. and Moniruzzaman, M., 2018. Spatial variability of reasonable government rebates for rainwater tank installations: A case study for Sydney. *Resources, Conservation and Recycling*, *133*, pp.112-119.

Jiang, S.C., Lim, K.Y., Huang, X., McCarthy, D. and Hamilton, A.J., 2015. Human and environmental health risks and benefits associated with use of urban stormwater. *Wiley Interdisciplinary Reviews: Water*, *2*(6), pp.683-699.

K Sissakian, V., Al-Ansari, N., Adamo, N., D Abdul Ahad, I. and A Abed, S., 2022. Flood hazards in erbil City Kurdistan region Iraq, 2021: A case study. *Engineering*, *14*(12), pp.591-601.

Kang, J.H., Weiss, P.T., Wilson, C.B. and Gulliver, J.S., 2008. Maintenance of stormwater BMPs, frequency, effort and cost. *Stormwater*, *9*(8), pp.18-28.

Kim, H.I. and Kim, B.H., 2020. Flood hazard rating prediction for urban areas using random forest and LSTM. *KSCE Journal of Civil Engineering*, *24*(12), pp.3884-3896.

Kopp, J. and Raška, P., 2017. *Ekohydrologický management mikrostruktur městské krajiny*. Západočeská univerzita v Plzni.

Krishnan, S.R., Nallakaruppan, M.K., Chengoden, R., Koppu, S., Iyapparaja, M., Sadhasivam, J. and Sethuraman, S., 2022. Smart water resource management using Artificial Intelligence—A review. *Sustainability*, *14*(20), p.13384.LIAO, K.-H., DENG, S. & TAN, P. Y. 2017. BGI : new frontier for sustainable urban stormwater management. *Greening cities: Forms and functions***,** 203-226.

Lieberherr, E. and Green, O.O., 2018. Green infrastructure through citizen stormwater management: Policy instruments, participation and engagement. *Sustainability*, *10*(6), p.2099.

Li, H., Ding, L., Ren, M., Li, C. and Wang, H., 2017. Sponge city construction in China: A survey of the challenges and opportunities. *Water*, *9*(9), p.594.

Li, Z., Dong, M., Wong, T., Wang, J., Kumar, A.J. and Singh, R.P., 2018. Objectives and indexes for implementation of Sponge Cities—A case study of Changzhou City, China. *Water*, *10*(5), p.623.

Lim, H.S. and Lu, X.X., 2016. Sustainable urban stormwater management in the tropics: An evaluation of Singapore's ABC Waters Program. *Journal of Hydrology*, *538*, pp.842-862.

Liu, Q., Cui, W., Tian, Z., Tang, Y., Tillotson, M. and Liu, J., 2022. Stormwater management modeling in "Sponge City" construction: Current state and future directions. *Frontiers in Environmental Science*, *9*, p.816093.

Maliva, R.G. and Maliva, R.G., 2020. Low impact development and rainwater harvesting. *Anthropogenic Aquifer Recharge: WSP Methods in Water Resources Evaluation Series No. 5*, pp.765-825.

McCarthy, D.T., Hathaway, J.M., Hunt, W.F. and Deletic, A., 2012. Intra-event variability of Escherichia coli and total suspended solids in urban stormwater runoff. *Water research*, *46*(20), pp.6661-6670.

Mejía-Ferreyra, L.D., García-Romero, L., Sánchez-Quispe, S.T., Apolinar-Cortés, J. and Orantes-Avalos, J.C., 2024. Automatic Rainwater Quality Monitoring System Using Low-Cost Technology. *Water*, *16*(12), p.1735.

Meshram, S.G., Singh, V.P., Kisi, O., Karimi, V. and Meshram, C., 2020. Application of artificial neural networks, support vector machine and multiple model-ANN to sediment yield prediction. *Water Resources Management*, *34*(15), pp.4561-4575.

Mitchell, V.G., Deletic, A., Fletcher, T.D., Hatt, B.E. and McCarthy, D.T., 2007. Achieving multiple benefits from stormwater harvesting. *Water science and technology*, *55*(4), pp.135-144.

Mosavi, A., Ozturk, P. and Chau, K.W., 2018. Flood prediction using machine learning models: Literature review. *Water*, *10*(11), p.1536.

Mustafa, A., Szydłowski, M., Veysipanah, M. and Hameed, H., 2022. Challenges in Flood Risk Identification, Assessment and Modeling in Data Scarcity Regions; Erbil, Kurdistan Region of Iraq as a Case Study. *Assessment and Modeling in Data Scarcity Regions*.

Mustafa, A.M., Muhammed, H. and Szydłowski, M., 2019. Extreme rainfalls as a cause of urban flash floods; a case study of the Erbil-Kurdistan region of Iraq. *Acta Scientiarum Polonorum Formatio Circumiectus*, *18*, pp.113-132.

Nasution, T.H., Muchtar, M.A., Siregar, I., Andayani, U., Christian, E. and Sinulingga, E.P., 2017, April. Electrical appliances control prototype by using GSM module and Arduino. In *2017 4th International Conference on Industrial Engineering and Applications (ICIEA)* (pp. 355-358). IEEE.

Ochoa-Rodriguez, S., Wang, L.P., Willems, P. and Onof, C., 2019. A review of radar-rain gauge data merging methods and their potential for urban hydrological applications. *Water Resources Research*, *55*(8), pp.6356-6391.

Pathak, S., Ojha, C.S.P., Zevenbergen, C. and Garg, R.D., 2017. Ranking of storm water harvesting sites using heuristic and non-heuristic weighing approaches. *Water*, *9*(9), p.710.

Poslad, S., Middleton, S.E., Chaves, F., Tao, R., Necmioglu, O. and Bügel, U., 2015. A semantic IoT early warning system for natural environment crisis management. *IEEE Transactions on Emerging Topics in Computing*, *3*(2), pp.246-257.

Qiao, X.J., Kristoffersson, A. and Randrup, T.B., 2018. Challenges to implementing urban sustainable stormwater management from a governance perspective: A literature review. *Journal of Cleaner Production*, *196*, pp.943-952.

Quinn, R., Melville-Shreeve, P., Butler, D. and Stovin, V., 2020. A critical evaluation of the water supply and stormwater management performance of retrofittable domestic rainwater harvesting systems. *Water*, *12*(4), p.1184.

Rahman, A., Snook, C., Haque, M.M. and Hajani, E., 2020. Use of design curves in the implementation of a rainwater harvesting system. *Journal of cleaner production*, *261*, p.121292.

Ramovha, N., Chadyiwa, M., Ntuli, F. and Sithole, T., 2024. The Potential of Stormwater Management Strategies and Artificial Intelligence Modeling Tools to Improve Water Quality: A Review. *Water Resources Management*, pp.1-34.

Rivera, A., Ponce, P., Mata, O., Molina, A. and Meier, A., 2023. Local weather station design and development for cost-effective environmental monitoring and real-time data sharing. *Sensors*, *23*(22), p.9060.

Rui, Y., Fu, D., Do Minh, H., Radhakrishnan, M., Zevenbergen, C. and Pathirana, A., 2018. Urban surface water quality, flood water quality and human health impacts in Chinese cities. What do we know?. *Water*, *10*(3), p.240.

Saeedi, I. and Goodarzi, M., 2020. Rainwater harvesting system: A sustainable method for landscape development in semiarid regions, the case of Malayer University campus in Iran. *Environment, Development and Sustainability*, *22*(2), pp.1579-1598.

Salam, A., 2024. Internet of things for water sustainability. In *Internet of Things for Sustainable Community Development: Wireless Communications, Sensing, and Systems* (pp. 113-145). Cham: Springer International Publishing.

Schroll, E., Lambrinos, J., Righetti, T. and Sandrock, D., 2011. The role of vegetation in regulating stormwater runoff from green roofs in a winter rainfall climate. *Ecological engineering*, *37*(4), pp.595-600.

Sheffield, J., Wood, E.F., Pan, M., Beck, H., Coccia, G., Serrat-Capdevila, A. and Verbist, K.J.W.R.R., 2018. Satellite remote sensing for water resources management: Potential for supporting sustainable development in data-poor regions. *Water Resources Research*, *54*(12), pp.9724-9758.

Seitz, C.M., Reese, R.F., Strack, R.W., Frantz, S. and West, B., 2014. Identifying and improving green spaces on a college campus: A photovoice study. *Ecopsychology*, *6*(2), pp.98-108.

Seymour, R.M., 2005, April. Capturing rainwater to replace irrigation water for landscapes: rain harvesting and rain gardens. In *Proc. of the 2005 Georgia Water Resources Conf., Athens, GA, The University of Georgia, Athens, Georgia*.

Sidhu, J.P., Hodgers, L., Ahmed, W., Chong, M.N. and Toze, S., 2012. Prevalence of human pathogens and indicators in stormwater runoff in Brisbane, Australia. *Water research*, *46*(20), pp.6652-6660.

Siwiec, E., Erlandsen, A.M. and Vennemo, H., 2018. City greening by rain gardens-costs and benefits. *Environmental Protection and Natural Resources*, *29*(1), pp.1-5.

Sojka, S., Younos, T. and Crawford, D., 2016. Modern urban rainwater harvesting systems: design, case studies, and impacts. *Sustainable water management in urban environments*, pp.209-234.

Song, Y., Du, X. and Ye, X., 2019. Analysis of potential risks associated with urban stormwater quality for managed aquifer recharge. *International Journal of Environmental Research and Public Health*, *16*(17), p.3121.

Steffen, J., Jensen, M., Pomeroy, C.A. and Burian, S.J., 2013. Water supply and stormwater management benefits of residential rainwater harvesting in US cities. *JAWRA Journal of the American Water Resources Association*, *49*(4), pp.810-824.

Suleiman, L., Olofsson, B., Saurí, D. and Palau-Rof, L., 2020. A breakthrough in urban rain-harvesting schemes through planning for urban greening: Case studies from Stockholm and Barcelona. *Urban Forestry & Urban Greening*, *51*, p.126678.

Taguchi, V.J., Janke, B.D., Herb, W.R., Gulliver, J.S., Finlay, J.C. and Natarajan, P., 2022. Wet Pond Maintenance for Phosphorus Retention.

Tian, S., 2011. Managing stormwater runoff with green infrastructure: Exploring practical strategies to overcome barriers in citywide implementation.

Van Leeuwen, J., Awad, J., Myers, B. and Pezzaniti, D., 2019. Introduction to urban stormwater: A global perspective. *Urban stormwater and flood management: Enhancing the liveability of cities*, pp.1-28.

Vargas, D.M., 2009. Rainwater harvesting: A sustainable solution to stormwater management.

Velasco-Muñoz, J.F., Aznar-Sánchez, J.A., Batlles-delaFuente, A. and Fidelibus, M.D., 2019. Rainwater harvesting for agricultural irrigation: An analysis of global research. *Water*, *11*(7), p.1320.

Wilbers, G.J., de Bruin, K., Seifert-Dähnn, I., Lekkerkerk, W., Li, H. and Budding-Polo Ballinas, M., 2022. Investing in urban blue–green infrastructure—Assessing the costs and benefits of stormwater management in a Peri-urban catchment in Oslo, Norway. *Sustainability*, *14*(3), p.1934.

Zhang, L., Ye, Z. and Shibata, S., 2020. Assessment of rain garden effects for the management of urban storm runoff in Japan. *Sustainability*, *12*(23), p.9982.

Zhang, X. and Hu, M., 2014. Effectiveness of rainwater harvesting in runoff volume reduction in a planned industrial park, China. *Water resources management*, *28*, pp.671-682.