EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology, 2025, 26(2), 363–378
https://doi.org/10.12912/27197050/199325
ISSN 2719–7050, License CC-BY 4.0

Received: 2024.11.20
Accepted: 2024.12.27
Published: 2025.01.01

Integrated approach for assessing suitable location of the subsurface dams in the Al Kur watershed, Iraq

Mustafa Najdat Kasim[1*], Imad Habeeb Obead[1], Ibtehaj Taha Jawad[1]

[1] Civil Engineering Department, University of Babylon, Babylon, Iraq
* Corresponding author's e-mail: inm.ame@atu.edu.iq

ABSTRACT

This study used advanced hydrological models, such as AGWA2 with SWAT and KINEROS2 extensions, to assess the water basins that lack observed field measurements. This approach provides a practical understanding of data systems for ungauged watersheds. Consequently, the research aimed to evaluate and identify suitable sites for subsurface dams in the Al Kur basin in northern Iraq. Additionally, this will contribute to the development of these areas, creating opportunities for the return of residents and sustainable organization of population and agricultural activities after two decades of unstable conditions as a result of conflicts and military operations where local governments are actively working towards achieving this goal. The analytical hierarchy process (AHP) identified Basin No. 20 as the most suitable location based on multiple decision criteria, including evapotranspiration, percolations, water yield, transmission losses, and sediment yield, which were obtained by applying the SWAT model for the study watershed. The evaluated SWAT model results indicate that Basin No. 20 received the highest rating based on these criteria. Using the KINEROS2 model, the response Basin No. 20 to individual rainstorm events was analyzed. Its ability to utilize runoff for groundwater recharging with minimal sediment load was confirmed, with only 0.286% of sediment load volume from the total outflow volume. This makes it a promising site for constructing a subsurface dam and contributes to improving water resource management in the region.

Keywords: AGWA2 model, AHP model, Al Kur watershed, hydrological modeling, subsurface dam, watershed management.

INTRODUCTION

Water management is essential to conserving water resources, especially in arid and semi-arid regions with water scarcity. These areas face major challenges due to low rainfall and high evapotranspiration rates (Food and Agriculture Organization of the United Nations (FAO), 2020), which worsens the water shortage problems. Subsurface dams are an innovative and effective solution for groundwater management (Jamali, 2016a). These dams work to preserve and store groundwater by building barriers below the surface of the earth that prevent the flow of water and allow it to accumulate in the underground layers (Apaydin, 2009). Subsurface dams improve the quality and quantity of groundwater; reduce water losses as well as support environmental and development sustainability in the areas suffering from water scarcity (Onder and Yilmaz, 2005; Qureshi et al., 2010).

Two consecutive decades of conflicts and military operations have caused population and demographic changes in the areas south of the study basin, which resulted in resident migration and the termination of agricultural activities related to their presence in close villages and inside conflict areas (IOM, 2012). After stability has been rebuilt, local administrations have been motivated to work hard to enable the return of inhabitants and agricultural operations to these areas, thus creating actual chances for sustainable development in these regions (Alwash et al., 2018; NCR, 2023).

Several previous studies that used hydrological models and multi-criteria decision-making techniques to identify suitable sites for constructing subsurface dams and managing water resources in arid and semi-arid regions were reviewed. Table 1 summarizes these studies in terms of the locations in which they were conducted, the methods and models used, the main objectives of each study, and the most important findings they reached.

Characteristic of study area

The Al Kur basin is in northern Iraq within the Kirkuk governorate. It covers a total area of 813 km^2 and is considered one of the watershed basins that supply the Zaghitun River, which flows into the existing Adhaim dam reservoir (Najdat, 2015; Mahmoud and Kasim, 2019). This catchment is distinguished by its important geographical location and its impact on the water resources in the region (Al-Ansari, 2018). The watershed extends over a wide area and includes geographic and climatic diversity that can influence groundwater and surface water dynamics. By studying the Al Kur watershed, it is possible to understand the hydrological and geological characteristics that contribute to figuring out the best locations for constructing subsurface dams.

The study area is in the Al Kur watershed, which extends between the Kirkuk and Sulaymaniyah governorates in northern Iraq, as shown in Table 2. The basin is bordered north by Kirkuk

Table 1. Studies in determining suitable locations for underground dams

Study/reference	Location	Methods/models used	Objective/focus	Key findings/applications
(Izady et al., 2021)	Al-Aswad Falaj, Oman	Risk-Based Optimization Approach	Allocating water resources to reduce risks and uncertainties	Achieved an optimal balance between water allocation and associated risks
(Ebrahimi et al., 2021)	South-East Bushehr Province, Iran	Multi-Criteria Decision-Making (MCDM), including AHP, ANP, VIKOR, TOPSIS, ELECTRE methods	Prioritizing suitable locations for subsurface dams	Effective prioritization of suitable sites
(Rohina et al., 2020) (Mobarakabadi, 2012); (Taslicali and Ercan, 2006)	Various Locations	Analytical Hierarchy Process (AHP)	Extensive use of AHP model for site selection	Demonstrated success in using AHP for efficient site selection
(Jamali, 2016a; Jamali et al., 2013, 2014, 2018); Jamali et al., 2018; (Tavakoli Sayed Reza Hashemi and Khashei-Siuki Hossein Khozeyme-Nezhad, 2018)	Pakistan Iran	Combination of AHP and ANP techniques; Boolean and Fuzzy logic	Efficient site selection for constructing subsurface dams	Simplified complex problems into manageable parts using Boolean and Fuzzy logic
(Dortaj et al., 2020b)	Semiarid Region, Iran	Modified ELECTRE III methods	Ranking alternatives and reducing uncertainties in site selection for subsurface dams	Successful ranking of alternatives, reducing uncertainties
(Sheikhipour et al., 2018); (Dortaj et al., 2020a)	Iran	Hybrid Multiple Criteria Decision-Making (HMCDM) model	Prioritizing scenarios for managing groundwater use from an aquifer	Developed a hybrid model for prioritizing management scenarios
(Ali et al., 2014); (Jamali et al., 2013); (Karlsson et al., 2014);(Jamali, 2016b)	Various Locations	Geospatial analysis, GIS applications, Soil Water Assessment Tool (SWAT), multi-criteria decision-making	Determining potential locations for subsurface dams	Enhanced ability to determine suitable locations using geospatial models and decision-making methods
(Talebi et al., 2019); (Kim et al., 2017); (Wei et al., 2019); (Wang and Brubaker, 2014)	Various Locations	Integration of SWAT and spatial multi-criteria decision-making methods	Suitability assessment of locations for subsurface dams	Provided advanced capabilities for assessing the suitability of locations using integrated geospatial and decision-making models

Table 2. Geographical location and coordinates of the study area

Province	Basin	Longitude (E)	Latitude (N)	Elevation (m a.s.l.)
Kirkuk	Al Kur	44°15’	35°00’	170
Sulaymaniyah		44°45’	35°30’	962

and to the southeast by the Tuz Khurmatu region. The basin includes important areas such as Daquq and Chamshamal as shown in Figure 1.

The Al Kur watershed is characterized by its diverse topography, which includes floodplains, valleys, and rivers. These geomorphological formations are mostly due to geological processes that occurred during the Quaternary era, which influenced the current geomorphology of the basin (Forman and Stinchcomb, 2015, Alfatlawi and Hussein, 2024). This area, known as the Cham-Chmal-Klar hydrogeological zone, covers a total area of approximately 9,863.1 km² and ranges in height from 158 meters to 1.855 meters above sea level. This area represents a catchment area for the streams of the Adhaim and Upper Diyala rivers, and thus these rivers represent the regional drainage area of this hydrogeological region (Al-Zubedi and Al, 2022, Alfatlawi and Hussein, 2024).

The study area is covered by various soil types, depending on their underlain parent rocks, which are decomposed into covered soil by the action of weathering (Nachtergaele et al., 2009). The outcrops of silty claystone rock (Lower Bakhtiari Formation) are Formation weathered in silt and clay soils. While the area is dominant with conglomerate (Upper Bakhtiari Formation), the topsoil is characterized by weathered gravels, in addition to the transported (alluvium) soils that differ from their underlain rocks (Mahmoud and Kasim, 2019).

RESEARCH DATA AND METHODOLOGY

Geology, climate and water resources in the study area

Geological importance and groundwater

Several authors studied the geology of the study area (Al-Zubedi and Al, 202; Sadeq and Mohammad, 2022; Tamar-Agha and Mandeel, 2015). All the rock units in the study area belong to the Tertiary (T) age (Kareem, 2013). The main exposed formations in the area are Fat'ha, Injana, Mukdadiya, and Bai Hassan formations (Ali et al., 2014), and Quaternary (Q) deposits, as shown in Figure 2. Fatha formation (middle Miocene) is characterized by the prevalent evaporitic (sulphatic and homogeneous) facies (Sadeq and Mohammad, 2022). The main aquifers in this region are confined and unconfined within the Bakhtiyar groundwater systems (Bir Hassan and Muqdadiyah), with modern alluvial aquifers in small areas and various locations. The results of the pumping test in the wells that penetrate the aquifers of Muqdadiyah and Bir Hassan indicated that the permeability ranged between (3–1950 m²/day), the hydraulic conductivity varied between (0.1–42.6 m³/day), and the well drainage ranged between (20–3360 m³/day). The constant water level ranged between (5–90 m) below the ground surface. The salinity

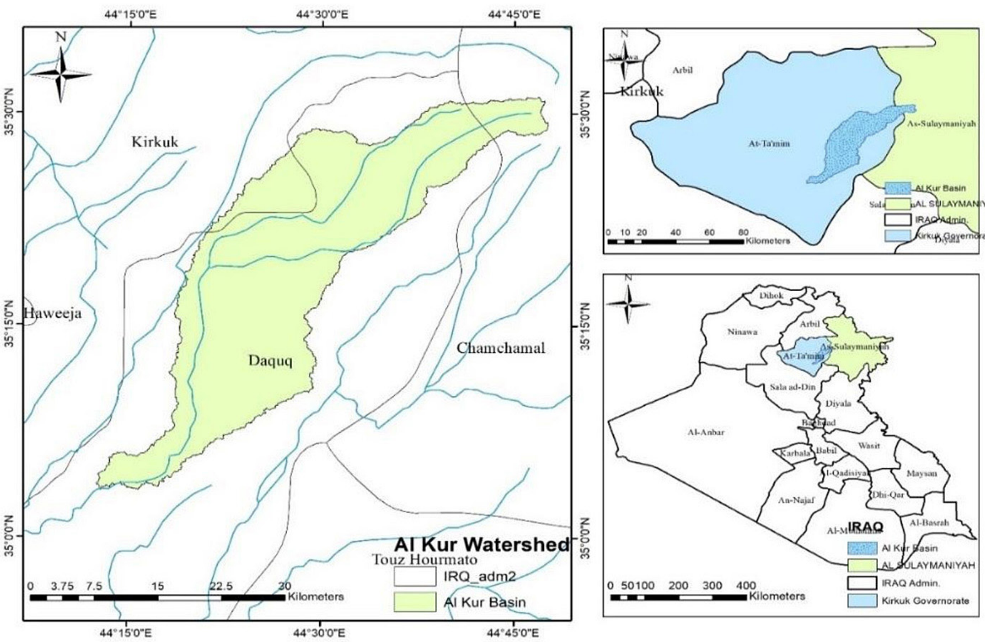

Figure 1. Layout map for the study area (Basin within Kirkuk Governorate) (produces by the author from Kirkukimage by ArcMap v.10.8 software)

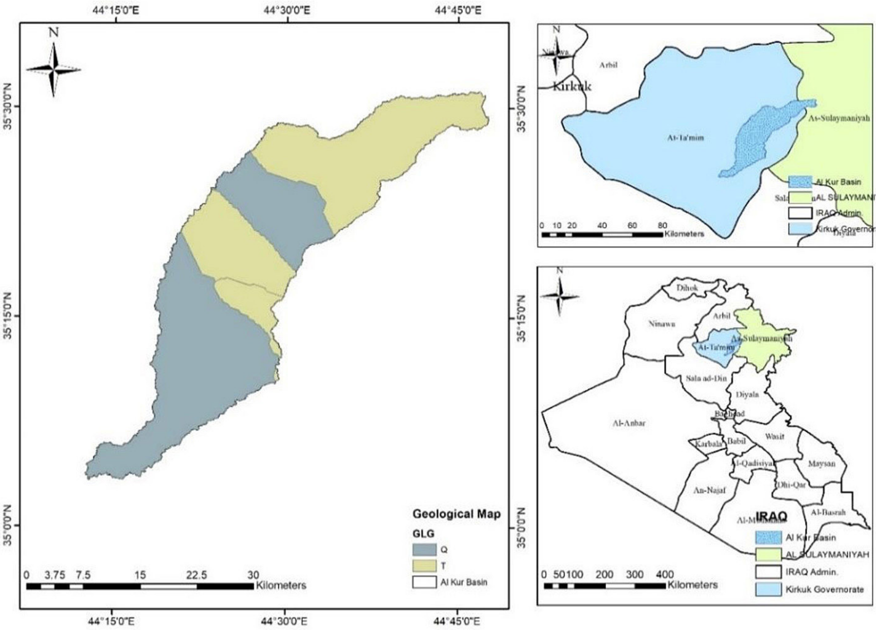

Figure 2. Total annual rainfall for the stations

of groundwater in these basins ranges between (150–1600 mg/L) with bicarbonate and sulfuric water types (Al-Zubedi and Al, 2022; Al-Ansari et al., 2018, Saad et al., 2022).

Climate

The meteorological station of Kirkuk provides climate compiled by the Iraqi Meteorological Organization Table 3 shows a summary of climatic factors (Najdat, 2015). Daily precipitation data from (1981–2021) is modified with calibration from the available satellite daily precipitation data and Kirkuk station for missing or unknown data (Kidd and Huffman, 2011). Figure 3 reveals the maximum and minimum daily precipitation data.

Table 3. Summary of meteorological data of meteorological station of Kirkuk (Najdat, 2015)

Meteorological parameter	Maximum value	Minimum value	Average value
Temperature (°C)	49.52	-6.7	22.4
Relative humidity (%)	72	22	46
Wind speed (m/s)	30	-	2.8
Evaporation (mm)	398.8	46.3	-
Evaporation (free water surface/year) (mm)	-	-	1642.9
Precipitation (mm/yr)	769.9	201.6	369.3

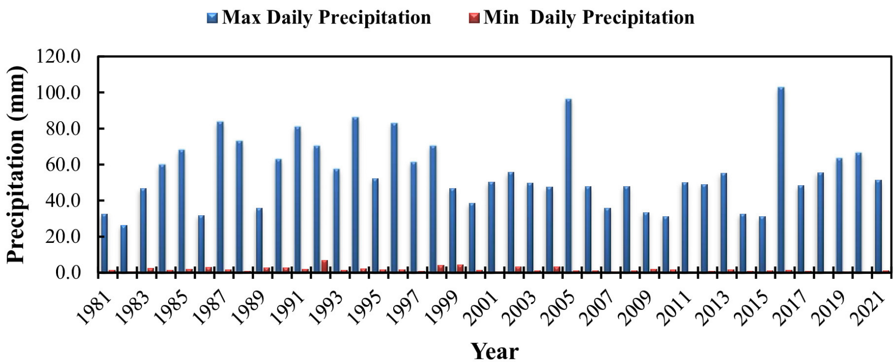

Figure 3. Variation of maximum and minimum daily precipitation in the study area

Methodology

The methodology used in this research is illustrated in Figure 4, which involves linking and analysing geospatial data of the study area. The data was then modeled using the automated geospatial water assessment (AGWA), and soil water assessment tool (SWAT) to determine the hydrological characteristics of the basin and identify the sub-basins that are most responsive and sensitive to the requirements of subsurface storage. This information helps identify the sub-basins that can be selected using analytic hierarchy process (AHP) and assess their hydrological response using the kinetic erosion model (KINEROS).

Hydrological modeling

Evaluating the general hydrological characteristics of the study area is achieved by applying the AGWA modeling with both extensions, i.e. SWAT and KINEROS. It offers a wide range of hydrological results for the watershed based on climate and geospatial data (Burns et al., 2004; Guertin et al., 2015, Hussein et al., 2018).

The results of the AGWA model represent an assessment of the effects of land use and land cover on the response of watersheds to hydrological elements according to the available climate data and the designated study area (Mahmoud and Kasim, 2019). The SWAT extension of the AGWA model provides detailed hydrological results outputs based on available data, the accuracy of results improves with longer data duration. In the conducted study, 40 years of climate data and high-resolution geospatial data were used, which improves the accuracy of results.

Analytic hierarchy process

The AHP is a multi-criteria decision-making tool that helps determine the relative importance of a set of criteria by pairwise comparison between these criteria (Ishizaka and Nemery, n.d.; Yoon and Hwang, 1995; Wolff et al., 2024). This tool is widely used in many fields, including site selection for various projects, such as the construction of subsurface dams (Rohina et al., 2020; Mobarakabadi, 2012, Ali et al., 2022, Al-Wahid et al. 2022).

The criteria used for the evaluation depended on the direct contribution in decision-making according to SWAT model results for general hydrological behavior in the Al Kur watershed, the

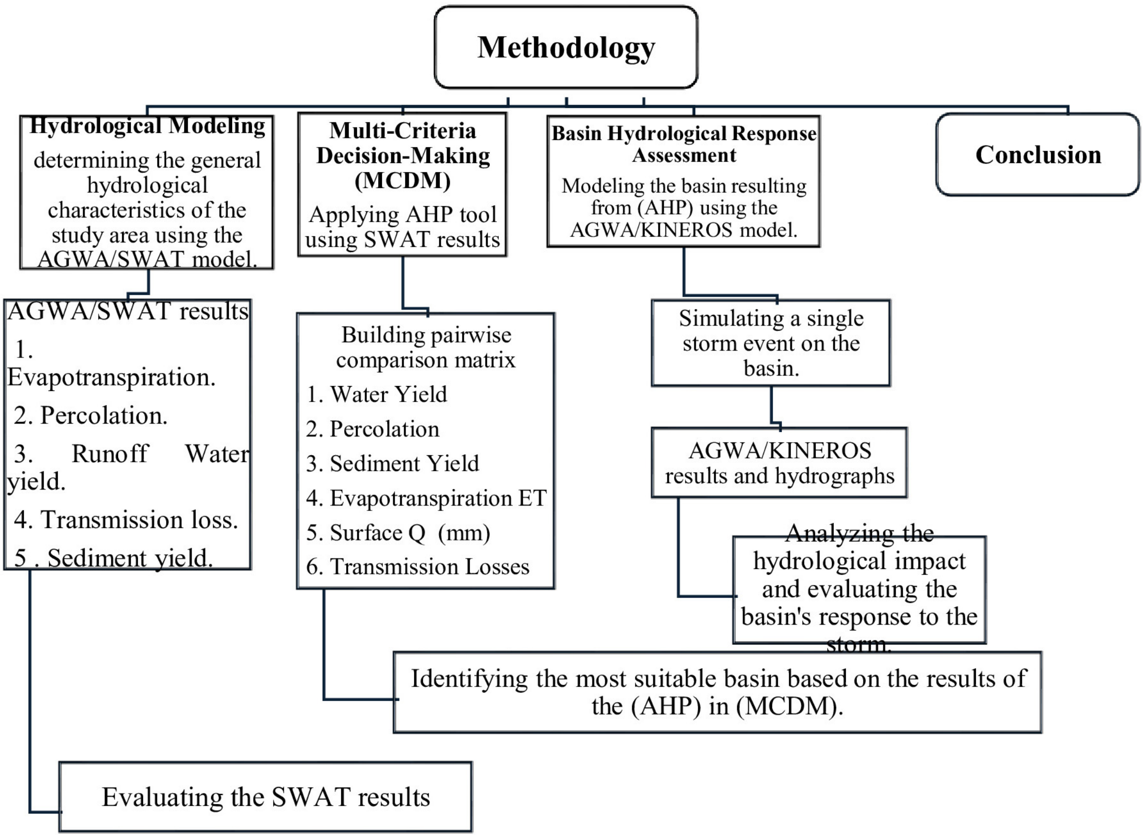

Figure 4. Navigating through the sequence of the methodology

criteria include (water yield, percolation, sediment yield, evapotranspiration ET, surface runoff and transmission losses).

Hydrological response assessment

The KINEROS model is utilized to assess the hydrological response during a single storm event. It uses a network of channels and planes to represent a watershed, and the kinematic wave method routes water off the watershed. It is a physically based model designed to simulate runoff and erosion for single storm events in small watersheds less than approximately (100) km^2 (Goodrich et al., 2011).

RESULTS

Results of hydrological modeling

The AGWA/SWAT model results demonstrate two-scale hydrological outputs: basin (sub-watersheds) level and channel (streams) level, providing a comprehensive and accurate analysis of the hydrological system response

Percolation

Percolation rates in sub-watersheds are significant indicators of sub-watershed contribution to groundwater recharge. The modeling results indicate variations in percolation values across sub-basins due to differences in land cover and topsoil characteristics. The highest percolation rates reach approximately 27 mm as shown in Figure 5.

Evapotranspiration

Evapotranspiration results at the basin (sub-watershed) level show that the northern parts of the Al Kur watershed are the most exposed to evapotranspiration, with rates reaching approximately 331 mm as shown in Figure 6.

Water yield

In the Al Kur watershed, higher water yield values are observed in the basins that correspond to the streams of the southern part of the watershed. The maximum values are approximately 18 mm at the basin level and around 17 mm at the stream level, as shown in Figure 7.

Transmission losses

Determining transmission losses is crucial for understanding the impact on the water balance equation within sub-watersheds. They are influenced directly by hydrological parameters, such as land cover/land use, topsoil type and spatial topography. Figure 8 shows that these losses are higher in the areas that act as the main route of the streams toward the southern part of the Al Kur watershed, with recorded values of around 27 mm in the basin level and 0.2 m^3/s at the stream level.

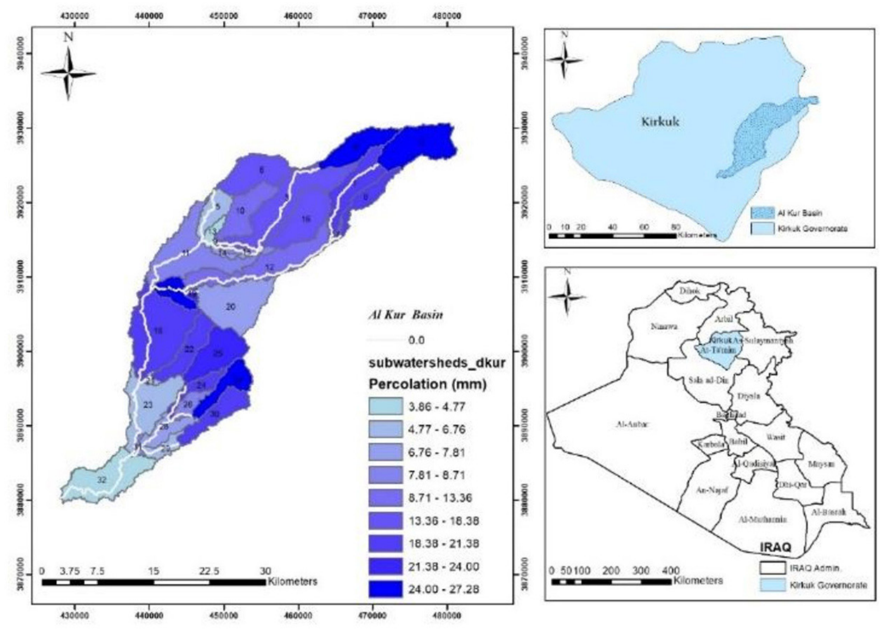

Figure 5. Distribution of annual percolation rate in sub-watersheds

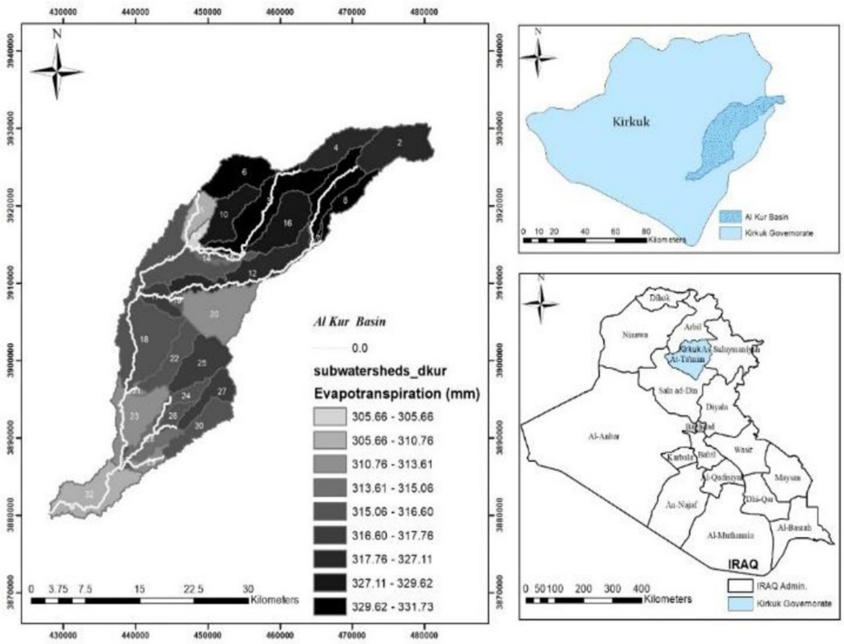

Figure 6. Distribution of annual evapotranspiration rate in sub-watersheds

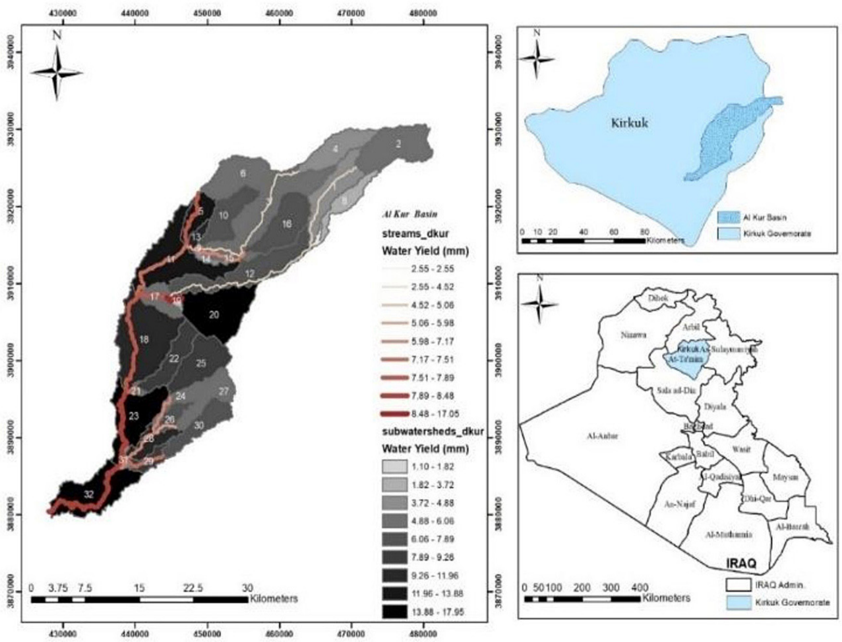

Figure 7. Distribution of annual water yield rate in sub-watersheds and streams

Sediment yield

The efficiency of hydraulic systems and projects that utilize the natural water features of a basin to ensure the amount of sediment deposits adversely influence water security. These deposits reduce the water storage capacity and affect the geomorphology of the basin. Figure 9 demonstrates how land use/land cover, soil, and the hydraulic gradient affect the amount of sediment yield in the Al Kur watershed. The highest sediment levels were found to be around 0.08 tons per hectare at the basin level, while at the stream level, it reached 194 tons.

Surface runoff

The rates of surface runoff in sub-watersheds are important indicators that contribute to the overall water discharge of the Al Kur watershed. Modeling results have revealed variations in these rates across

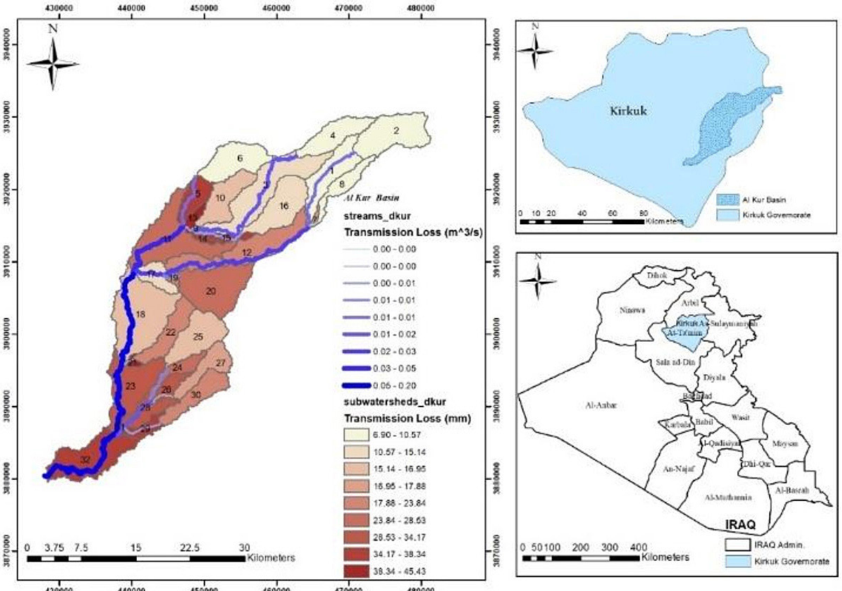

Figure 8. Distribution of annual transmission losses rate in sub-watersheds and streams

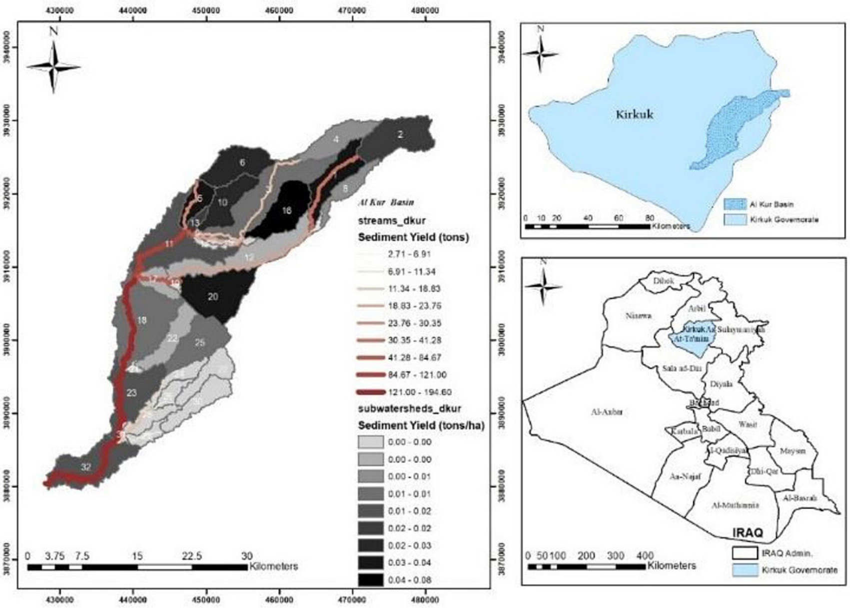

Figure 9. Distribution of annual sediment yield rate in sub-watersheds and streams

sub-watersheds due to differences in land use/land cover and topsoil. The highest runoff rates reach approximately 56 mm, as shown in Figure 10.

Channel discharge

Figure 11 reveals the hydrological modelling response of the Al Kur watershed to the water discharge at the main outlet at the stream level, it was found to be close to 18,878 m^3/day This predicted channel discharge indicates the flow at the bottom outlet channel of the basin, after accounting for infiltration, evapotranspiration, sediment load, and losses, along with the water yield from upstream sub-basins.

Results of the analytic hierarchy process

Pairwise comparison matrix

On the basis of the criteria identified and the Pairwise Comparison weight scale, the Pairwise Comparison Matrix was built, as shown in Table 4.

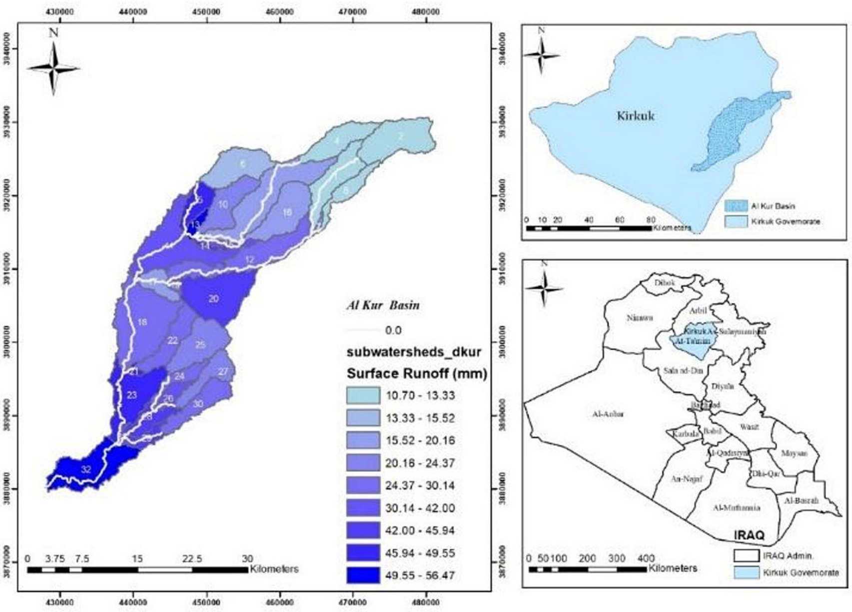

Figure 10. Distribution of annual surface runoff rate in sub-watersheds

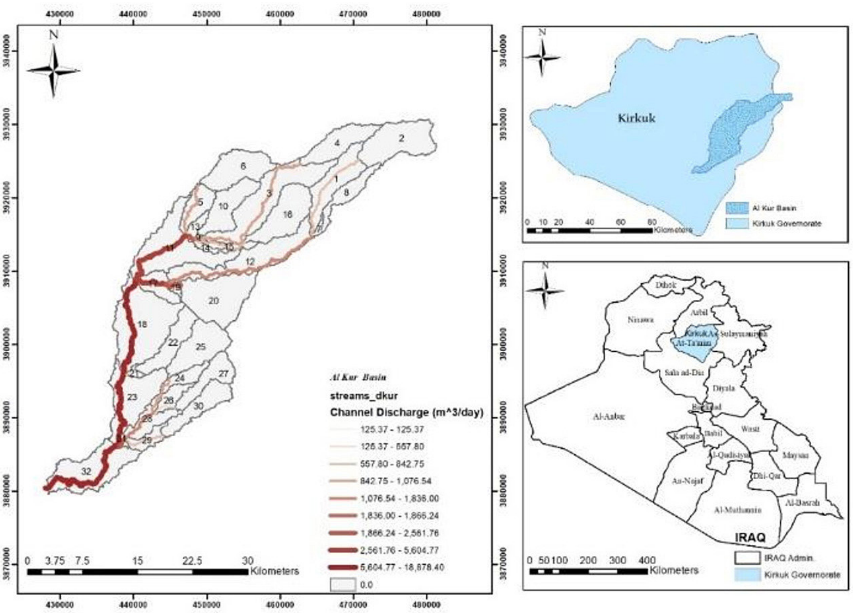

Figure 11. Distribution of annual water discharge in the streams

Table 4. Pairwise comparison matrix

Criteria	Water yield (mm)	Percolation (mm)	Sediment yield (tons/ha)	Evapotranspiration (mm)	Surface (mm)	Transmission Losses (mm)
Water yield	1	3	3	5	2	2
Percolation	3	1	1	2	0.33	0.33
Sediment yield	3	1	1	2	0.33	0.33
Evapotranspiration	0.50	0.50	0.50	1	0.33	0.33
Surface	0.50	3	3	3	1	1
Transmission losses	0.50	3	3	3	1	1
Sum	8.500	11.50	11.50	16.0	5.0	5.0

Matrix processing

The λ_{max} value is calculated by multiplying the sum of each column by the corresponding weight and then calculating the average of these values as shown in Table 5. The consistency index (CI) is expressed by (Ishizaka and Nemery, 2013; Hussein, 2024):

$$CI = \frac{\lambda_{Max.} - n}{(n-1)} \quad (1)$$

where: n is the number of criteria.

The consistency ratio (CR) can be written as (Ishizaka and Nemery, 2013):

$$CR = \frac{CI}{RI} \quad (2)$$

where: RI is the random consistency index based on the number of criteria and is equal to 1.24.

The consistency ratio (CR) was calculated and was equal to 0.09. At values less than 0.1, the matrix is considered consistent, and the calculated weights are reliable.

From the results of matrix processing, the calculated weights for each criterion and the different sub-watersheds can be evaluated and the optimal location for constructing sub-surface dams can be determined based on the overall performance of each sub-watershed. It was found that sub-watershed No. 20 was rated better in terms of location and area compared to sub-watershed No. 23, as shown in Table 6. The sub-watersheds south of the Al Kur watershed were adopted because of their hydrological characteristics derived from SWAT modeling.

Table 5. Values of λ_{max}

Criteria	Water yield (mm)	Percolation (mm)	Sediment yield (tons/ha)	Evapotranspiration (mm)	Surface (mm)	Transmission losses
Water yield	0.331	0.274	0.274	0.294	0.428	0.428
Percolation	0.992	0.091	0.091	0.118	0.071	0.071
Sediment yield	0.992	0.091	0.091	0.118	0.071	0.071
Evapotranspiration	0.165	0.046	0.046	0.059	0.071	0.071
Surface	0.165	0.274	0.274	0.176	0.214	0.214
Transmission losses	0.165	0.274	0.274	0.176	0.214	0.214
Sum	2.809	1.05	1.05	0.9	1.1	1.1
$l_{Max.}$	8.50	4.27	4.27	12.35	5.00	5.00

Table 6. Results of the AHP analysis

Sub watershed	Area (km²)	Evapotranspiration (mm)	Percolation (mm)	Surface (mm)	Transmission losses (mm)	Water yield (mm)	Sediment yield (tons/ha)	Sum
11	58.25	24.08	2.06	8.88	6.10	4.35	0.040	45.51
12	51.04	24.89	2.83	5.87	4.40	2.40	0.005	40.39
17	13.79	24.21	6.72	4.31	3.24	1.95	0.039	40.47
18	71.88	24.08	5.27	6.02	3.58	3.95	0.023	42.92
19	2.54	24.10	5.48	5.73	5.10	1.23	0.053	41.70
20	51.76	23.90	1.72	9.69	5.89	5.93	0.113	47.24
21	2.31	23.78	1.52	10.22	8.95	2.00	0.059	46.52
22	24.91	24.05	5.10	6.23	4.63	2.68	0.011	42.70
23	43.37	23.84	1.61	9.97	6.66	5.15	0.047	47.27
24	12.56	24.04	4.94	6.45	5.31	1.90	0.000	42.64
25	34.88	24.14	5.91	5.21	3.55	2.85	0.043	41.72
26	9.57	24.12	2.15	8.69	7.03	2.61	0.014	44.61
27	21.35	24.17	6.18	4.93	3.82	1.95	0.006	41.06
28	15.58	23.95	1.80	9.49	7.31	3.41	0.009	45.97
29	9.19	23.87	1.67	9.83	7.87	3.06	0.015	46.31
30	24.51	24.08	5.25	6.04	4.53	2.51	0.006	42.41
31	2.34	24.06	2.02	8.98	8.07	1.44	0.000	44.58
32	47.98	23.53	1.18	11.23	7.61	5.63	0.054	49.22

Kinetic erosion model results

From the results of the AHP, the watershed (Basin No. 20) was selected as the primary candidate for the construction of the subsurface dam. The KINEROS model was applied to provide a detailed analysis of (Basin No. 20), as shown in Figure 12. This analysis aimed to study the response of this selected sub-watershed to a single rainstorm event regarding water yield, infiltration capacity, and groundwater recharge. The hydrological modeling included outputs such as peak flow, infiltration, sediment yield, and runoff at both the sub-watershed (plane) and channel (streams) levels. The KINEROS model provided a simulation of hydrological interactions within this basin, allowing a better understanding of the efficiency of the site chosen.

Runoff

The surface runoff and its depth resulting from the basin response to the impact of the rainstorm event constitute an important element in determining

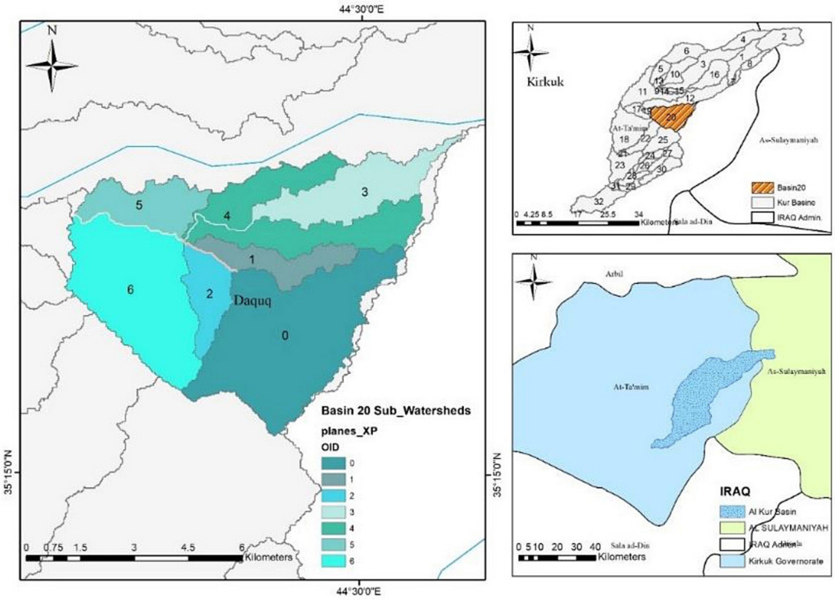

Figure 12. Basin No.20 derived by KINEROS through AGW A

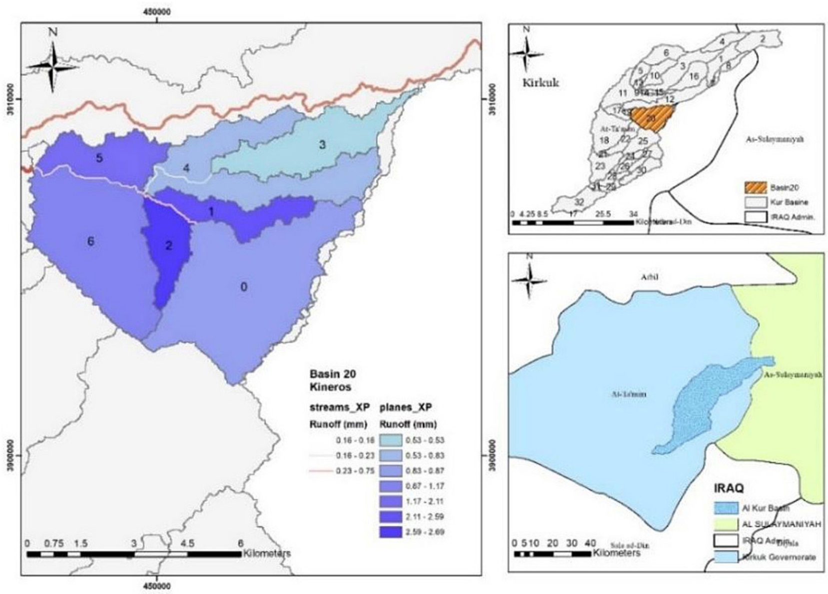

Figure 13. Runoff distribution in (mm) in Basin No.20

the sensitivity of the basin to water yield and its susceptibility to groundwater recharge, especially considering the availability of highly permeable soils with infiltration rate in both basins and stream levels. In Basin No. 20, variation in surface runoff appears, as shown in Figure 13, because of different terrain and land cover. This variation is evident in the hydrograph of peak flow, which has two peaks, indicating the influence of topography, the calculated area under the curve of peak outflow hydrograph, as shown in Figure 14, approximates 285 m^3 water load and represents a single storm event.

Sediment load

The sedimentary load and its quantity resulting from the basin response to the impact of the rainstorm is an important element in determining the sensitivity of the basin to water yield and its ability to groundwater recharge, considering the availability of highly permeable soils, as the sedimentary load, especially with the distribution of fine particles, which reduces the opportunity of the surface soil to receive water in the direction of its infiltration and penetration into groundwater. In Basin No. 20, a variation in the sedimentary load appears, as shown in Figure 15, because of the difference in terrain, land cover, and surface soil, bringing the sedimentary load at the bottom outlet of the basin to 2163.76 kg from calculating the area under the curve of the hydrograph for the total sediment load as is shown in Figure 16.

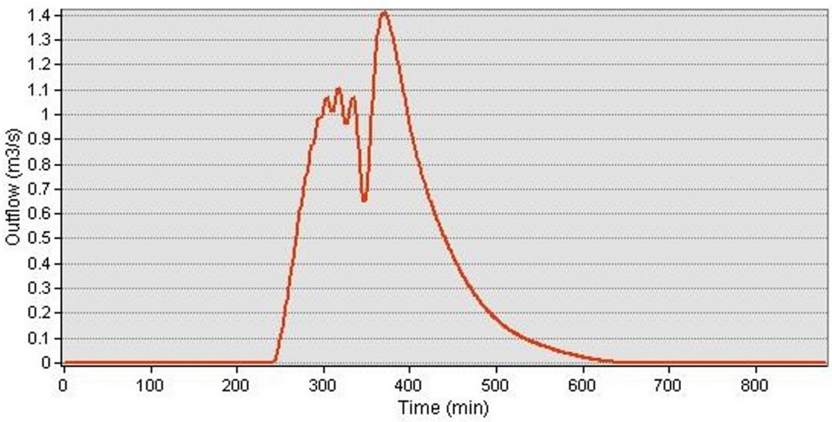

Figure 14. Outflow hydrograph in (m^3/sec) in Basin No.20

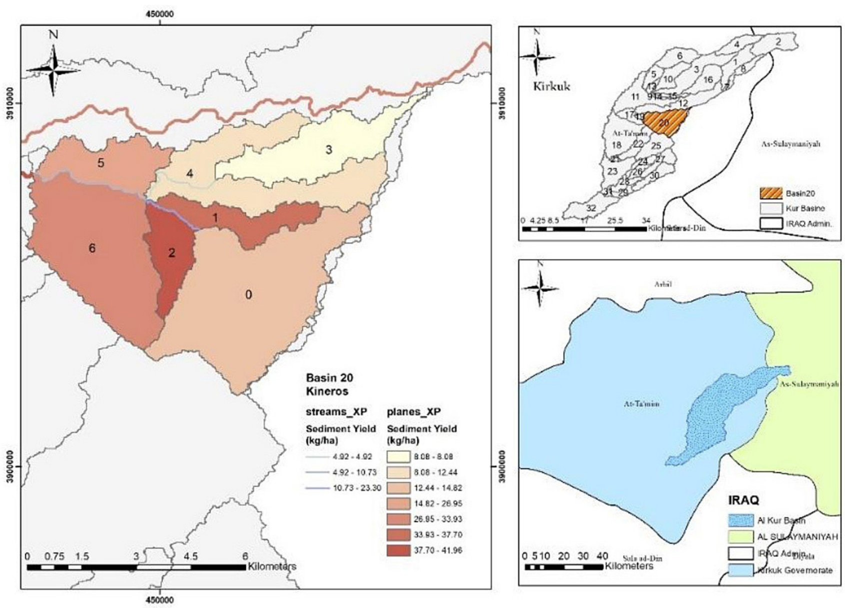

Figure 15. Sediment yield distribution in Basin No.20

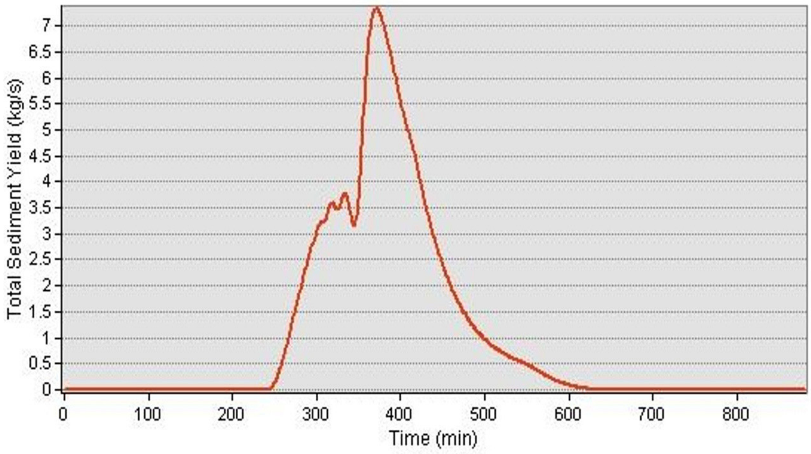

Figure 16. Total sediment load hydrograph in Basin No. 20

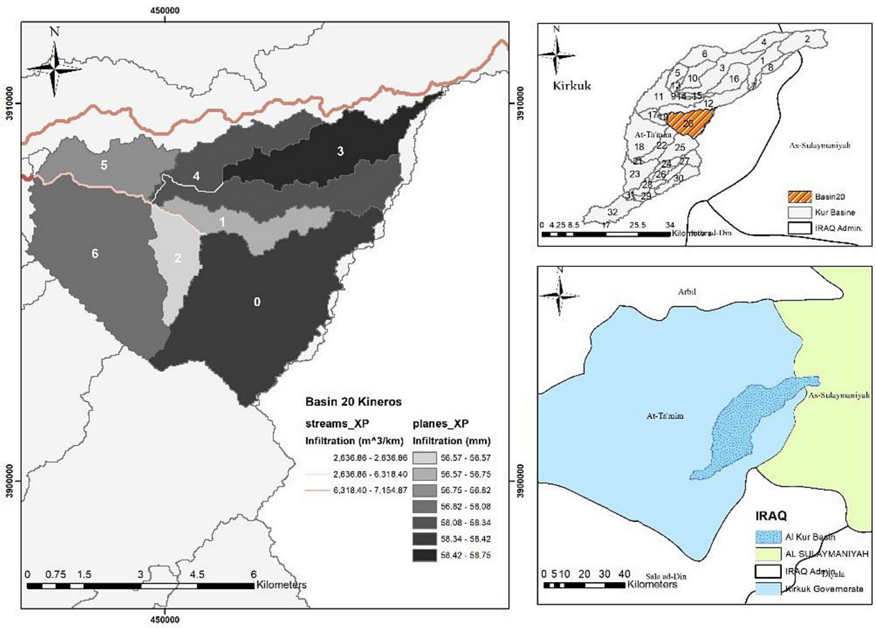

Figure 17. Infiltration distribution m Basin No. 20

Infiltration

Rainstorm impact modeling shows the response of the upper and middle parts of Basin No. 20 along mainstream to high infiltration rates. It is influenced by the topography distribution in the sub-watersheds, which is developed by land cover conditions and high soil permeability, as shown in Figure 17.

CONCLUSIONS

The result of this study indicates the importance of using advanced hydrological models, such as AGWA with SWAT and KINEROS extensions, in evaluating and determining suitable locations for subsurface dam construction for the study area of the Al Kur watershed. SWAT modeling results identified the hydrological practices of the study area as well as their performance and ability in managing water resources for securing a sustainable water balance, as it is characterized by their ability to recharge groundwater according to the high infiltration rates.

In addition, the implementation of the AHP model assisted in the evaluation of multiple criteria that influence the selection of the suitable location for the subsurface dam, such as percolation, water yield, transmission losses and sediment yield. The results showed that basin No. 20 had the highest rating based on these criteria adopted, which enhances its feasibility as a predicted site for constructing a subsurface dam.

In the analysis using the KINEROS model, it was observed that Basin No. 20 can effectively use runoff to replenish groundwater with a low sediment load. The sediment load was found to be only 0.286% of the total outflow water volume. These findings suggest that Basin No. 20 is a promising site for constructing a subsurface dam, which would help with better water resource management in the Al Kur watershed.

Finally, the research will contribute to the development of these areas, creating opportunities for the return of residents and sustainable organization of population and agricultural activities after two decades of unstable conditions because of conflicts and military operations. The local governments are actively working towards achieving this goal and clearing the opportunities for future studies using observed field data to calibrate the sensitivity of these hydrological models and their validation for expected projects to achieve the demanded development. Accordingly, this approach will enable effective sustainable planning for water resource management.

REFERENCES

1. Al-Ansari, N., Adamo, N. and Sissakian, V.K. (2018). *Groundwater Quality and Their Uses in Iraq*. Available at: https://www.researchgate.net/publication/324681023
2. Alfatlawi, T.J.M., & Hussein, A.H. (2024a). A numerical study of diversion flow to determine the optimum flow system in open channels. *Water Practice & Technology, 19*(4), 1330–1347. https://doi.org/10.2166/wpt.2024.056
3. Alfatlawi, T. J. M., & Hussein, A. H. (2024b). Probing the complexities of optimal flow in open channels: experimental and numerical validation with diversion flow. *Journal of Hydroinformatics, 26*(10), 2618-2638. https://doi.org/10.2166/hydro.2024.143
4. Alfatlawi, T. J., & Hussein, A. H. (2024c). A review of studying the flow characteristics in branching open channels. *International Journal of Heat & Technology, 42*(2). https://doi.org/10.18280/ijht.420222
5. Ali, A., Al-Murshedi, A. S. N., Al-Okbi, Y., & Saad, H. A. K. (2022). Investigations for the critical vehicle velocities on a curved path. In *AIP Conference Proceedings* 2386(1). AIP Publishing. https://doi.org/10.1063/5.0067921
6. Al-Wahid, A., Wisam, A., Saad, H. A. K., Hasan, Z. H., & Sopian, K. (2022). Experimental study of the performance of hemispherical solar still with optimum value of rocks as heat transfer enhancers. *AIMS Energy, 10*(4). https://doi.org/10.3934/energy.2022040
7. Ali, S.S., Al-Umary, F.A., Salar, S.G., et al. (2014). Evaluation of selected site location for subsurface dam construction within isayi watershed using GIS and RS Garmiyan Area, Kurdistan Region. *Journal of Water Resource and Protection*, *6*(11): 972–987. https://doi.org/10.4236/jwarp.2014.611092
8. Alwash, A., Istepanian, H., Tollast, R., et al. (2018). *TowardsSustainable WaterResources ManagementInIraq 30August2018*. Available at: www.iraqenergy.org
9. Al-Zubedi, A.S. (2022). *Groundwater in Iraq.* Araa Publication, Baghdad, Iraq.
10. Apaydin, A. (2009). Malibogazi groundwater dam: An alternative model for semi-arid regions of Turkey to store and save groundwater. *Environmental Earth Sciences*, *59*(2): 339–345. https://doi.org/10.1007/s12665-009-0030-8
11. Burns, I.S., Scott, S., Levick, L., et al. (2004) *Automated Geospatial Watershed Assessment (AGWA)-A GIS-Based Hydrologic Modeling Tool: Documentation and User Manual Version 1.4*. https://www.tucson.ars.ag.gov/
12. Dortaj, A., Maghsoudy, S., Doulati Ardejani, F., et al. (2020a). A hybrid multi-criteria decision making method for site selection of subsurface dams in semi-arid region of Iran. *Groundwater for Sustainable Development*, 10. https://doi.org/10.1016/j.gsd.2019.100284
13. Dortaj, A., Maghsoudy, S., Doulati Ardejani, F., et al. (2020b). Locating suitable sites for construction of subsurface dams in semiarid region of Iran: using modified ELECTRE III. *Sustainable Water Resources Management*, *6*(1). https://doi.org/10.1007/s40899-020-00362-2
14. Ebrahimi, J., Reza Moradi, H. and Chezgi, J. (2021). *Prioritizing suitable locations for underground dam construction in south east of Bushehr Province*. https://doi.org/10.21203/rs.3.rs-161525/v1
15. Food and Agriculture Organization of the United Nations (FAO) (2020) *Water Scarcity*. Available at: http://www.fao.org/neareast/perspectives/
16. Forman, S.L. and Stinchcomb, G.E. (2015). Views on grand research challenges for Quaternary geology, geomorphology and environments. *Frontiers in Earth Science*, 3. https://doi.org/10.3389/feart.2015.00047
17. Goodrich, D.C., Guertin, D.P., Burns, I.S., et al. (2011). AGWA: The automated geospatial watershed assessment tool to inform rangeland management. *Rangelands*, *33*(4): 41–47. https://doi.

org/10.2111/1551-501X-33.4.41

18. Guertin, D.P., Goodrich, D.C., Burns, I.S., et al. (2015). Automated Geospatial Watershed Assessment Tool (AGWA). In *Proceedings of the Watershed Management Symposium*. 2015. American Society of Civil Engineers (ASCE). 120–130. https://doi.org/10.1061/9780784479322.012
19. Hussein, A. H. (2024). Innovative calibration strategies for weirs with half-round crest edge modifications. *Instrumentation, Mesures, Métrologies, 23*(5). https://doi.org/10.18280/i2m.230502
20. Hussein, A. H., Al–Delewy, A. A., & Nasir, M. J. (2018). Estimating the capability of Shatt Al-Hilla within Hilla City to carry the total bed–material load. In: *IOP Conference Series: Materials Science and Engineering* 454(1), 012020. IOP Publishing.
21. IOM (2012) *Water Scarcity Iraq Special Report*. Available at: http://environmentalmigration.iom.int/sites/g/files/tmzbdl1411/files/documents/Water%20 Scarcity.pdf (Accessed: 9 August 2024).
22. Ishizaka A. and Nemery P. (2013) *Multi-criteria decision analysis: methods and software*. Wiley.
23. Izady, A., Khorshidi, M.S., Nikoo, M.R., et al. (2021). Optimal water allocation from subsurface dams: A risk-based optimization approach. *Water Resources Management, 35*(12): 4275–4290. https://doi.org/10.1007/s11269-021-02946-9
24. Jamali, A.A., Randhir, T.O. and Nosrati, J. (2018) Site suitability analysis for subsurface dams using boolean and fuzzy logic in arid watersheds. *Journal of Water Resources Planning and Management*, *144*(8). https://doi.org/10.1061/(asce)wr.1943-5452.0000947
25. Jamali, I.A. (2016) *Subsurface dams in water resource management: Methods for assessment and location*. Doctoral thesis. https://www.diva-portal.org/smash/record.jsf?pid=diva2%3A902012&dswid=7229
26. Jamali, I.A., Mörtberg, U., Olofsson, B., et al. (2014). A spatial multi-criteria analysis approach for locating suitable sites for construction of subsurface dams in Northern Pakistan. *Water Resources Management*, *28*(14): 5157–5174. https://doi.org/10.1007/s11269-014-0800-2
27. Jamali, I.A., Olofsson, B. and Mörtberg, U. (2013). Locating suitable sites for the construction of subsurface dams using GIS. *Environmental Earth Sciences*, *70*(6): 2511–2525. https://doi.org/10.1007/s12665-013-2295-1
28. Karlsson, C.S.J., Jamali, I.A., Earon, R., et al. (2014). Comparison of methods for predicting regolith thickness in previously glaciated terrain, Stockholm, Sweden. *Geoderma*, 226–227(1): 116–129. https://doi.org/10.1016/j.geoderma.2014.03.003
29. Kidd, C. and Huffman, G. (2011). Global precipitation measurement. *Meteorological Applications*. *18*(3): 334–353. https://doi.org/10.1002/met.284
30. Kim, J.T., Choo, C.O., Kim, M. Il, et al. (2017). Validity evaluation of a groundwater dam in Oshipcheon River, eastern Korea using a SWAT–MODFLOW model. *Environmental Earth Sciences*, 76(22). https://doi.org/10.1007/s12665-017-7085-8
31. Mahmoud, M.I. and Kasim, M.N. (2019). Sediment yield problems in Khassa Chai Watershed Using Hydrologic Models. *Cihan University-Erbil Scientific Journal*, *3*(1): 34–41. https://doi.org/10.24086/cuesj.v3n1y2019
32. Mobarakabadi, M.K. (2012). Model for determination the optimum location of subsurface dam using analytical hierarchy process AHP Mohammad Karimi Mobarakabadi; Model for determination the optimum location of subsurface dam using analytical hierarchy process AHP. *Advances in Environmental Biology*, *6*(3): 1292–1297.
33. Nachtergaele, F., Van Velthuizen, H., Verelst, L., et al. (2009). *Harmonized World Soil Database - Version 1.1*.
34. Najdat, M. (2015). *Sedimentation Problem in Khassa Chai Reservoir and Methods of Combat*. Available at: https://www.researchgate.net/publication/354342859 (Accessed: 13 June 2023).
35. NCR. (2023). *Inadequate and inequitable: water scarcity and displacement in Iraq*. Available at: https://www.nrc.no/globalassets/pdf/reports/water-scarcity-and-displacement-in-iraq/water-scarcity-and-displacement-in-iraq-arabic.pdf (Accessed: 9 August 2024).
36. Onder, H. and Yilmaz, M. (2005). *Underground Dams - A Tool of Sustainable Development and Management of Groundwater Resources*.
37. Qureshi, A. S., McCornick, P. G., Sarwar, A., et al. (2010). Challenges and prospects of sustainable groundwater management in the Indus Basin, Pakistan. *Water Resources Management*, *24*(8): 1551–1569. https://doi.org/10.1007/s11269-009-9513-3
38. Kareem, I. R. (2013). Artificial groundwater recharge in Iraq through rainwater harvesting (Case Study). *Engineering and Technology Journal*, *31*(A 6): 1069–1080. https://doi.org/10.30684/etj.31.6a4
39. Rohina, A., Ahmadi, H., Moeini, A., et al. (2020). Site selection for constructing groundwater dams through Boolean logic and AHP method (case study: watershed of Imamzadeh Jafar Gachsaran). *Paddy and Water Environment*, *18*(1): 59–72. https://doi.org/10.1007/s10333-019-00764-9
40. Saad, H. A. K., Dikici, B., Villarroel, G., & Divo, E. A. (2022). *Characterization methods for biomass materials and optimizing heat transfer by using genetic algorithms*. In ASTFE Digital Library. Begel House Inc. https://doi.org/10.1615/TFEC2022.emt.040794

41. Sadeq, S. N. and Mohammad, J. K. (2022). The application of watershed delineation technique and water harvesting analysis to select and design small dams: A Case study in Qara-Hanjeer Subbasin, Kirkuk-NE Iraq. *Iraqi Geological Journal*, *55*(1): 57–70. https://doi.org/10.46717/igj.55.1B.6Ms-2022-02-22
42. Semmens, D.J. et al. (2007) *KINEROS2 and the AGWA Modeling Framework*. In: H. Wheater, S. Sorooshian, K.D. Sharma (Eds.) Hydrological Modelling in Arid and Semi-Arid Areas. Cambridge University Press, 49-68.
43. Sheikhipour, B., Javadi, S. and Banihabib, M. E. (2018). A hybrid multiple criteria decision-making model for the sustainable management of aquifers. *Environmental Earth Sciences*, *77*(19). https://doi.org/10.1007/s12665-018-7894-4
44. Talebi, A., Zahedi, E., Hassan, M. A., et al. (2019). Locating suitable sites for the construction of underground dams using the subsurface flow simulation (SWAT model) and analytical network process (ANP) (case study: Daroongar watershed, Iran). *Sustainable Water Resources Management*, *5*(3): 1369–1378. https://doi.org/10.1007/s40899-019-00314-5
45. Tamar-Agha, M. and Mandeel, M. (2015). *Basin analysis of Cretaceous to Tertiary selected wells in Kirkuk and Bai Hassan Oil Fields, Kirkuk, Northern Iraq*. Available at: https://www.researchgate.net/publication/289479300
46. Taslicali, A. K. and Ercan, S. (2006) *The Analytic Hierarchy & The Analytic Network Processes In Multicriteria Decision Making: A Comparative Study*.
47. Tavakoli Sayed Reza Hashemi, S. and Khashei-Siuki Hossein Khozeyme-Nezhad, A. (2018). *Comparison of FAHP and FANP Decision-Making Methods in Determining the Appropriate Locations for Constructing an Underground Dam for Water Harvesting*., *3*(2): 81–91. https://doi.org/10.22077/JWHR.2019.1057
48. Wang, Y. and Brubaker, K. (2014). Implementing a nonlinear groundwater module in the soil and water assessment tool (SWAT). *Hydrological Processes*, *28*(9): 3388–3403. https://doi.org/10.1002/hyp.9893
49. Wolff, M., Abada, H. H., & Saad, H. A. K. (2024). Numerical investigation of supersonic flow over a wedge by solving 2D euler equations utilizing the steger–Warming flux vector splitting (FVS) scheme. *Mathematics, 12*(9), 1282. https://doi.org/10.3390/math12091282
50. Wei, X., Bailey, R. T., Records, R. M., et al. (2019). Comprehensive simulation of nitrate transport in coupled surface-subsurface hydrologic systems using the linked SWAT-MODFLOW-RT3D model. *Environmental Modelling and Software*, 122. https://doi.org/10.1016/j.envsoft.2018.06.012
51. Yoon K. and Hwang C. L. (1995). *Multiple attribute decision making: An introduction*. Sage Publications.