Performance Evaluation of Recently Constructed Ponds for Flood Mitigation in Erbil City and Their Impacts on the Environment

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Graphical Abstract

Table 3: Different return times and 24-hour rainfalls for the Study Area.

Return Period (year)	Frequency Factor (K)	Maximum Probable precipitation(mm)
2	-0.15	43.57
5	0.74	59.98
10	1.32	70.84
50	2.61	94.74
100	3.15	104.85
200	3.70	114.91
500	4.41	128.20
1000	4.95	138.24

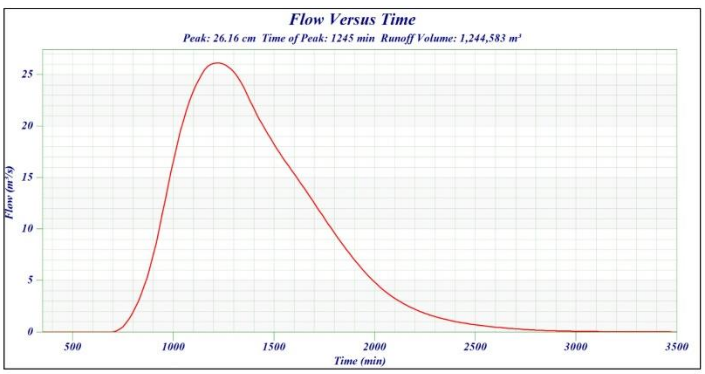


Figure 4: Grdjotyar Watershed Unit Hydrograph

Abstract

This study investigates the performance of 35 recent ponds (which are under tendering, under construction, and finished in Erbil City), focusing on their role in flood mitigation across 11 distinct catchment areas. The total storage capacity of these ponds is approximately 9,926,394 m³, significantly enhancing the city's ability to manage stormwater runoff and reduce flood risks. The Watershed Modeling System (WMS), along with the Soil Conservation Service Curve Number (SCS-CN) method, was utilized for hydrological modeling to evaluate runoff behavior and water retention performance. Calculated Retention Capacity Ratio (RCR) values vary from as low as 21 % in the smallest system to 136 % in the Kasnazan catchment, with Chamarga similarly exceeding full capacity at 131 %. These over-capacity networks not only attenuate peak flows but also promote groundwater recharge, improve downstream water quality by trapping sediments and nutrients, and create valuable aquatic and riparian habitats. Our findings demonstrate the multifaceted benefits of high-capacity retention ponds and provide a replicable model for integrating green infrastructure into urban planning to build flood resilience and sustainable water management in rapidly urbanizing regions.

Keywords: Catchment Areas, Hydrologic Modeling, Groundwater Recharge, Biodiversity Conservation, WMS.

1. Introduction

In recent years, floods have become a common phenomenon globally. Climate change and a decrease in impermeable surfaces driven by growing populations are the main causes (Ozkan and Tarhan, 2016). As cities expand and populations increase, the risk of natural disasters like floods also rises. Urban areas, particularly residential zones, are highly vulnerable to flooding. This threat is even more pronounced in regions affected by climate change, where developing countries often bear the greatest impact (Mustafa et al., 2025). The conversion of bare ground, farmyards, and vegetation into grading surfaces and concrete significantly impacts flooding and hydrological processes. Hazards related to climate, weather, and water are becoming more frequent and severe due to climate change. Flooding is now considered the worst calamity compared to other disasters such as earthquakes and typhoons. Retention ponds are constructed basins primarily designed to lower peak flow during heavy rainfall. In addition to collecting excess water, bed load, and alluvial deposits from these processes, retention ponds may also reduce flooding risk by rerouting excess water and bedload around the pond, thereby decreasing the likelihood of flooding (Aziz and Muhammed, 2024). Political and economic issues, land use, urbanization, and climate change contribute to the increasing impermeable layers and urbanization in Iraq's Erbil Province. According to the study, urbanization has expanded since 2017, accompanied by a decline in farmland and green spaces and a rise in construction zones and shrub areas. Only in the last four years has the growth in infiltration areas and impermeable layers slowed. Geological, topographical, demographic, political, economic, and transportation factors are among those contributing to these shifts (Ahmed et al., 2024).

Erbil City has seen a tremendous population increase and built-up area expansion, which has placed a significant strain on the city's drainage system. The city has seen many floods in recent years (Aziz et al., 2023). (Mustafa et al., 2019) indicated that the land cover and land usage in Erbil City Center have changed significantly, and these changes have a significant impact on the rising frequency of flash floods. From 1984 to 2014, farming dropped in percentage from 64% to 32%, and vegetation from 31% to 3%. There was a significant increase in the surface areas of naked soil and impermeable surfaces from 1% to 31% and from 5% to 35%, respectively. Hydrological information from Kurdistan indicates that it is mostly Erbil City that bears the brunt of the flood destruction. Other causes of urban or stream floods are loss of green spaces, urban sprawl, and disposal of construction debris into drainage systems (Aziz et al., 2023). Constructed ponds are important for flood management and environmental sustainability in urban areas. The capture and subsequent storage of excess rainfall greatly reduce surface runoff and lower the risk of flooding during wet periods. They assist in flood prevention, infrastructure protection, and property damage reduction by holding large amounts of water. Besides, the ponds improve water quality and groundwater recharge through natural filtering mechanisms. Furthermore, constructed ponds contribute to nature, adding green spaces, places of recreation for communities, and habitats for local wildlife. According to Aziz et al. (2023), these ponds are effective in flood control and provide good ecological performance, integrating such natural solutions into urban planning, allowing for a decrease in flood risk and promoting sustainable urban development. Erbil City, due to both topography and geographic location, constitutes an additional vulnerability to flooding. Many seasonal wadis cross the city's flat, moderately sloped terrain and may undergo flash flooding during periods of heavy rainfall.

Flash floods begin swiftly, posing a serious hazard to life and extensive property damage (Sissakian et al., 2022). Al-Nassar and Kadhim (2021) analyzed flash floods in Iraq using European Centre for Medium-Range Weather Forecasts data and collected data from various stations. Three scenarios were envisioned using statistical techniques and a geographical information system (GIS) based on the longest duration of the rainfall storm in months, its depth, and the frequency of occurrence within a given month. Mustafa et al. (2019) used weather data in Climate Forecast System Reanalysis and that from the General Directorate of Meteorology and Seismology in the Kurdistan Province of Iraq to statistically analyze flash floods from high-intensity rainfall in Erbil City from 1980-1991 and from 1992-2022, using GIS for analyzing soils and land use. Gupta and Dixit (2022) demonstrated how GIS and remote sensing can be used to calculate the CN for the Assam region in India, helping to differentiate surface runoff caused by rainfall. A useful technique for tracking and analyzing the topography of the Earth is remote sensing, which makes use of satellite photos and aerial photography. Because it provides accurate and current data, it is essential for environmental research, disaster management, and resource monitoring. For example, Sentinel-2 satellite imagery offers extensive spatial and temporal coverage, making it highly valuable for flood prediction. Babu et al. (2024) demonstrated its effectiveness by integrating Sentinel-2 data with a VANET-MARL-based deep neural RNN model to enhance early flood prediction capabilities. Karthik et al. (2025) found that the Chaotic Artificial Hummingbird Optimizer (Ch-AHO) greatly increases the accuracy of flood predictions in Chennai when the Extended Elman Spiking Neural Network (ExESNN) is used. With an R2 value of 0.994 and an RMSE of 0.851, the model demonstrated a strong prediction performance through the use of climatological data and sophisticated preprocessing techniques like MaxAbsScaler. By overcoming the drawbacks of conventional techniques, this strategy offers a more dependable framework for disaster management in regions that are vulnerable to flooding. Venkatraman et al. (2023) introduced an Optimization-driven Deep Differential RecurFlowNet (ODD-RecurFlowNet) model for water quality prediction and classification. The model utilizes advanced preprocessing techniques and employs a logistic-based Giant Armadillo Optimization algorithm for feature selection. Achieving an accuracy of 98.01% and an RMSE of 0.039, the framework effectively addresses the nonlinearity and nonstationary inherent in water quality data. Sundarapandi et al. (2024) propose the Light Weighted Dense and Tree Structured Simple Recurrent Unit (LDTSRU) for flood prediction, which utilizes meteorological variables to enhance forecasting accuracy. By combining dense and tree-structured recurrent units, the model offers a computationally efficient and robust solution for real-time flood prediction, demonstrating potential for improving flood mitigation strategies.

In Erbil City, floods are primarily caused by heavy rainfall, blockages in drainage systems like inlets, sewers, and culverts, as well as obstacles in catchment areas. Other contributing factors include changes to natural water flow, design flaws in infrastructure, and improper waste disposal in drainage channels (Aziz et al., 2023). To protect Erbil City against future flood disasters, Aziz et al. (2023) emphasized the importance of a holistic flood management strategy that combines structural solutions, like construction ponds and creating new diversion channels, with non-structural measures such as maintaining storm sewers and clearing debris from catchment areas. Proper planning of new developments and infrastructure is also essential. This paper examines the role of recently constructed ponds in Erbil City, focusing on their ability to reduce flooding and their environmental benefits. The study highlights how these ponds contribute to sustainable urban management by improving groundwater recharge, enhancing water quality, and supporting local biodiversity. The research stands as the first complete study about constructed ponds in the Erbil City area because no previous investigations have been conducted in this region. The research provides a fresh evaluation through the implementation of WMS and SCS-CN methods to assess the flood risk reduction capabilities of these ponds. The research stands out because it unites flood mitigation assessment with ecological assessment and urban planning evaluation.

2. Materials and Methods

2.1. Study Area and Data Acquisition

Erbil City is the capital of Iraq's Kurdistan Region. According to the Universal Transverse Mercator (UTM) coordinate system, Erbil City is located between 426842.3 and 4019021.4 from the northeast and 402309.2 and 3996615.9 from the southwest. Figure 1 illustrates the maps of the study area. The most recent satellite picture shows that the region is around 700 km² in area. This city has around 930,389 residents, according to the most recent study conducted in 2015 (Mustafa et al., 2019). Erbil City is around 430 m above sea level and is located on a wide, comparatively level plain. Many temporary valleys, dry riverbeds that momentarily flood with water during intense rainfall, cross the city. The hilly terrain around the city adds to its diverse environment and impacts regional hydrological patterns. Erbil experiences hot, dry summers and warm, rainy winters, making it a semi-arid climate. Approximately 375 mm of rainfall on average each year, with almost all of the precipitation falling between November and April (Noori et al., 2024). The Kurdistan Region has a semi-arid climate. The summers in Erbil City are long and pleasant, while the winters are chilly and wet. The summer months of June through September have either extremely little or no precipitation. However, the rain starts to fall in October and lasts until the end of May. In addition, January is the coldest month of the year. The average annual temperature in this city is 21°C, with variations ranging from 7°C to 47°C. About 400 mm of precipitation falls on average each year, with 200 mm occurring in dry years and 650 mm in wet years (Hameed, 2017).

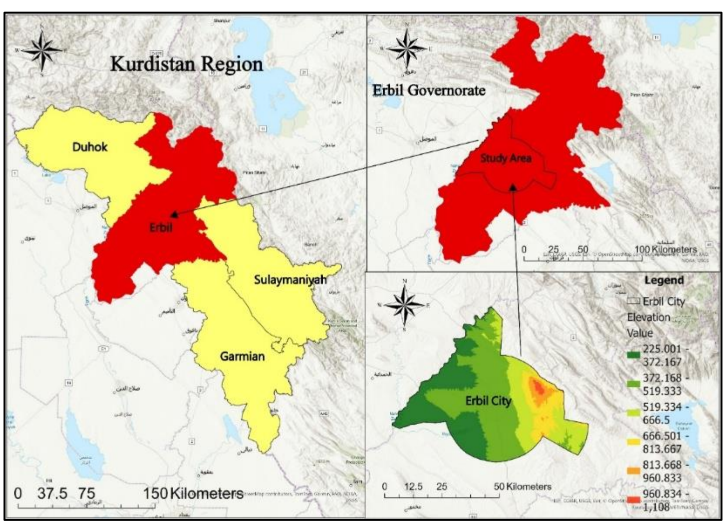


Figure 1: Study Area

Some areas in Erbil City, including Korean Village, Zereen City, Zilan Quarter, Roshnbiri Quarter, Daratu Sub-District, Bnaslawa region (Dashti Hawler), and Zhyan Quarter, experienced flooding in 2021 and 2022 (see Figure 2) (Aziz et al., 2023). The primary dataset for this study consists of maximum daily rainfall records obtained from the General Directorate of Meteorology and Seismology in the Kurdistan Region from 1992 to 1993 and from 2023 to 2024.

(a)

(b)

(c)

(d)

(e)

(f)

(g)

Figure 2: Locations in Erbil City that experienced flooding in 2021 and 2022 include (a) Daratu Culvert, (b) Roshnbiri-Daratu Culvert Upstream, (c) Roshnbiri-Daratu Culvert Downstream, (d) Zerin City Drainage Trench, (e) Roshnbiri Bridge, and (f, g) Korean Village Drainage Trench.

2.2. Work Methodologies

This study examines 11 recently flooded areas in Erbil City, evaluating the role of ponds in mitigating floods by managing the water flow. To achieve this, we utilize the WMS software and conduct hydrological investigations. Watersheds for 11 catchment regions were defined using the WMS 11.1 software. To improve the accuracy of the hydrological analysis, geospatial datasets such as the Harmonized World Soil Database v1.2, Global Land Cover Map, Worldwide Elevation Data (15.4 m resolution), and World Imagery were included. Figure 3 illustrates the hydrological catchment delineation and stream network analysis for the eastern watershed of Erbil City. Key geometrical and hydrological characteristics were examined for each of these catchments. These comprised, among other factors, the maximum flow slope, basin length, average overland flow, watershed area, slope, stream length, and stream slope, as shown in Table 1. The volume data for all 35 ponds were also obtained from the Directorate of Irrigation – Erbil

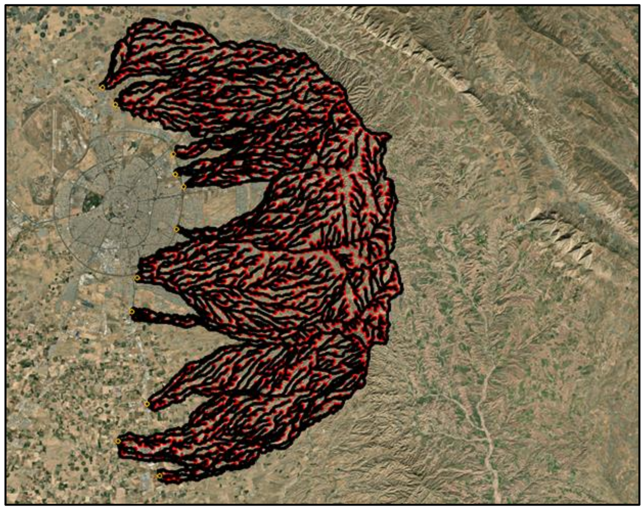


Figure 3: Hydrological Catchment Delination and Stream Network Analysis for Study Area

Table 1: Geometrical and Hydrological Characteristics of Catchment Areas

Catchment Parameter	Unit	Flooded Zones										
		Grd Jotyar	Permam	Hawleri Nwe1	Hawleri Nwe2	Hawleri Nwe3	Kasnazan	Bnslawa & Daratoo	Chamarga	Mortka	Qoshatpa 1	Qoshatpa 2
Area of Watershed	Km^2	50.49	66.33	14	15.4	19	28.7	175.38	47	32.8	84.53	24.96
Parameter	m	54425.84	51202.5	23614.35	39174.8	32586.49	62475.71	84778.97	78646.4	40601.3	75965.94	61612.15
Watershed Slope	m/m	0.0444	0.0698	0.0291	0.086	0.0514	0.1077	0.063	0.0813	0.0376	0.0485	0.0505
Average Overland Flow	m	397.27	505.06	631.66	503.94	612.26	478.68	246.17	241.13	232	215.27	213.27
Basin Length	m	17391.5	19384.94	19360.8	13688.95	11713.45	18054.1	23751.13	22539.61	13402.02	22734.9	19534.7
Maximum Flow Slope	m/m	0.0243	0.029	0.0216	0.0326	0.0294	0.0261	0.0186	0.014	0.0157	0.0156	0.0182
Maximum Stream Length	m	18865.3	22656.65	6947.96	15568.48	11885.09	22763.79	32630.25	29164.24	15450.61	29007.58	23569.13

Table 1: Geometrical and Hydrological Characteristics of Catchment Areas (Cont.)

maximum stream Slope	m/m	0.0205	0.0253	0.0161	0.0272	0.0246	0.0245	0.0152	0.0134	0.0147	0.0151	0.0167
Mean Basin Elevation	m	536.67	644.5	557.52	686.5	608.5	796.94	631.88	668.67	504.29	548.13	550.46
CN Number		62.9298	63.8014	74	69.8208	66.2959	63.6117	66.373	65.8846	76.1778	69.4183	66.9242

2.3. Retention Capacity Ratio (RCR)

The RCR serves as a unified, dimensionless metric that evaluates the performance of constructed ponds in flood mitigation studies. The RCR is calculated as the percentage ratio of total pond storage volume across all catchment ponds to the modeled runoff volume from a specific rainfall event.

$$RCR\ (\%) = \left(\frac{Total\ pond\ storgevolume}{Modeledrunoff\ volume} \right) * 100$$

The RCR indicates that pond capacity matches runoff production at 100% but exceeds 100% when the pond network stores more water than the received natural runoff. The RCR provides direct scale-independent comparisons between catchments through its storage-to-runoff ratio, which reveals system capacity for extreme event management and identifies situations where pond infrastructure exceeds basic flood attenuation capabilities.

3. Results and Discussions

3.1. Rainfall and Runoff Data Analysis

Maximum daily rainfall data from 1992 to 2024, obtained from the General Directorate of Meteorology and Seismology in the Kurdistan Region, provided the basis for studying flood peak discharge in Erbil City. Maximum daily data is utilized rather than daily or monthly averages to better represent short-term peak rainfall occurrences during storms (Aziz et al., 2023). Table 2 shows the maximum daily rainfall

Table 2: The Maximum Daily Rainfall at Erbil Gauge Station from 1992 to 2024

Year	Maximum Daily Rainfall (mm)	Year	Maximum Daily Rainfall (mm)	Year	Maximum Daily Rainfall (mm)
1992-1993	79	2003-2004	41.4	2014-2015	51
1993-1994	57.9	2004-2005	40.6	2015-2016	55.8
1994-1995	41.7	2005-2006	34	2016-2017	42.4
1995-1996	75.7	2006-2007	103.9	2017-2018	31.4
1996-1997	23.9	2007-2008	38	2018-2019	51.1
1997-1998	35.8	2008-2009	41	2019-2020	59.5
1998-1999	36.8	2009-2010	28.2	2020-2021	36.8
1999-2000	28.3	2010-2011	33.8	2021-2022	59.2
2000-2001	46.4	2011-2012	67	2022-2023	38.8
2001-2002	48.3	2012-2013	29.4	2023-2024	63.9
2002-2003	59.2	2013-2014	71.8		

In extreme value analysis, especially when modeling hydrological extremes like maximum daily rainfall, floods, and peak discharges, the Gumbel distribution is important. This statistical method makes it easier to estimate rainfall value corresponding to different return periods (for example, 2, 5, 10, 25, 50, 100, 200, 500, and 1000 years) by examining record maximum daily rainfall data, from 1992–1993 to 2023–2024, as illustrated in Table 3. In this study, we select a 100-year return period to calculate the Maximum Daily Runoff. This return period is chosen to account for extreme rainfall events and ensure the reliability of hydrological assessments. Based on Table 3, the maximum probability of rainfall for a 100-year return period in this study is 104.85 mm.

Table 3: Different return times and 24-hour rainfalls for the Study Area.

Return Period (year)	Frequency Factor (K)	Maximum Probable precipitation(mm)
2	-0.15	43.57
5	0.74	59.98
10	1.32	70.84
50	2.61	94.74
100	3.15	104.85
200	3.70	114.91
500	4.41	128.20
1000	4.95	138.24

The HEC-1 model was used for rainfall-runoff simulation, while precipitation data was incorporated into the analysis. The SCS-CN method was used to estimate runoff parameters (Mishra and Singh, 2013). Based on land use, soil type, and hydrologic conditions, each catchment's CN was estimated, providing an accurate basis for estimating runoff potential (Sahu et al., 2020).

These features influence runoff production, flow accumulation, and peak discharge estimation, and they are crucial to understanding the hydrological response of each watershed. The time of concentration was calculated to evaluate flow dynamics, and hydrological models were employed to determine the total runoff volume. WMS and HEC-1 models were also utilized to create unit hydrographs for each catchment area based on the Type II 24-hour rainfall distribution. Figures 4 to 14 show the unit hydrographs produced for each of the 11 watersheds using the HEC-1 models.

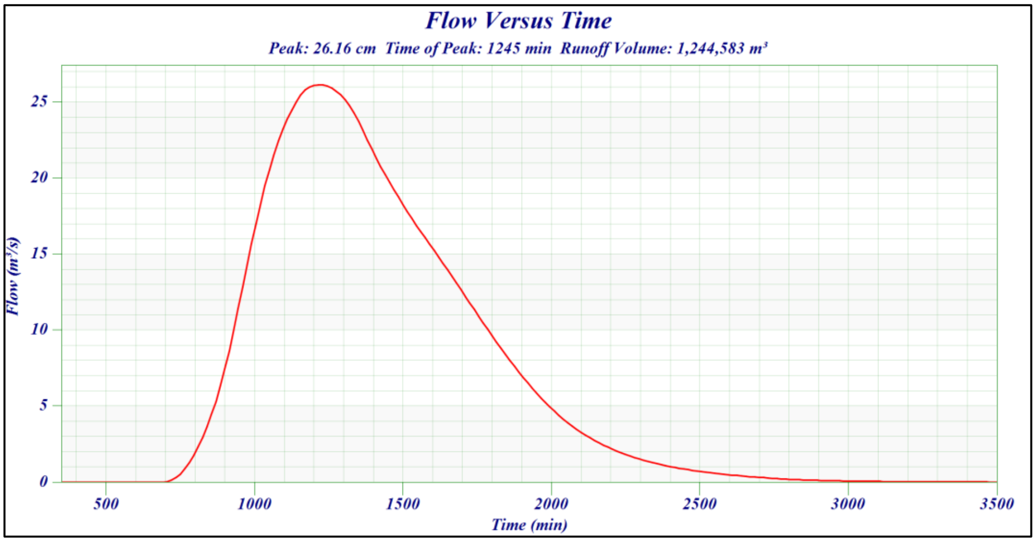


Figure 4: Grdjotyar Watershed Unit Hydrograph

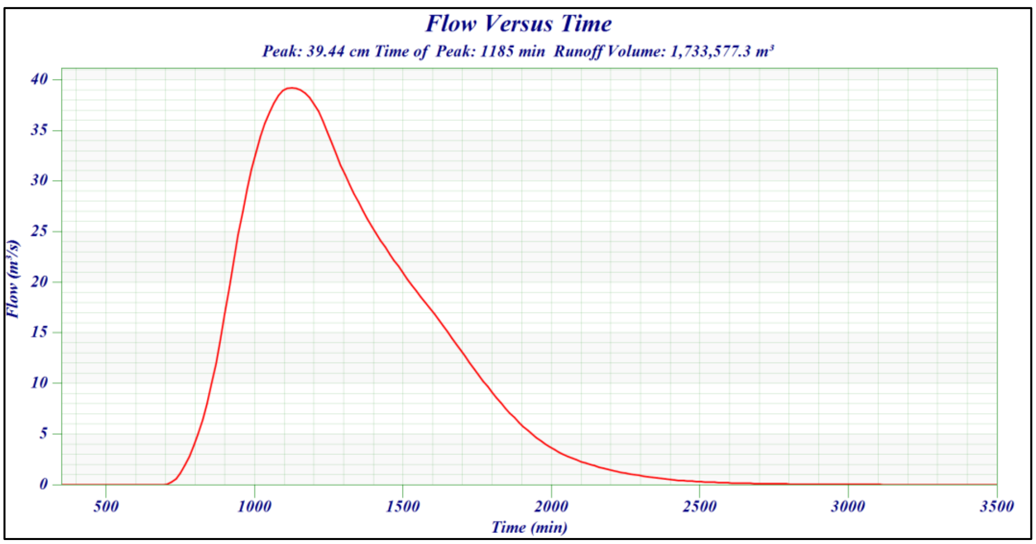


Figure 5: Permam Watershed Unit Hydrograph

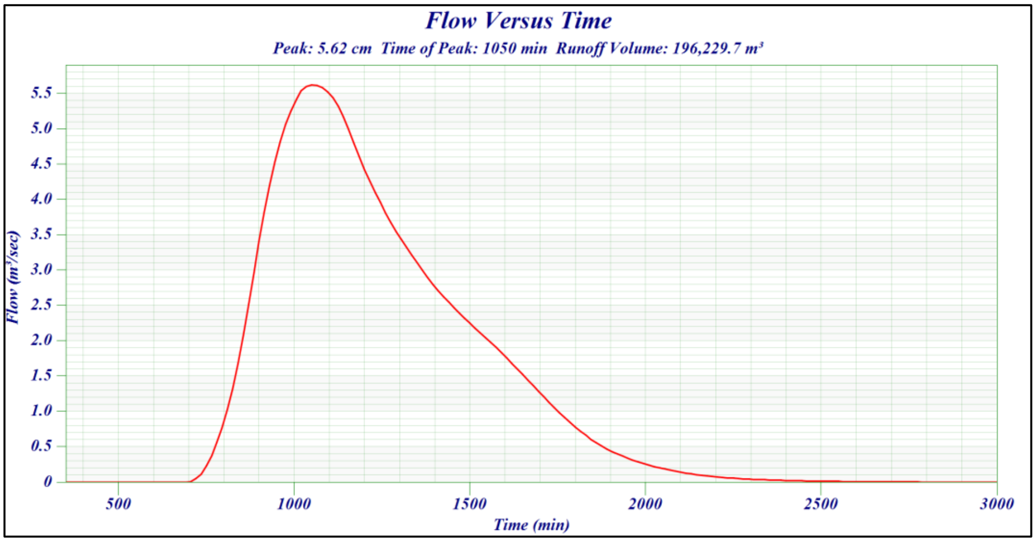


Figure 6: Hawleri New 1 Watershed Unit Hydrograph

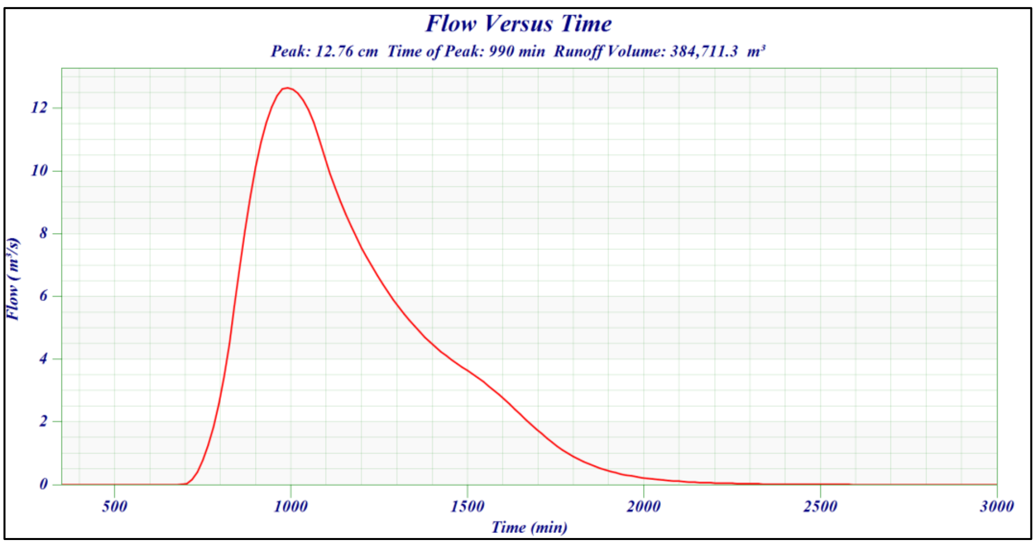


Figure 7: Hawleri New 2 Watershed Unit Hydrograph

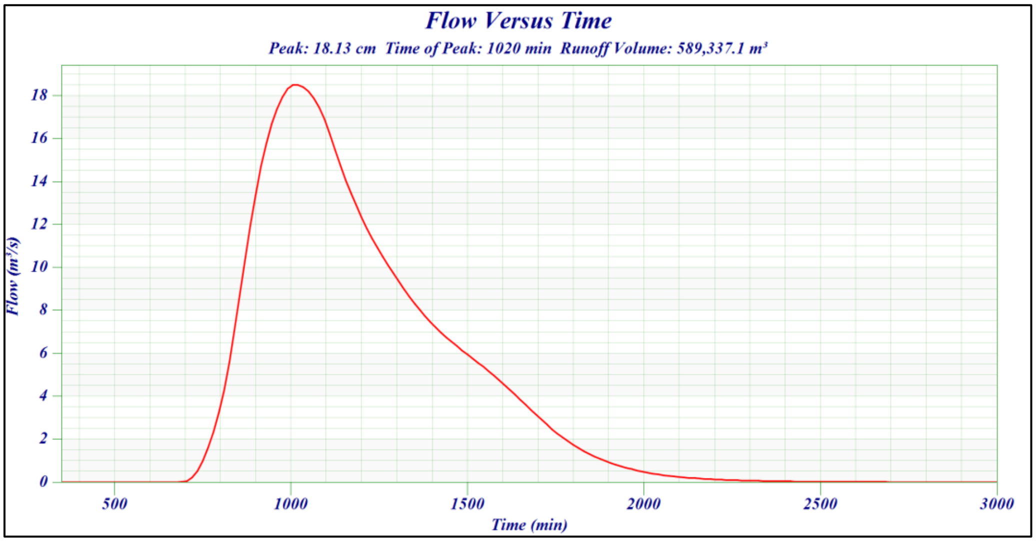


Figure 8: Hawleri New 3 Watershed Unit Hydrograph

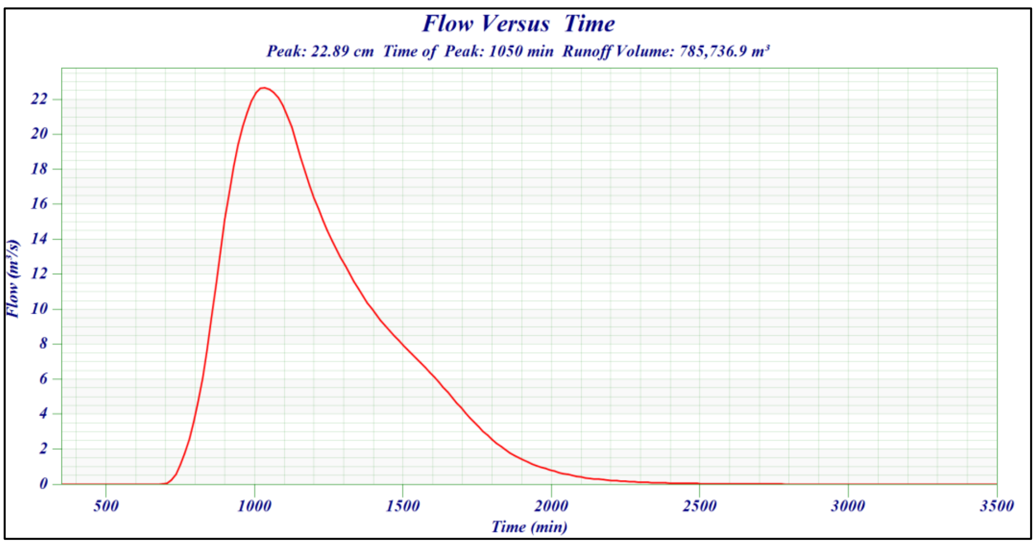


Figure 9: Kasnazan Watershed Unit Hydrograph

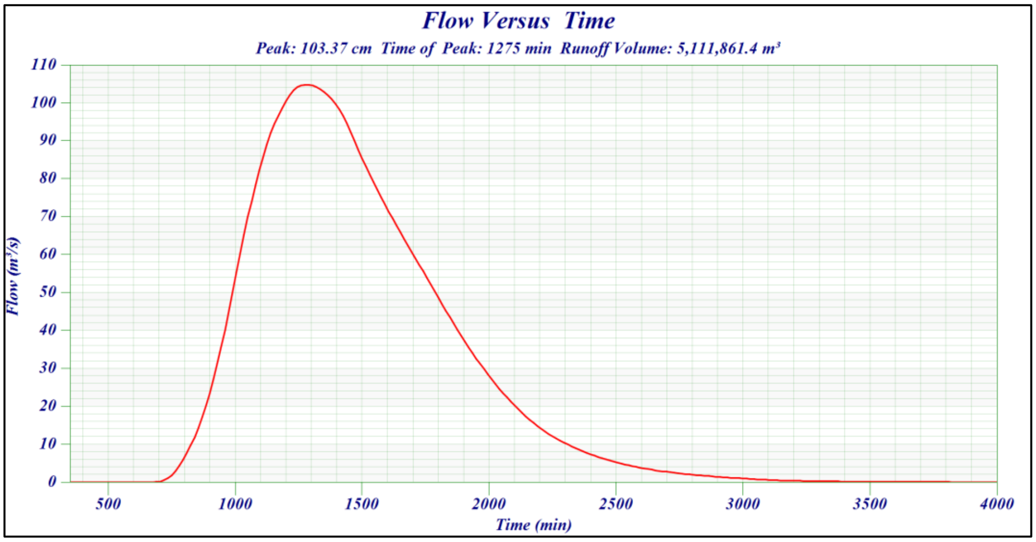


Figure 10: Bnslawa and Daratoo Watershed Unit Hydrograph

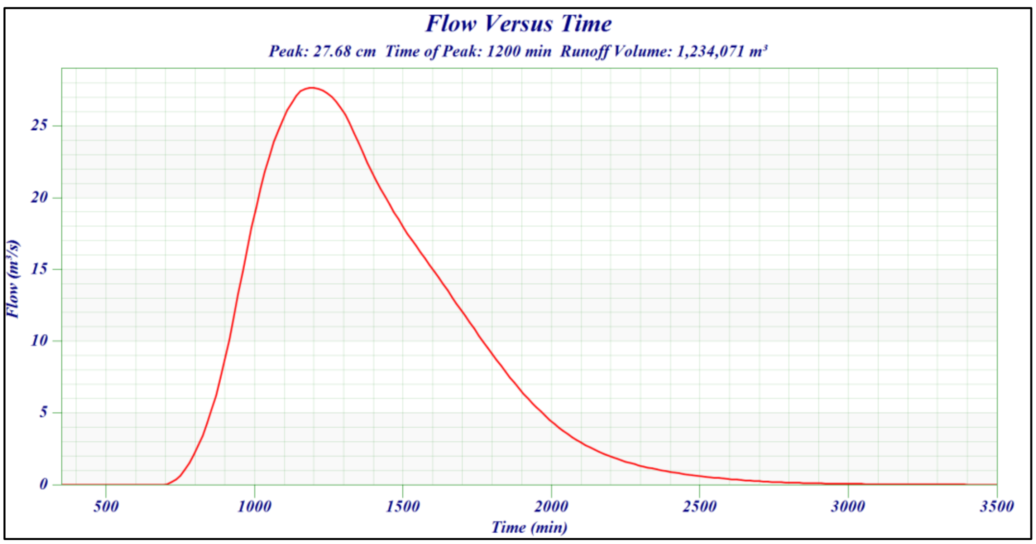


Figure 11: Chamarga Watershed Unit Hydrograph

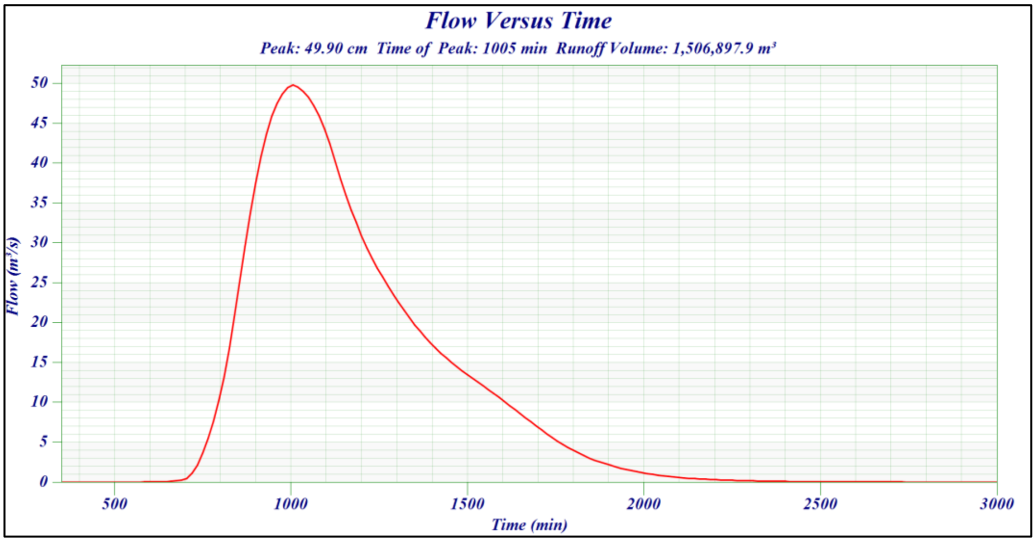


Figure 12: Mortka Watershed Unit Hydrograph

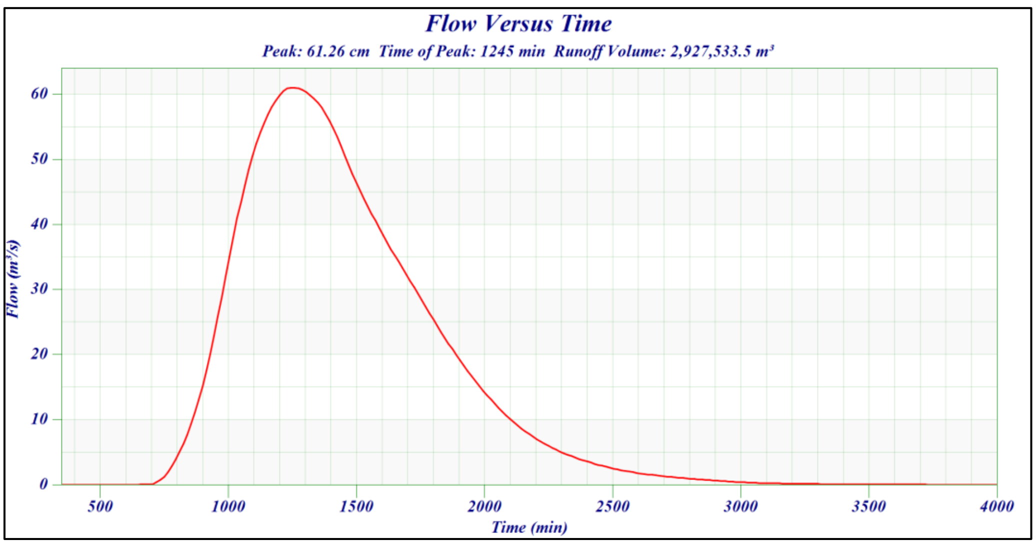


Figure 13: Qoshtapa 1 Watershed Unit Hydrograph

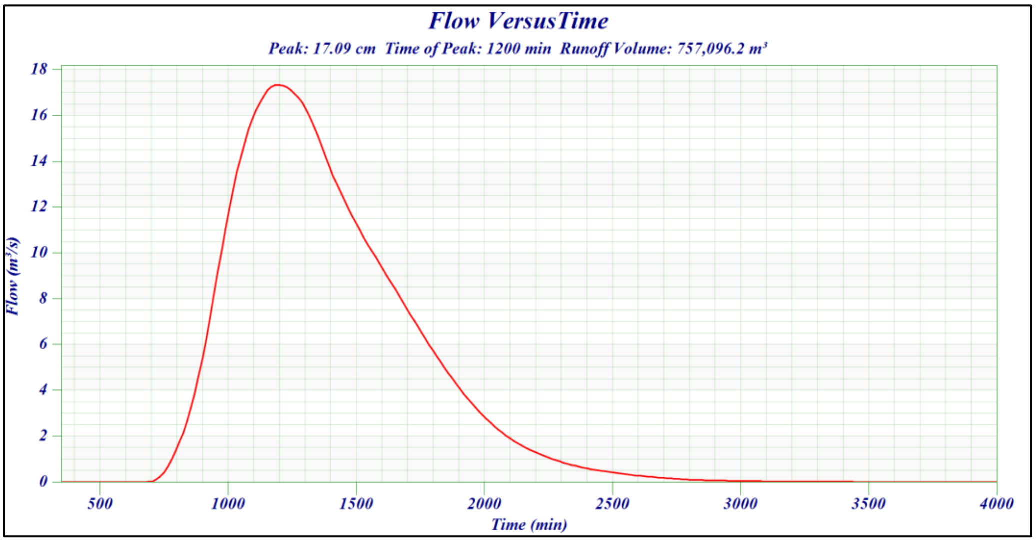


Figure 14: Qoshtapa 2 Watershed Unit Hydrograph

3.2. Evaluating the Role of Ponds in Runoff Reduction and Flood Mitigation

This study evaluates the effectiveness of ponds in reducing peak flow and mitigating floods within the study area. Two scenarios were considered to assess their impact: (1) when the pond construction is complete and the storage is empty, and (2) when the ponds are filled to their dead storage level. By analyzing these scenarios, the study aims to determine how pond storage influences runoff volume and peak discharge. The first scenario examines the capacity of empty ponds to retain excess runoff, thereby reducing flood risks. In contrast, the second scenario assesses the extent to which ponds, when at full dead storage capacity, can still contribute to flood mitigation. This evaluation provides valuable insights into the role of ponds as a sustainable flood management strategy within the study area. As shown in Table 4.

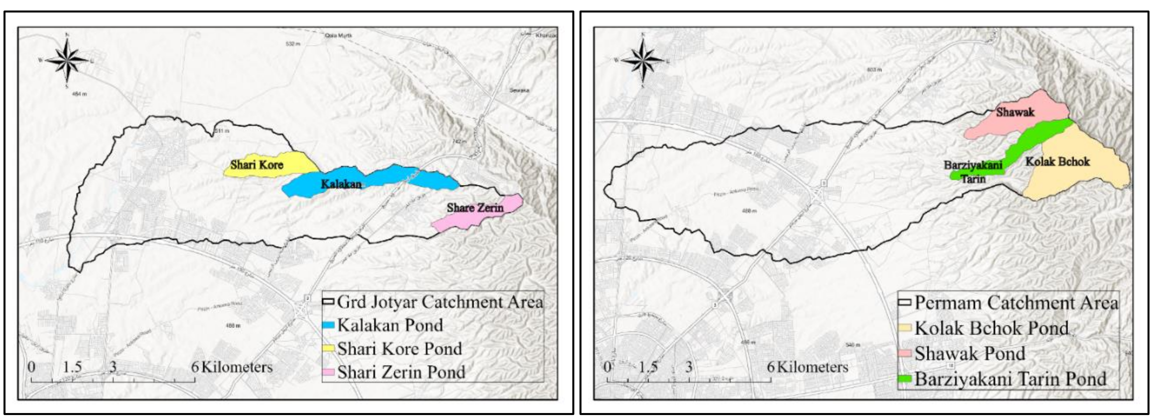
Table 4: Runoff Volume for Catchment Area and Pond Construction Effect in Reducing Floods

Catchment Name	Runoff Volume (m³)	Total Pond Storage (Scenario 1) (m³)	% Retention Capacity (Scenario 1)	Total Pond Storage (Scenario 2) (m³)	% Retention Capacity (Scenario 2)
Grdjotyar	1,244,583	560,735	45	510,922	41
Permam	1,733,577	1,348,546	78	1,297,546	75
Hawleri Nwe1	196,230	212,864	108	177,864	91
Hawleri Nwe2	384,711	141,755	37	125,755	33
Hawleri Nwe3	589,337.10	140,404	23.82	105,237	18
Ksnazan	785,737	1,068,000	136	987,719	126
Bnslawa and Daratoo	5,111,861	3,195,490	63	2,858,326	56
Chamarga	1,234,071	1,614,428	131	1,152,706	93
Mortka	1,506,897.90	340,000	22.56	315,000	21
Qoshtapa 1	2,927,534	930,571	32	772,775	26
Qoshtapa 2	757,096	373,601	49	308,601	41

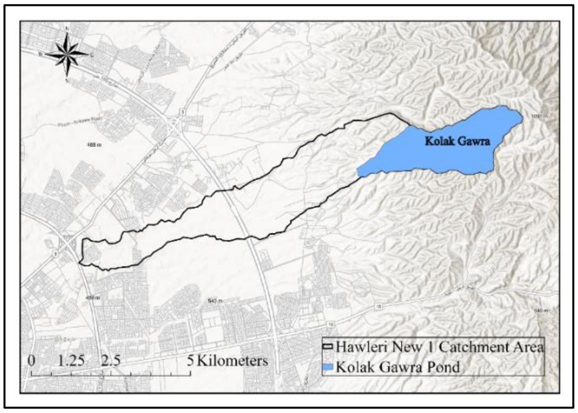
The RCR results for thirty-five ponds distributed across 11 catchments appear in Table 4 under two storage conditions, which include full design capacity (Scenario 1) and reduced capacity (Scenario 2). The flood-mitigation performance of Girdjotyar remains moderate because its RCR decreases only slightly from 45 % to 41 % even when storage capacity is limited. The effectiveness of Permam remains high because its RCR decreases only slightly from 78 % to 75 %. The storage capacity of Hawleri Nwe

1 exceeds its design limits because it reaches 108 % RCR during full capacity operation and 91 % RCR when capacity is reduced, which demonstrates its potential for groundwater recharge. The retention capacity of Hawleri Nwe 2 remains moderate at 37 % to 33 %, while Hawleri Nwe 3 shows the lowest values at 23.8 % to 18 %, which indicates these systems need additional flood-control systems. The storage networks of Kasnazan and Chamarga demonstrate outstanding overcapacity performance through their retention rates of 136 % to 126 % and 131 % to 93 %, respectively. The RCR values for Mortka (22.5 % to 21 %) and Qoshtapa sub-catchments (32 % to 26 % in Qoshtapa 1; 49 % to 41 % in Qoshtapa 2) show potential for design improvements or supplemental flood-mitigation approaches. The combined data shows that properly designed pond systems effectively reduce runoff, while catchments with RCR values below 30 % should implement additional storage solutions or flood-mitigation approaches. Ratios above 100 % reflect that, in their current configuration, the pond systems can capture and store a greater volume than the baseline runoff, underscoring their over-capacity potential.

Figures 15 illustrate the distribution of ponds within each catchment, created using ArcGIS Pro. These maps provide a spatial representation of pond locations in their respective catchment areas, highlighting their role in flood mitigation and water management.



(a) (b)


Kolak Gawra
Hawleri New 1 Catchment Area
Kolak Gawra Pond
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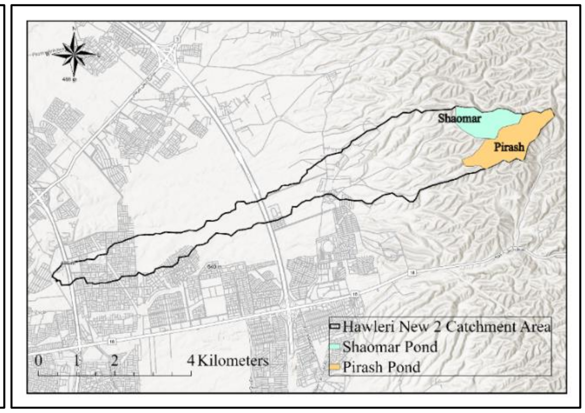
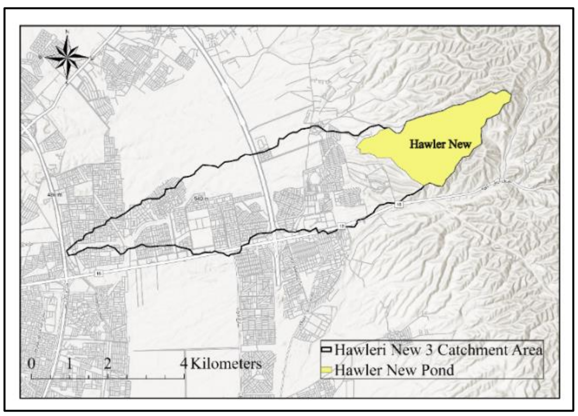
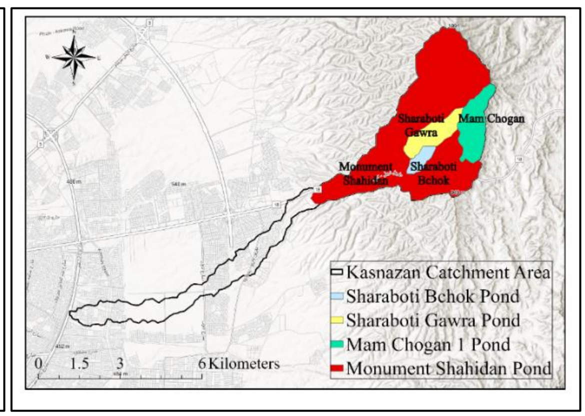
(c)


Shaomar
Pirash
Hawleri New 2 Catchment Area
Shaomar Pond
Pirash Pond
0 1 2 4 Kilometers

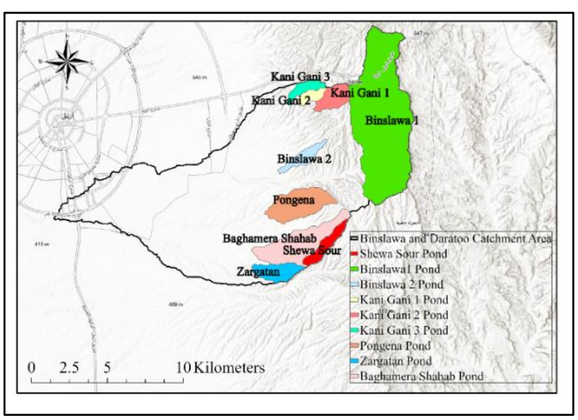
(d)


Hawler New
Hawleri New 3 Catchment Area
Hawler New Pond
0 1 2 4 Kilometers

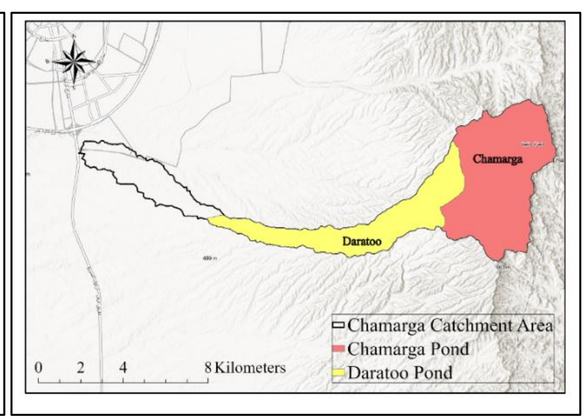
(e)


Sharaboti Gawra
Mam Chogan
Monument Shahidan
Sharaboti Bchok
Kasnazan Catchment Area
Sharaboti Bchok Pond
Sharaboti Gawra Pond
Mam Chogan 1 Pond
Monument Shahidan Pond
0 1.5 3 6 Kilometers

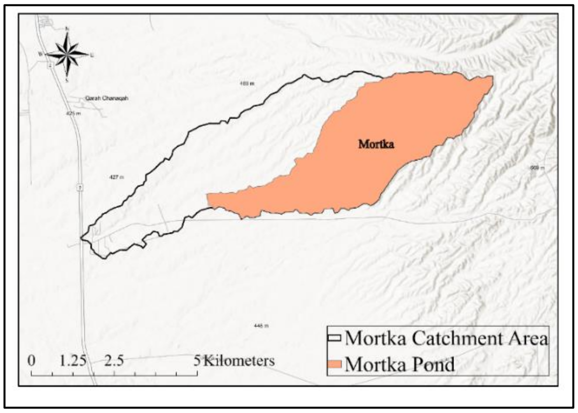
(f)

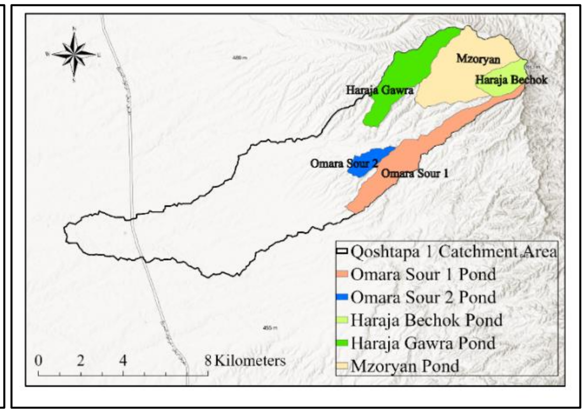

Kani Gani 3
Kani Gani 2
Kani Gani 1
Binslawa 1
Binslawa 2
Pongena
Baghamera Shahab
Shewa Sour
Zargatan
Binslawa and Daratoo Catchment Area
Shewa Sour Pond
Binslawa1 Pond
Binslawa 2 Pond
Kani Gani 1 Pond
Kani Gani 2 Pond
Kani Gani 3 Pond
Pongena Pond
Zargatan Pond
Baghamera Shahab Pond
0 2.5 5 10 Kilometers

(g)

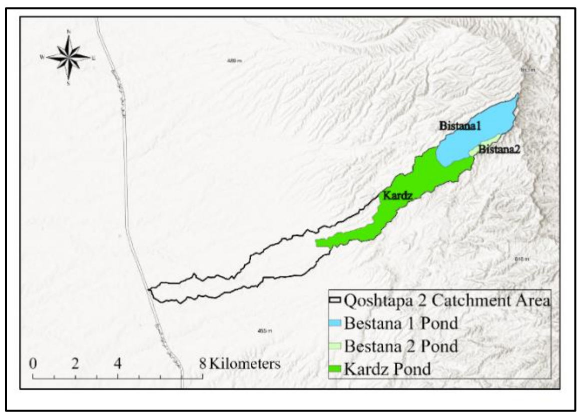

Chamarga
Daratoo
Chamarga Catchment Area
Chamarga Pond
Daratoo Pond
0 2 4 8 Kilometers

(h)





(i) (j)



(k)

Figure 15: Locations of Ponds within 11 Catchments Area (a): Grdjotyar, (b): Permam, (c): Hawleri New 1, (d): Hawleri New 2, (e): Hawleri New 3, (f): Kasnazan, (g): Bnslawa and Daratoo, (h): Chamarga, (i): Mortka, (j): Qoshtapa 1, (k): Qoshtapa 2.

3.3. Environmental Impact

The many effects of built ponds on the environment, ecology, and economics are shown in Table 5. These ponds are essential for boosting biodiversity, lowering soil erosion, promoting groundwater recharge, and improving water quality. They also aid in changing land use, expanding irrigated areas, and creating recreational possibilities. Ponds provide major economic advantages as well since they help prevent flooding, lessen the financial losses caused by natural calamities, and increase agricultural output and tourism. However, appropriate administration and monitoring are crucial to maximizing their advantages and reducing any possible hazards. A thorough summary of these effects is provided in the table below:

Table 5: Environmental, Ecological, and Economic Impacts of Constructed Ponds

No.	Parameter	Description	Citation
1	Water Quality	Pond management is vital for the quality of stormwater produced in urban areas. These ponds help purify water and decrease floods by filtering pollutants and contamination. If not kept properly, however, ponds could eventually become polluted by chemicals, such as chemical fertilizers or heavy metals. Nutrients can then run off and pollute streams, which can lead to eutrophication and harmful algae blooms.	(Grogan et al., 2023)
2	Biodiversity	Constructing a pond can greatly increase local biodiversity, providing birds, amphibians, and aquatic plants with more habitats. These bodies of water also serve as food, shelter, and habitat for birds, enhancing the ecological wellness of the area. However, native species diversity and abundance may be affected by changes to habitat structure and water chemistry. Ponds can also serves as a habitat for invasive species,	Petit-Prost et al., (2024)

		threatening the habitat of native flora and fauna and reducing biodiversity. To avoid these risks and ensure a positive effect on the local ecology, continuous monitoring and management are needed.	
3	Soil Erosion & Sedimentation	Building ponds can significantly impact water storage capacity and environmental health by affecting sediment movement and soil erosion. Unmanaged ponds can cause excessive sedimentation, reducing water storage capacity and affecting flooding regulation. Recent studies emphasize monitoring and controlling sedimentation in constructed ponds to minimize negative impacts.	Cuenca-Cambronero et al., (2023)
4	Vegetation & Land Use	Ponds can dramatically change local vegetation and land use patterns by modifying hydrology and drawing plant species from wetter landscapes. And that can result in wetland species replacing the existing vegetation in urban areas, pond construction can further cause land-use change by lowering access to agricultural land and generating economic demand. Ponds have become focal points for research that explores their dual role in shaping vegetation through design and management, as well as the potential for land use change—both aquatic and terrestrial.	Petit-Prost et al. (2024) Cuenca-Cambronero et al., (2023)
5	Increasing Irrigated Areas	The combination of climate change and drought, together with oil production and rising car usage in Erbil City, has resulted in reduced green and agricultural land while creating hotter	Aziz et al., (2023)

		temperatures and groundwater problems, and desertification. The agriculture sector has been negatively affected by these changes, which have resulted in desertification and decreased livestock numbers, and reduced crop yields. Research shows that ponds located in dry or semi-arid regions enhance agricultural productivity while preventing desertification through their ability to collect rainfall and support plant development.	Adamo et al., (2018)
6	Groundwater Recharge	The new master plan for Erbil City features multiple ponds in reconnaissance areas, which serve to control rainfall and surface runoff while supporting groundwater recharge. The ponds receive essential support from ArcGIS Pro software in regions where water resources are limited. Surface water can penetrate soil through these ponds, which speeds up the process of water level replenishment. The implementation of recharge ponds has proven effective in Colorado and Iraq by increasing water table levels. The success of water availability depends on proper planning and maintenance practices.	Deng and Bailey(2022) Hassan et al (2023)
7	Recreation	The ponds in Erbil City provide recreational opportunities to both residents and visitors, which improves the quality of life in the neighborhood. The ponds increase property values because they affect both parks and residential areas. The Kurdistan governorate established multiple ponds to develop tourism and recreational activities that promote community	(Cuenca-Cambronero et al., 2023) Cuenca-Cambronero et al., (2023)

		participation. Research indicates that environmental management should be integrated with recreational design to achieve maximum pond benefits.	
8	carbon sequestration	Constructed ponds significantly contribute to carbon sequestration by acting as carbon sinks. These ponds enhance organic carbon burial in sediments due to their small size and low oxygen levels, which slow down decomposition processes. Additionally, the vegetation in and around constructed ponds plays a crucial role in capturing atmospheric carbon dioxide. Studies have shown that strategically designed and managed ponds can sequester substantial amounts of carbon, comparable to larger aquatic systems.	Guo et al., (2025)
9	Economic Benefits	In 2021 and 2022, there were several floods in Erbil City, which resulted in substantial damage and 12 fatalities. The Crisis Coordination Center (JCC) and the Erbil government recovery team made an effort to help residents and lessen the effects. Their assistance for the three floods totaled 7,731,072,500 Iraqi dinars. Building ponds offers several financial advantages, such as regulating rainfall, lowering insurance costs, and lowering flood recovery costs. By increasing food output, decreasing farmers' income, and supplying consistent water supplies, it also improves irrigation, tourism, and fish farming. Ponds may also give people a source of revenue and leisure through boating, bird watching, fish sales, and picnics.	Aziz et al., (2023) Cuenca-Cambronero et al., (2023)

The exceptionally high retention-capacity ratios observed in Kasnazan (136 %) and Chamarga (131 %) where pond storage exceeds modeled runoff, underscore the ability of well-designed retention ponds to provide more than complete flood attenuation in urban catchments. These results corroborate a growing body of evidence that green-infrastructure measures, including high-capacity stormwater ponds, play a vital role in enhancing urban flood resilience by not only attenuating peak flows but also by enabling surplus water capture, groundwater recharge, and improved water quality in rapidly urbanizing environments. Throne (2020) articulates how green infrastructure solutions, such as urban wetlands and ponds, can significantly mitigate flood risks by capturing and retaining stormwater runoff during intense rainfall events. Their analysis indicates that integrating these natural systems into urban planning not only addresses immediate flooding concerns but also promotes long-term sustainability within urban ecosystems. Moreover, the multifunctional benefits of constructed ponds extend well beyond immediate flood control. These ponds contribute to groundwater recharge and enhance local biodiversity, as highlighted by Manoj and Padhy (2015), who discuss how constructed wetlands can filter pollutants, improve water quality, and create vital habitats for various flora and fauna. This function is particularly crucial in urban areas where natural habitats are diminishing due to development. The ecological enhancements provided by these ponds not only support wildlife but also improve the overall health of urban ecosystems, creating a more resilient environment. Additionally, the presence of these ponds serves social and economic functions, providing recreational spaces for communities. As Cuenca-Cambronero et al. (2023) have documented, such green spaces can lead to increased property values and foster community engagement through activities like fishing, birdwatching, and picnicking. These benefits are compounded by the psychological advantages associated with green spaces, including enhanced well-being and community cohesion. However, the implementation of constructed ponds must be approached with careful planning and management to mitigate potential adverse effects such as habitat disturbance and water contamination.

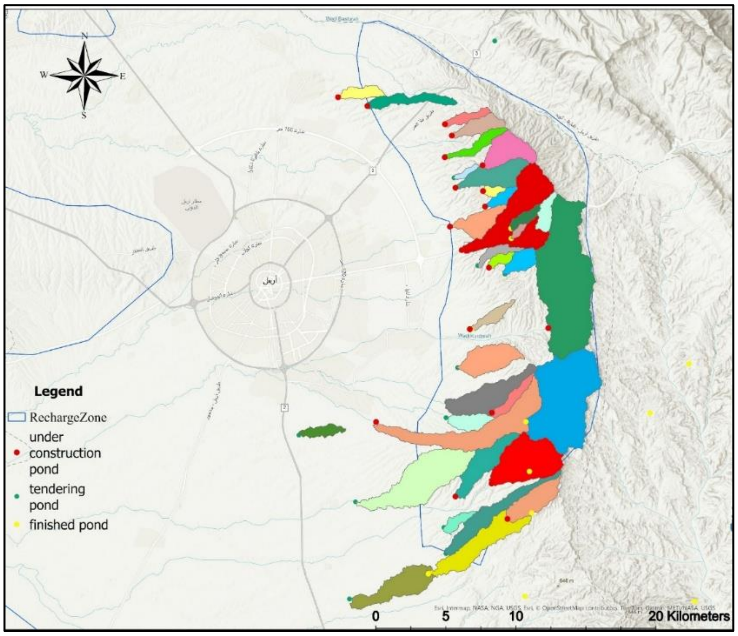


Figure 16: Integrated Recharge Zone and Pond Development Map – Erbil Region

4. Conclusions

This study assessed the performance of 35 newly constructed ponds distributed across 11 catchments in Erbil City using the WMS and SCS-CN methods. The RCR ranged from 21 % in the least effective systems to 136 % in Kasnazan, where pond storage exceeded modeled runoff, and Chamarga reached a similar RCR of 131 %. The current pond system capacity exceeds baseline runoff volumes according to ratios above 100 %, which indicates their potential for overcapacity. The RCRs maintained their strength at 75 % in Permam and other ponds when storage capacity was reduced, thus showing both strong pond network design and storage sensitivity. These outcomes significantly exceed previous findings by Yoshikawa et al. (2010), who reported an average reduction of 75% in peak flood flows. The constructed ponds in Erbil thus provide strong evidence of their superior capacity for flood mitigation.

In addition to hydrological benefits, the ponds contributed to a measurable improvement in the local environment. Specifically, they enhanced overall environmental quality in Erbil City by approximately 13%, as indicated by increases in green spaces, improved microclimatic conditions, and ecological restoration. The ponds supported a 10% to 15% expansion in urban green areas, facilitated groundwater recharge, and contributed to better air quality. Moreover, their presence has been associated with localized reductions in temperature and increases in relative humidity, thereby promoting a more stable and livable urban climate.

These findings align with studies by Ahmadisharaf et al. (2021), who demonstrated the flood control and pollutant reduction effectiveness of large retention ponds, and Ardeshir et al. (2013), who confirmed the value of hydrologically optimized detention ponds. Griffiths et al. (2024) further emphasized the multifunctionality of nature-based solutions, noting their contributions to flood mitigation, biodiversity enhancement, and ecosystem services.

The study also identified certain limitations. The reliance on a single rainfall gauge may constrain spatial representativeness, while sediment accumulation over time may reduce pond efficiency. These challenges underscore the importance of routine monitoring, effective sediment management, and enhanced spatial data coverage. Future research should incorporate advanced hydrological modeling and IoT-based monitoring systems to enable real-time flood forecasting and performance evaluation.

In conclusion, this study provides compelling evidence that recharge ponds are a highly effective and scalable nature-based solution for urban flood management. Their multifunctional contributions—including flood mitigation, groundwater recharge, green infrastructure expansion, microclimate regulation, and biodiversity support—underscore their role in promoting environmental sustainability and enhancing urban climate resilience in semi-arid regions like Erbil.

5. Conflict of interest

There are no conflicts of interest by the authors regarding the publication of this research.

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