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Managing the Excess Floodwaters in the Lake Hemrin Using Remote Sensing and GIS Techniques

Hussain Muhamed*, **Mustafa N. Hamoodi**, **Abd Alrazzak T. Ziboon**

Civil Engineering Dept., University of Technology-Iraq, Alsina'a street, 10066 Baghdad, Iraq.
*Corresponding author Email: bce.1974@grad.uotechnology.edu.iq

HIGHLIGHTS

- The mapping of flood areas with Landsat images at Hemrin Lake basin was employed.
- Optimizing flood escape paths from Hemrin Lake and away from Diyala River was investigated.
- AHP and Genetic Algorithm were combined to achieve the optimization goal.
- Experts agreed that agricultural lands are more important than population density and residential areas.

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ABSTRACT

Lake Hemrin is located in the middle east of Iraq, about 50 km from the Iraqi-Iranian border. The lake is the main fish source and provides water for nearby farms. However, due to various socio-economic and environmental management issues, the Hemrin system is a difficult water resources challenge. Moreover, Lake Hemrin receives floodwaters annually over its storage capacity; therefore, there is a risk of flooding in the areas downstream of the lake. To this end, this research developed optimization solutions to design flood escape paths in the area using Analytic Hierarchy Process (AHP) and Genetic Algorithm (GA). Among three initial proposals, i.e., Adhaim River, Wadi Naft, and Salahdin, the developed models optimized each of the proposals and suggested that Wadi Naft would require only 3.88 km3 of cut and fill volume compared to Adhaim River of 34.33 km3. However, the latter would serve more people and agricultural lands. GA and AHP techniques to optimize flood escape paths have shown that these models can discover shorter pathways requiring less cut and fill costs while retaining other flood escape features. The proposed optimal flood escape path can substantially influence the construction of flood-prevention strategies in the area.

List of Acronyms

Acronym	Meaning
AHP	Analytic Hierarchy Process
GA	Genetic Algorithm
GIS	Geographic Information System
MCDM	Multicriteria Decision Making
DEM	Digital Elevation Models
GDEM	Global Digital Elevation Model
DDWR	Directorate of Diyala Water Resources
UAV	Unmanned Aerial Vehicle
LiDAR	Light Detection and Ranging
SAR	Synthetic Aperture Radar
USGS	United States Geological Survey
CIESIN	Center for International Earth Science Information Network

1. Introduction

Water scarcity has been a serious issue in Diyala (eastern Iraq) in recent years [1] due to a considerable decline in the water level of Hemrin lake, the governorate's main source of water Figure 1. However, due to heavy rainfall, the Hemrin dam occasionally reaches full capacity (3.76 billion cubic meters) [2], posing a flood hazard to nearby communities and agricultural areas. Subsequently, the flood waves continue to reach the Diyala River, causing greater destruction to the neighboring areas.A flood can also lead to life loss, a major preventable concern. As a result, flood risk management should be taken seriously to minimize severe consequences for communities and agricultural operations.

Floods are one of the most common natural disasters across the planet. It endangers people's health and disrupts our everyday lives. Floods are becoming increasingly common worldwide due to climate change [3], with excessive rainfall, snowmelt, and

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2412-0758/University of Technology-Iraq, Baghdad, Iraq

dam collapse being the primary causes [4]. Like other natural catastrophes, Floods are impossible to prevent, but their damage can be minimized by proper management.

Lake Hemrin reaches full capacity during flood seasons, and the flooding waves flow into Diyala River. Failure to maintain the river regularly decreases its capacity to 750 m^3/s (DDWR, Flood Report of 2019), resulting in flooding large river areas. Diyala River has seen several floods, notable floods in 1988 and 2019. Following the 1988 flood, a flood escape known as Salahdin Escape was built from the river, 500m upstream of the Diyala Weir, and into the Ashweicha Marsh. This escape was built as a preventative measure following the flood. However, the lands along a section of the escape route were unlawfully exploited for residential use and the development of communities. As a result, during the 2019 flood, Salahdin Escape could not be used as a flood escape.

Consequently, planning and managing flood escape from Lake Hemrin has become a significant study topic.When designing a flood escape route, many factors should be considered, including geology, geographical settings, and cut and fill expenses [2]. Other considerations include enhancing the social advantages of the waterways to local towns and agricultural uses and benefiting as many people as feasible. Because these factors are interconnected and complex due to their dynamic nature [2], research is required to determine the optimum routes to escape the flood waves from Lake Hemrin and away from Diyala River.

A geographic Information System (GIS) is a system for storing, organizing, analyzing, and displaying geographical data that can be used to conduct spatial analysis to determine the optimum pathways for avoiding flood waves from Lake Hemrin and away from Diyala River. With its spatial modeling capability, GIS provides essential data analysis tools for calculating elevation profiles from Digital Elevation Models (DEM), estimating the volume of cut and fill along with a selected route [2]. In addition, it recommends routes based on predefined conditions such as distance from roads, population density served, and crossing or not residential areas. Furthermore, Multicriteria Decision Making (MCDM) is a method for weighing the factors that contribute to the selection of the best flood escape routes [5]. MCDM is based on expert views and tries to determine a numerical weight for each factor so that their contributions to the process's purpose are weighted depending on their relevance. Both GIS and MCDM require data as inputs to perform spatial analysis, such as identifying the best flood escape routes. Remote sensing is widely regarded as the primary source of spatial information [6], and it includes aerial photographs captured by sensors mounted on airplanes, sensors onboard spaceborne satellites, Unmanned Aerial Vehicles (UAVs), Light Detection and Ranging (LiDAR), and Synthetic Aperture Radar (SAR).

A review of flood mitigation methods was presented by [7]. They discussed methods that belong to nature-based solutions. They also provided a synopsis of several factors influencing the flood events, including Land-Use/Land Cover (LULC), topography, hydrometeorology, and river hydraulics. Tariq et al. [8] used satellite images from Landsat 8 with an integrated HEC-RAS and GIS to characterize the 2014 flood of the Indus River in Pakistan. They demonstrated that using a hydrological model and satellite images for flood mapping and flood damage assessment is beneficial in informing the development of risk mitigation strategies. Ghali et al. [2] presented a study on developing a flood escape channel away from Diyala River from Hemrin Dam. They intended to tackle the problem that may occur if Hemrin Dam reaches its maximum capacity, resulting in genuine risk of heavy floods. They utilized HEC-RAS to create a one-dimensional hydraulic model for the flood escape so that the flood wave may be discharged via it. The escape route branches off Hemrin Lake and travels south through Diyala Governorate until it reaches Ashweicha Marsh.

River floods cause catastrophic direct damage and fatalities and have far-reaching and long-term economic consequences [9]. Although the observed increase in flood impacts may be ascribed primarily to population and economic expansion in flood-prone regions, the predicted intensification of floods due to climate change may represent a significant threat to future generations [10]. Therefore, research on flood management should continue, particularly in many developing countries affected by monsoon floods. However, more accurate and appropriate data might be needed to keep the cost optimal. As a result, the high price of radar data or fine spatial resolution data, as well as limited coverage in these areas, might be a challenge for most developing countries. Therefore, it is necessary to research low-cost but effective flood management strategies for these countries. Locally, previous studies have indicated the necessity to construct additional flood escapes to discharge flood waves from the Lake Hemrin and keep Diyala Governorate safe after the real flood risks in recent years, similar to the flood of 1988 [4]. Therefore, designing flood escape pathways based on only geometric characteristics may not achieve the best options. However, additional factors such as population density, land cover, and road networks will contribute to better flood escape pathways design.

This study integrates remote sensing and GIS using MCDM to manage flood hazards in Hemrin Reservoir by determining optimal pathways of flood escapes from Hemrin dam and away from Diyala River. It aims to provide geomatics-based solutions for constructing flood escapes away from Diyala River. The specific objectives are to (1) extract, prepare, and rank factors that contribute to the decision of selecting optimal pathways for flood escape from Hemrin dam and away from Diyala River, and (2) generate flood escape pathways using optimization methods such as Genetic Algorithm (GA), utilizing the ranking factors. The research novelty is an approach based on GA-based optimization, which could automatically suggest pathways for flood escapes in the area in a way that can be constructed at low cost, serve more people, and have additional social benefits.

2. Study Area and Datasets

2.1 Study Area Description

Lake Hemrin is a significant lake in Iraq, located in the middle of Diyala River, a major tributary of the Tigris (34°06′45″ N–44°58′11″ E) [11]. The dam is located about 120 km northeast of Baghdad and 10 km upstream from Diyala Weir. It was constructed in 1981 for flood control, hydropower generation, and irrigation and to reregulate river flows for downstream water management. The total area of the Hemrin Dam watershed is 12,822 km^2, with 68 % of it in Iraq and the remainder in Iran. The total capacity of Hemrin Reservoir is 3.76 billion cubic meters. The Hemrin Dam system in Iraq is a difficult water resources challenge since it is located in a semi-arid region of the Middle East with various socioeconomic and environmental management issues [12].

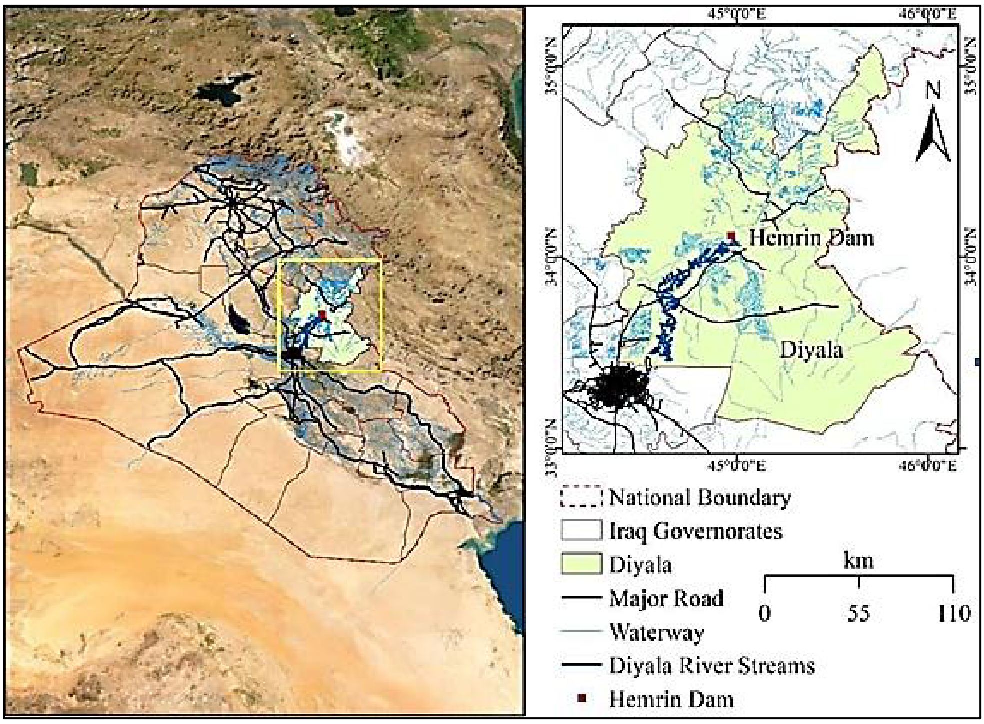


Figure 1: Map of the study area

2.2 Datasets

2.2.1 Landsat images

Landsat images are rich spatial information sources frequently utilized in various remote sensing applications such as urban, water resources, and environmental monitoring [13, 14]. Landsat satellites offer high-quality, moderate-resolution images of the Earth's surface.

Two images of Landsat 8 (OLI) at each period (before and after the 2019 flood) were obtained from the USGS website (https://earthexplorer.usgs.gov/) to cover Diyala River basin for this study. The two periods were January 16, 2019 (before the flood event) and April 22, 2019 (after the flood event). As a Level-2 product, the image datasets were obtained (Level-1 and atmospheric corrections).

2.2.2 Digital elevation model (DEM)

There are several sources to get DEM data for the Earth's surface. The ASTER Global Digital Elevation Model (GDEM), released in June 2009, is one source. The DEM data is created from stereo-pair images acquired by Terra's ASTER sensor. ASTER GDEM covers 99 percent of the Earth's surface from 83 degrees north to 83 degrees south latitude. The new GDEM V3 features more stereo pairs, greater coverage, and fewer artifacts. GDEM V3 has a spatial resolution of 30 meters. The root means square error (RMSE) measured for GDEM v3 is 8.52 meters [15]. In this study, GDEM data were obtained in 2019, retrieved from the Earth data website, and given in GeoTIFF format with a spatial resolution of 30m x 30m Figure 2.

2.2.3 GIS Data

In addition to satellite imagery and DEM, numerous thematic layers were employed to assist the evaluation of flood hazards in the study area. Table 1 outlines the GIS layers utilized in this study. The primary datasets are area shapefiles (Iraq, Iraq governorates, Diyala), population statistics, and land cover.

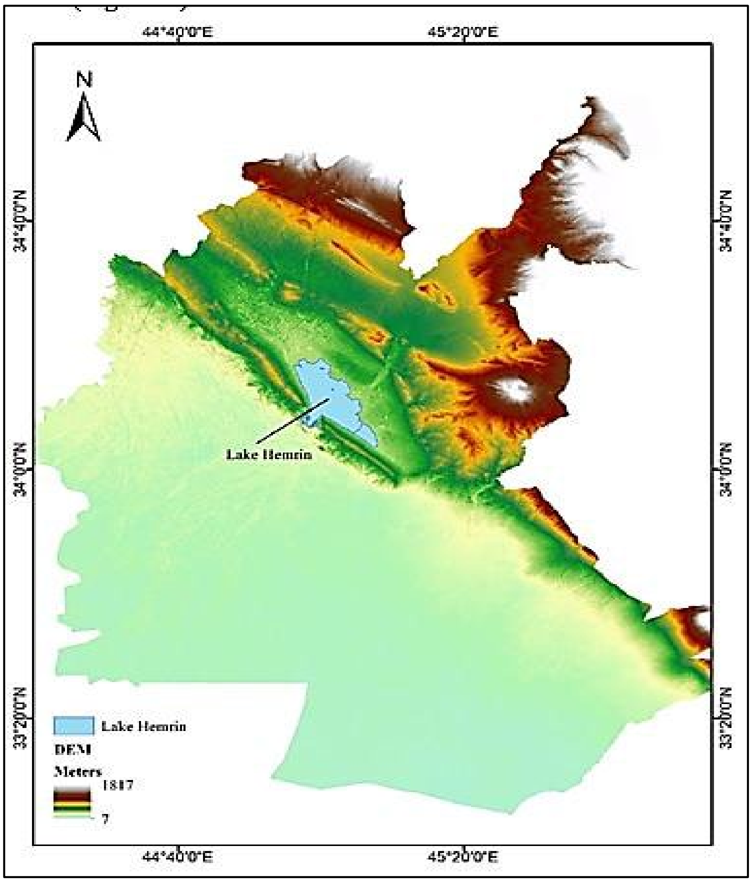


Figure 2: DEM of the study are

Table 1: Description of GIS datasets used in this research for flood hazard assessment

Data	Application	Source
Iraq governorates shapefile	The map of the study area and the spatial subset of the other data that has greater spatial coverage	GADM, version 4.0 - 2020
Land cover	Preparing conditioning criteria that are required for optimizing flood escape paths	Global Land Cover (GLC) - 2014
Population	Deriving population density, which is a conditioning criterion that is required to optimize the flood escape paths	CIESIN, Global gridded population database - 2018

3. Methodology

This research proposes a multi-criteria and multiobjective Genetic Algorithm (GA) optimization approach for designing flood escape paths. Landsat images were obtained and produced from the United States Geological Survey (USGS) (www. https://www.usgs.gov) before (January) and after (April) the 2019 flood event. ASTER Global Digital Elevation Model (GDEM) data was used to create a DEM of the region. A land cover map of the area was also obtained from the USGS, which contained the required data regarding land cover categories for the analysis in the current study. Furthermore, population data for the area was acquired from the Center for International Earth Science Information Network (CIESIN), a worldwide gridded population database. Finally, three flood escape plans have been collected and produced based on past research and relevant departments (e.g., Engineering Studies and Design Center, Ministry of Water Resources, and the Directorate of Diyala Water Resources, DDWR).

Two Landsat images were utilized to prepare data for extracting water indices. The DEM, on the other hand, was utilized to outline the area's watershed and stream network. The DEM was also used to calculate cut and fill volumes, which were then employed as a conditioning criterion for optimizing flood escape pathways. Several land cover types, including agricultural lands, residential areas, roadways, water bodies, and waterways, were identified and retrieved from the research area's land cover data. The gridded population data was utilized to determine population density in the area, which was then used as a conditioning criterion for constructing the best flood escape routes.

The agricultural and residential areas were used as inputs to the AHP method. However, in the multiobjective GA, the other three land cover categories, namely roads, water bodies, and waterways, were directly employed to influence the optimization of flood escape pathways. In the optimization phase, the population density calculated from the area's population data was also employed as a conditioning criterion. Five experts provided pairwise comparisons and their opinions on the relative relevance of each conditioning criterion. These comparative metrics were entered into the AHP technique, and a ranking of the criterion set was generated. Finally, after several iterations of optimization, the optimum flood escape pathways were generated using the flood escape suggestions as a starting point for the optimization based on the defined fitness function (based on weighted conditioning criteria).

Although this research developed a significant solution to suggest flood escape pathways using GA-based optimization automatically and by including several factors ranked by experts according to their importance, the methodology of this research has some limitations. First, only a general set of factors were considered. However, adding more socioeconomic, environmental, and hydrologic factors can improve the quality of the generated flood escape pathways. Ranking the factors was based on the standard AHP methods. However, other methods such as fuzzy AHP may also be considered. Finally, this research used the opinion of five experts to rank the factors influencing the flood escape pathways. Future works may ask more experts to understand better the interrelationship between the factors and their importance in finding optimal flood escape pathways.

3.1 Defining Conditioning Criteria

Five criteria were used as direct influential factors, weighted, and ranked by AHP using five expert opinions. Those criteria include agricultural lands, residential areas, population density, length of the path, and cut/fill volume Figure 3. Other criteria such as highways, main roads, powerlines, and oil pipelines were also included to guide the design of the best flood escape paths in the area.

3.2 Ranking Criteria with Analytic Hierarchy Process (AHP)

In planning flood escape routes, the set of conditioning criteria is important. The criteria, on the other hand, have distinct impacts and relevance. This study begins by determining weights and rankings for the criteria before sending them to a fitness function for optimization. The criteria are weighted and ranked using the AHP technique and the opinions of five experts.

Saaty [16] initially proposed AHP (1977), a multi-criteria decision-making approach. The factors are grouped hierarchically in this MCDM approach (including targets, standards, and plans). It is based on a pairwise comparison scale, in which the criteria are compared. Humans are regularly faced with situations where they must make decisions based on various variables. The AHP approach can give an optimal solution clearly by (a) qualitative and quantitative decision analysis, (b) easy assessment and representation of the solution via hierarchical model, (c) logical argumentation, (d) decision quality test, and (e) reduced time required. According to Saaty [17], AHP is ideal for making a choice that includes comparing decision factors and classifying them based on common characteristics. The decision components are ranked and compared between each pair in each group in the form of a matrix during the grouping phase. After that, each element's inconsistency ratio and weight will be determined. As a result, evaluating data consistency will be straightforward.

The AHP technique uses the ratio-scale form as an input, conveying one's viewpoint when faced with decision-making. The ratio's values are then arranged into a matrix known as the pairwise comparison matrix. Because of the limitations of human brainpower, the ratio scale is also restricted. The scale range 1–9 is believed to adequately represent human perception in the AHP technique [18].

By giving a measurement of assessment inconsistency, AHP can tolerate the discrepancy. According to the pairwise comparison, this measurement is one of the essential factors in the priority decision process. However, the evaluation result gets increasingly erratic as the consistency ratio rises. In most situations, a consistency ratio of less than or equal to 10% is acceptable. However, in rare cases, a consistency ratio of more than 10% is still considered acceptable [19]. The consistency ratio can be calculated using the Random Consistency Index (RI) Table 2. In this research, five experts with expertise in areas such as water resources (2 experts), civil engineering (1 expert), GIS (1 expert), and remote sensing (1 expert) were asked to provide pairwise comparisons among the conditioning criteria (length of paths, cut and fill volume, population density, agricultural lands, and residential areas) used to define the fitness function after ranking. The AHP technique was used to calculate the relative significance of each criterion and rank them accordingly after collecting expert pairwise comparisons.

3.3 Genetic Algorithm Optimization

The Genetic Algorithm (GA) is a method for optimizing evolutionary processes commonly used to fit parameters to experimentally observed data. GA can discover optimal solutions to various challenging optimization issues [20]. GA replicates the evolutionary processes of selection, reproduction, and mutation Figure 4. An initial population of potential solutions is produced to begin the optimal solution, which spans a predefined range of parameters. The core of the algorithm is the fitness function by which the evaluation of the individual solutions is rated. The higher the score of fitness function for a particular individual, the more likely this individual survives and is selected as a reproducing parent [20]. The entire population of the current generation is rated and ordered according to individual fitness. The selection principle commands that fitter individuals are more likely to reproduce than individuals of less fitness [20]. This mechanism ensures that the best individuals of a certain generation at least fit individuals better than the previous generation and therefore do not regress the algorithm. A mutation makes this optimization technique different from other optimization strategies, where a certain characteristic of a given individual is randomly changed. There are several possibilities to end the algorithm. The user can change everything, including the total number of generations, the total operating time, and minimal change in average fitness among generations. One drawback of GA is the relatively intensive use of computing resources and thus longer run times compared to other alternatives. However, in most situations, the assurance that it will uncover ideal solutions is worth the extra effort.

Table 2: Random Consistency Index (RI)

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

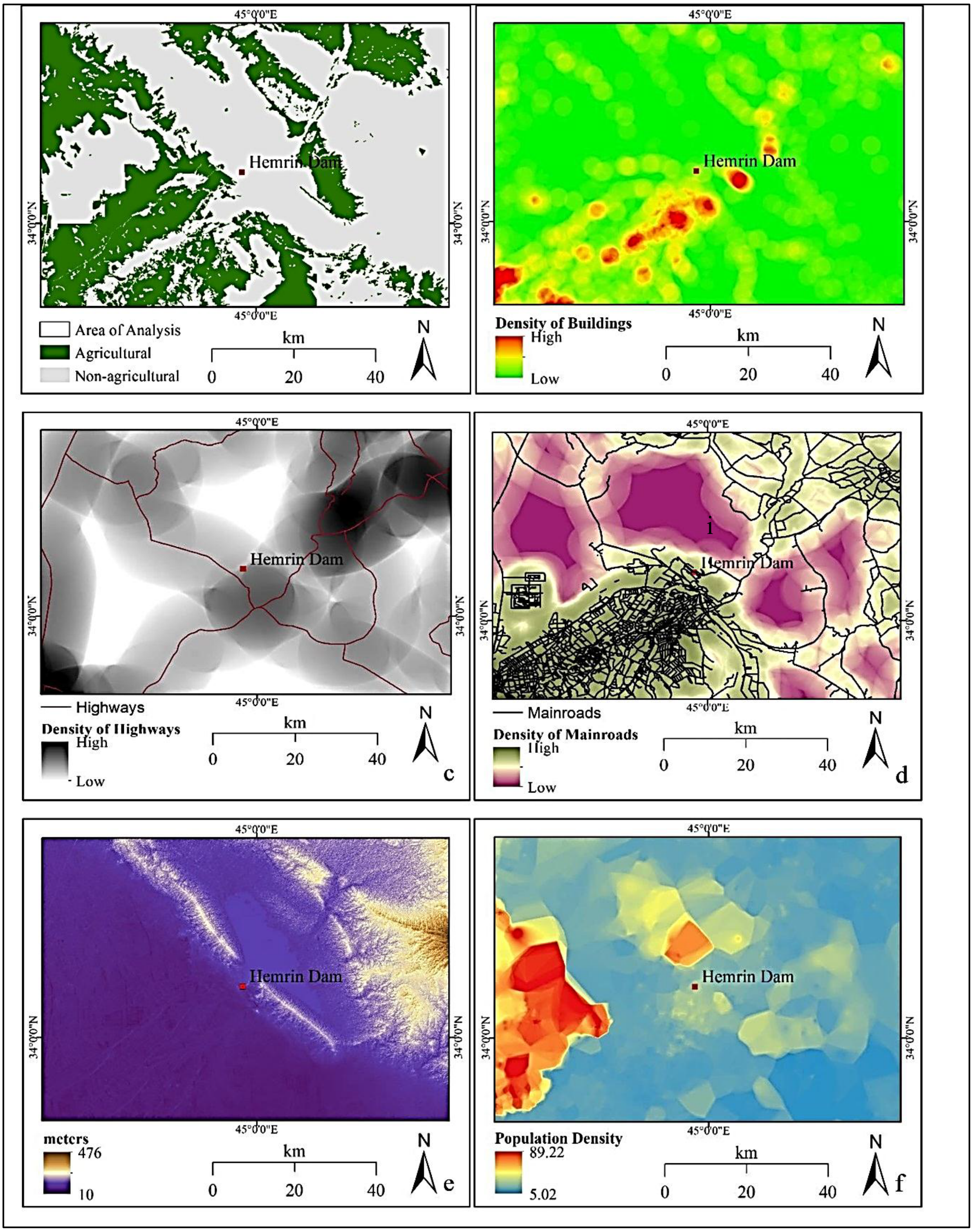


Figure 3: The maps of conditioning criteria were used to design optimal flood escape paths, (a) agricultural lands, (b) density of built-up areas, (c) density of highways,(d) density of main roads, (e) altitude, (f) population density, (g) density of powerlines, (h) density of oil pipes, and (i) land cover

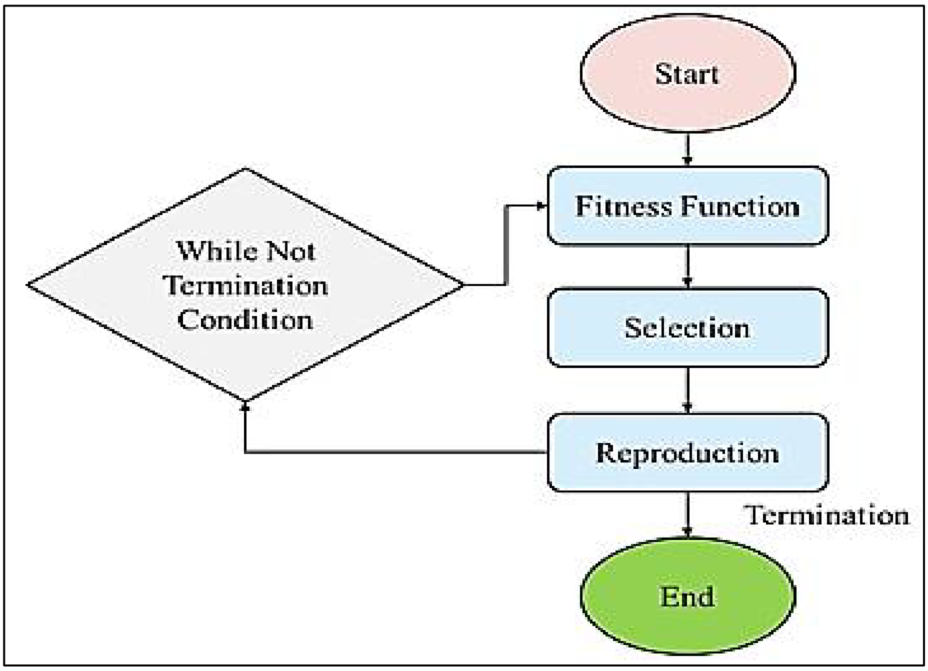


Figure 4: The basic structure of a GA (source Hariyadi et al. [21])

In this research, the developed GA was based on optimizing a multiobjective fitness function that contained several conditioning criteria and the weights obtained by the AHP method for each criterion. The process of the multiobjective GA is almost similar to the standard GA. However, its fitness function is defined to account for multiple variables.

Fitness is the core of a GA. The function takes an individual and determines the extent to which the algorithm satisfies any requirements. Everyone in the population should be fitness-functioned separately to decide if they are permitted to reproduce. The function can return a fitness score or a boolean for the individual to pass a certain reproduction threshold. This research developed the flowing fitness function (f) for the flood escape pathway problem:

$$f = w_l \times L + w_{cf} \times V_{cf} - w_p \times P - w_a \times A - w_r \times R + r + p + o \quad (1)$$

where w_l, w_{cf}, w_p, w_a, and w_r are the AHP-derived weights for the path length (L), cut and fill volume (V_{cf}), population density (P), agricultural lands (A), residential areas (R), conditioning criteria, r, p, and o represent the density of road networks, the density of powerlines, and the density of oil pipelines.

Flood escape path proposals for Hemrin Dam were also employed in this study Figure 5. Table 3 describes each of them. The three flood escape proposals are Adhaim River, Wadi Naft, and Salahdin. The data was used to develop the best flood escape pathways in the study area.

3.4 Assessment Methods

The optimal flood escape pathways were evaluated using the fitness function described in the GA and its factors (path length, cut and fill volume, agricultural lands, residential areas, and population density). In addition, the evaluation was conducted using statistical analysis to compare the proposed and optimum pathways.

Table 3: Description of the flood escape paths proposals

Flood Escape	Description	Length (km)
Flood Escape Proposal #1	Adhaim River	33.29
Flood Escape Proposal #2	Wadi Naft	27.85
Flood Escape Proposal #3	Salahdin	29.21

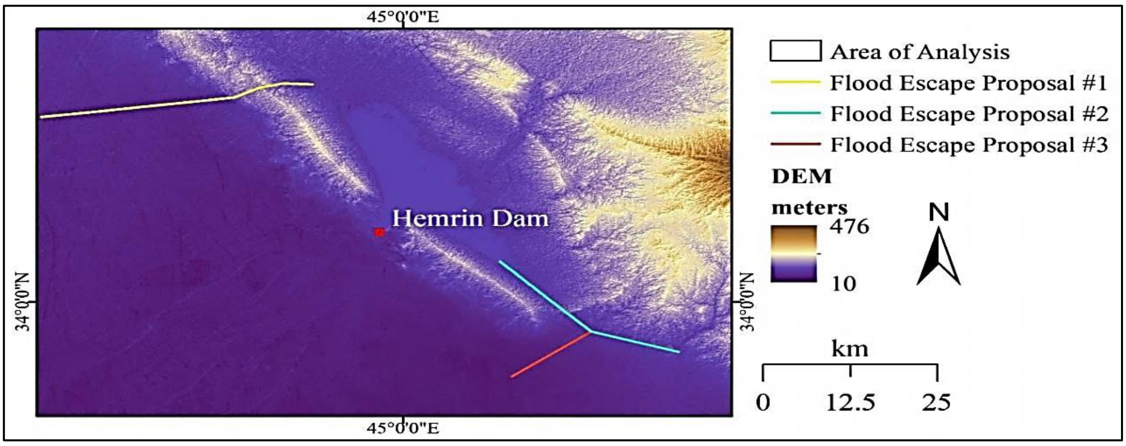


Figure 5: Proposals of flood escape paths in the study area

4. Results and Discussion

The research area of Diyala has experienced a significant and costly threat of floods, which are generally caused by heavy rain. The recent flood in Diyala, which happened in 2019, caused considerable damage to numerous communities, orchards, and agricultural lands located in Diyala River basin. The major findings from flood mapping and hazard assessment studies, as well as flood escape path optimization, are presented in this chapter. This chapter also explains the major results and key concepts acquired from the research.

4.1 Results of AHP (Weighting Conditioning Criteria)

This research used five main conditioning criteria (path length, cut and fill volume, population density, agricultural lands, and residential areas) to optimize the flood escape paths proposed in past research and relevant departments. In addition to those five criteria, other factors such as road network, powerline, and oil pipeline were also considered in the optimization process. The first five criteria were weighted using the proposed AHP method. Next, five experts were asked for their opinion about each criterion and its importance to the flood escape path design, and a pairwise comparison matrix was obtained from each expert. Next, the AHP method was applied to estimate the conditioning factors' average weight (by geometric mean, Equation 2). Finally, ranks were obtained based on the calculated average weights.

$$\bar{x} = \left(\prod_{i=1}^{n} x_i\right)^{\frac{1}{n}} \tag{2}$$

where $\bar{x}$ is the geometric mean of a given set of weights, n is the number of experts, and x_i is the weight given by an expert (i).

The pairwise comparisons of the conditioning criteria provided by the five experts are shown in Table 4. Expert #1's results indicate that the length of the flood escape path and the cut and fill volume are more significant than the other criteria, such as agricultural lands, population density, and residential areas. Expert #1 believes population density and residential areas are similarly critical but less significant than agricultural lands. Unlike Expert #1, the second Expert judged the flood escape path's length to be twice as significant as the cut and fill volume. Expert #2, like the first expert, believes that the length of the flood escape path and the cut and fill volume are more significant than the other criteria. Expert #2 has a different perspective on population density and residential areas. He considers population density to be two times more significant than residential areas. Expert #2 agrees with Expert #1 those agricultural lands are a more significant criterion than population density and residential areas. Expert #3 believes that the cut and fill volume is twice as significant as the length of the flood escape path. Expert #3 agrees with Experts #1 and #2 that the length of the flood escape path and the volume of cut and fill are more important than the other three criteria. According to Expert #3, population density is three times more important than residential areas. He also considered agricultural areas more critical than population density and cut and fill volume. Expert #4 thinks that the cut and fill volume is more important than the length of the flood escape path. Expert #4 assigned a relative importance of four to the cut and fill volume and one to the length of the flood escape path. Expert #4 also agrees with previous experts that the abovementioned factors are more important than population density, residential areas, and agricultural lands. In his opinion, population density is twice as important as residential areas. Furthermore, Expert #4 believes that agricultural lands are more essential than population density and residential areas. According to the data provided by Expert #5, the cut and fill volume is considerably valued (relative importance = 6) compared to the length of the flood escape path (relative significance = 1). The data also reveals that both criteria are more important than the other three, i.e., population density, residential areas, and agricultural lands. In addition, he believes that the population density is three times more significant than that of the residential areas. Expert #5 like other experts, believes agricultural lands are more essential than population density and residential areas.

Table 4: Pairwise comparisons were provided by the five experts for the five conditioning criteria

		Length	Cut and Fill	Population	Agricultural	Residential
Expert #1	Length	1.00	1.00	3.00	2.00	4.00
	Cut and Fill	1.00	1.00	3.00	4.00	5.00
	Population	0.33	0.33	1.00	0.50	1.00
	Agricultural	0.50	0.25	2.00	1.00	3.00
	Residential	0.25	0.20	1.00	0.33	1.00
Expert #2	Length	1.00	2.00	4.00	3.00	3.00
	Cut and Fill	0.50	1.00	2.00	3.00	4.00
	Population	0.25	0.50	1.00	0.33	2.00
	Agricultural	0.33	0.33	3.00	1.00	4.00
	Residential	0.33	0.25	0.50	0.25	1.00
Expert #3	Length	1.00	0.50	3.00	2.00	4.00
	Cut and Fill	2.00	1.00	3.00	3.00	4.00
	Population	0.33	0.33	1.00	0.25	3.00
	Agricultural	0.50	0.33	4.00	1.00	5.00
	Residential	0.25	0.25	0.33	0.20	1.00
Expert #4	Length	1.00	0.25	4.00	3.00	5.00
	Cut and Fill	4.00	1.00	5.00	4.00	6.00
	Population	0.25	0.20	1.00	0.25	2.00
	Agricultural	0.33	0.25	4.00	1.00	4.00
	Residential	0.20	0.17	0.50	0.25	1.00
Expert #5	Length	1.00	0.17	3.00	2.00	4.00
	Cut and Fill	6.00	1.00	5.00	4.00	6.00
	Population	0.33	0.20	1.00	0.33	3.00
	Agricultural	0.50	0.25	3.00	1.00	4.00
	Residential	0.25	0.17	0.33	0.25	1.00

Table 5 shows the weights and rankings of the five conditioning criteria, as calculated using the AHP method and data given by the five experts. The results are statistically acceptable because the Consistency Ratio (CR) determined based on the data provided by each expert is less than 10%. Therefore, 7.14 % is the average CR. The geometric mean is used to compute the average weights. The calculated weights are 26.64 for the length of the flood escape path, 40.21 for the volume of cut and fill, 8.58 for the population density, 16.70 for the agricultural lands, and 5.58 for the residential areas. As a result, the criteria were ranked from most important to least important: volume of cut and fill, length of flood escape path, agricultural lands, population density, and residential areas.

Table 5: AHP calculated weights and ranks of the five conditioning criteria

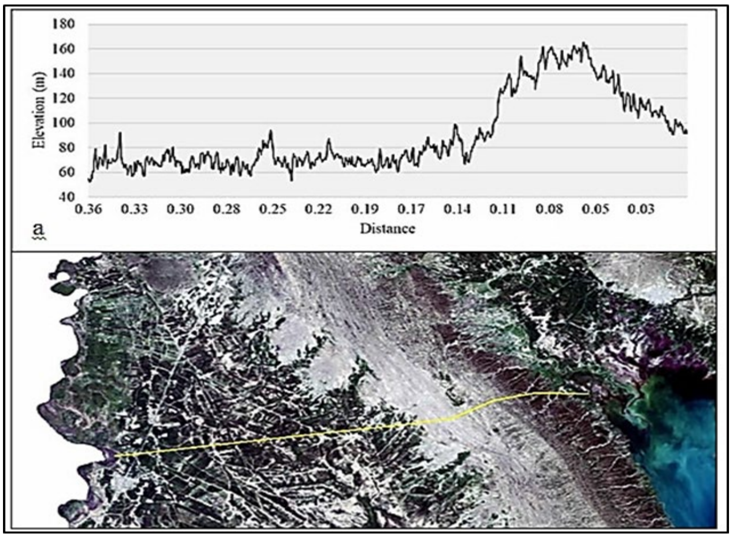
Criteria	Expert #1	Expert #2	Expert #3	Expert #4	Expert #5	Geometric Mean	Rank
Length	30.3	38.4	25.7	24.3	18.5	26.64	2
Cut and Fill	37.8	27.3	38	49.6	54.1	40.21	1
Population Density	9.1	9.8	9.8	6.6	8.1	8.58	4
Agricultural Lands	15.6	17.9	21.1	14.9	14.8	16.70	3
Residential Areas	7.1	6.7	5.4	4.6	4.6	5.58	5
CR	2.7%	7.9%	7.8%	8.5%	8.8%	7.14%	------

4.2 Optimizing Flood Escape Paths

Three flood escape pathway proposals are available, suggested by past research and relevant departments (Engineering Studies and Design Center, Ministry of Water Resources, and the Directorate of Diyala Water Resources, DDWR, [2]), including the Adhaim River, Wadi Naft, and Salahdin pathways. Each pathway has challenges, including construction costs, passing through inhabitant areas, etc. The length of the proposed pathways is for Adhaim River (33.82 km), Wadi Naft (26.65 km), and Salahdin (27.39 km). Based on the DEM data, the cut and full volume of these pathways, if constructed with a 258.7 m width of spillway cross-section [2], would be for Adhaim River (46.17 km^3), Wadi Naft (4.14 km^3), and Salahdin (9.83 km^3) (Table 6).

Table 6: Length and cut/fill volume of the flood escape pathways

Flood Escape Pathway	Length (km)	Cut and Fill Volume (km^3)
Adhaim River	33.82	46.17
Wadi Naft	26.65	4.14
Salahdin	27.39	9.83



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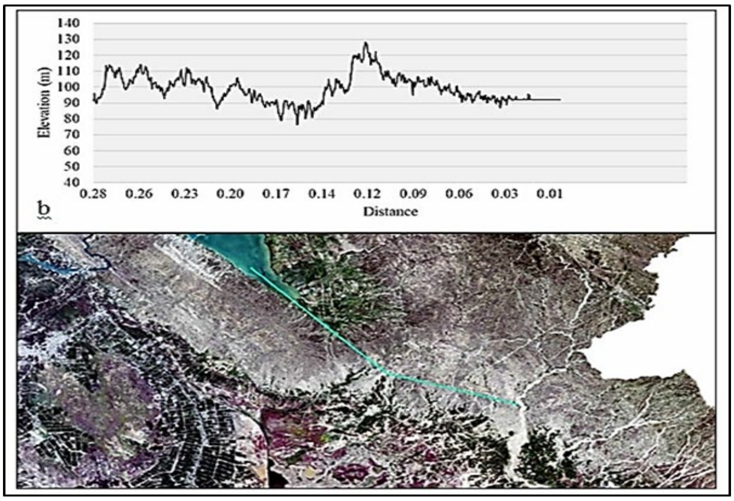
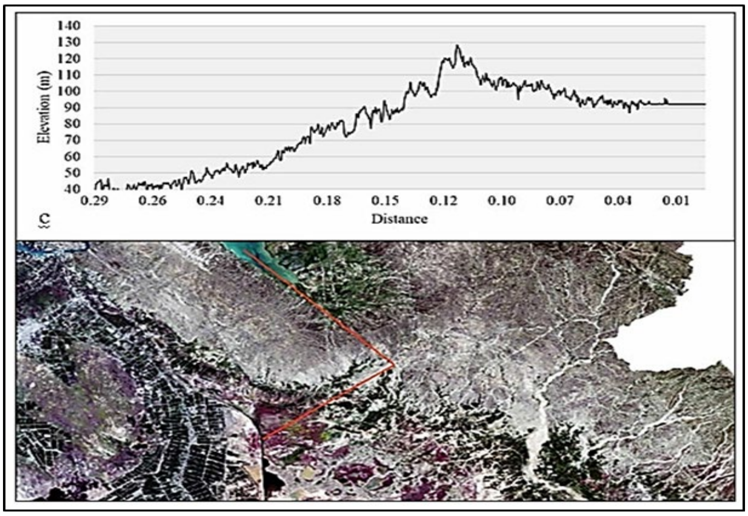


b



c

Figure 6: Elevation profile of (a) Adhaim River, (b) Wadi Naft, (c) Salahdin

The elevation profiles of the pathways are shown in Figure 6. It can be seen that the Adhaim River proposal passes through Hemrin Mountains, which can be very costly due to the cut-and-fill operations in those areas. Nevertheless, after Hemrin Mountains, the pathway almost follows the geography of the lands, which can have very few cut and fill operations. The Wadi Naft pathway has less cut and fills volume (4.14 km3) due to the nature of the land's topography. However, it may not be optimal due to other factors, including the agricultural and residential areas it serves. The Salahdin pathway, on the other hand, follows the path of Wadi Naft's proposal for the first 16.5 km. Then, it is directed toward the east south. Its cut and fill volume is estimated to approach 9.83 km^3, higher than the Wadi Naft. However, it can avoid some other challenges, including serving the agricultural and residential areas in a better way, compared to the Wadi Naft proposal.

Table 7 summarizes the results of optimizing the flood escape proposals using the GA-based optimization method. Several conditioning criteria were used to search for optimal paths starting from the initial proposals. Five criteria, i.e., path length, the volume of cut and fill, population density, agricultural lands, and residential areas, were included with expert-based weights in the optimization process. The results of the optimization were polylines indicating the pathway of the flood escape. Compared to the original proposals, the optimal paths have shorter lengths and require less cut and fill volumes, as presented in Table 7 and Figures 7-9. In addition, the optimal pathways can serve more people and agricultural lands. Moreover, the optimization process also considered road networks, powerlines, and oil pipelines which can be avoided as much as possible. Therefore, optimizing the proposed flood escape pathways can help better flood hazard management in Diyala River.

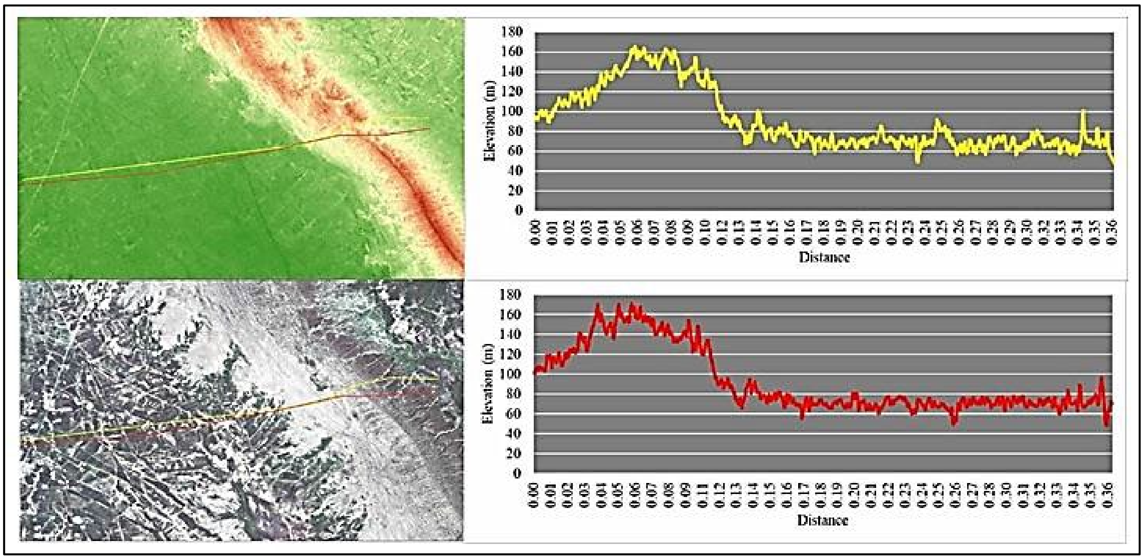


Figure 7: Optimized pathway for the Adhaim River flood escape

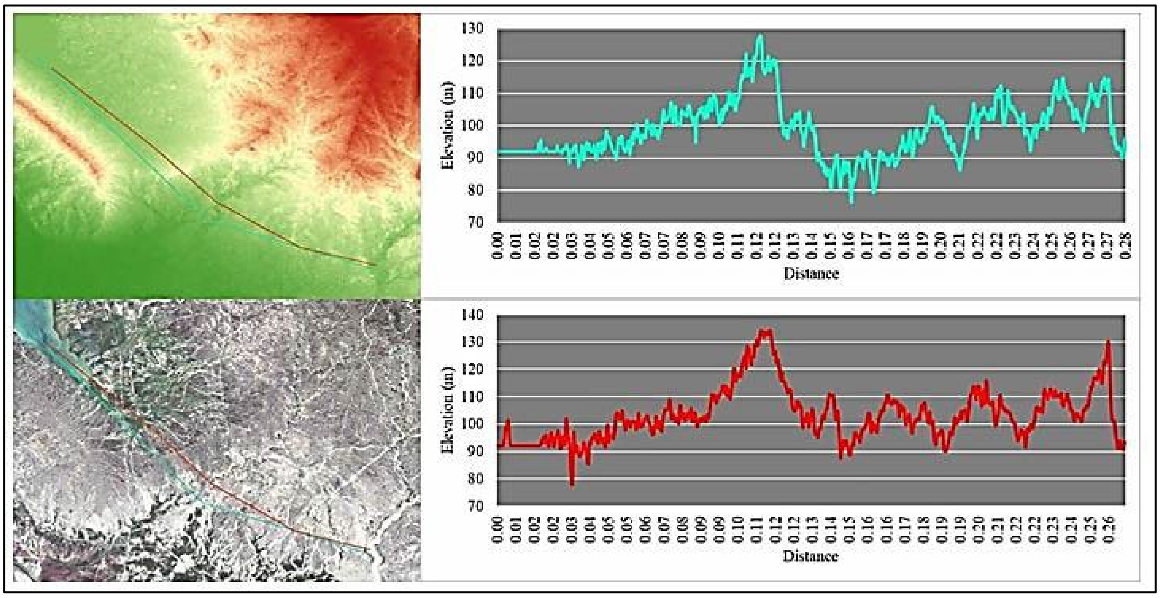


Figure 8: Optimized pathway for the Salahdin flood escape

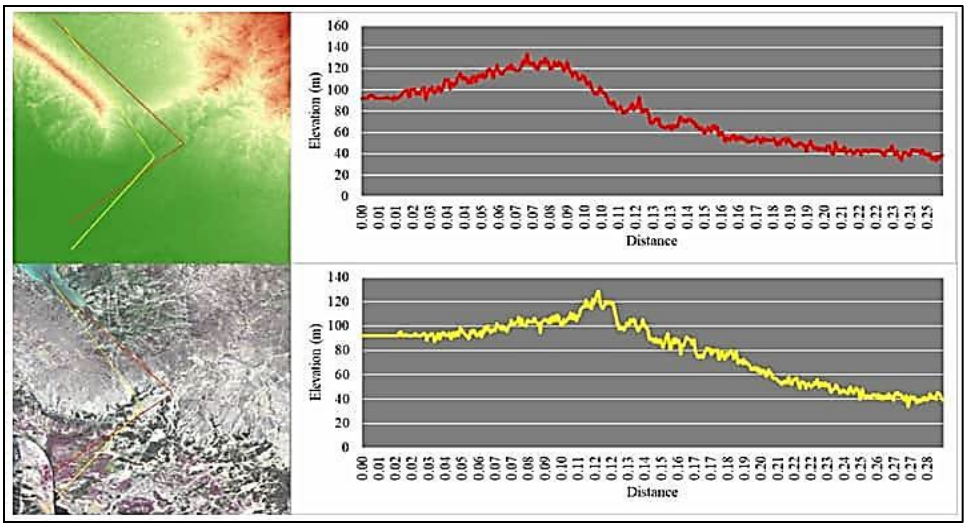


Figure 9: Optimized pathway for the Wadi Naft flood escape

Table 7: Length and volume of cut and fill of the optimal flood escape pathways

Flood Escape Pathway	Length (km)	Cut and Fill Volume (km^3)
Adhaim River	32.65	34.33
Wadi Naft	25.75	3.88
Salahdin	26.50	8.40

5. Conclusions

This research explored the optimization of flood escape pathways for Hemrin Reservoir to divert water during flood seasons away from Diyala River. There are three flood escape proposals in Diyala River basin to divert water away from Hemrin Reservoir and Diyala River during flood seasons: Adhaim River, Wadi Naft, and Salahdin. However, these flood escapes are not optimized. This research aimed to optimize the flood escape proposal starting from what has been proposed and considering several factors. These factors are the length of the pathway, the volume of cut and fill population density, agricultural lands and residential areas, and three additional conditioning factors, including road networks, powerlines, and oil pipelines. Using GA optimization and the AHP method, the proposed pathways were optimized. Optimizing the flood escape pathways using GA and AHP methods showed that those models can find shorter pathways that need less cut and fill costs while preserving other characteristics of flood escapes. Also, the models consider other factors such as population density, agricultural lands, and residential areas, which can also be a plus for the pathways to serve more people and have more social benefits.

The research contributed to the design and develop an MCDM approach for ranking factors affecting the decision process of selecting pathways of flood escapes specific for the case study of this research. A novel approach based on GA-based optimization is proposed for an automatic suggesting pathway for flood escapes in the area in a way that can be constructed with low cost, serve more people, and has additional social benefits. Future works should focus on the following points. First, designing optimization methods that are unrestricted to an initial proposal can be considered. This means the optimization model can generate pathways anywhere within Diyala River, starting from nearby Hemrin Lake. This way, the area can be explored, and maybe better pathways can be found. This includes drop structures into the pathways when they are found by the optimization model. This way, the generated pathways are not only optimized for geometry but also consider hydrologic factors. Better optimization models can be designed that automatically find the best crest levels as well as the width of the spillway. Finally, more data can further strengthen the optimization process, such as climatic variables, precipitation, and temperature.

Author contribution

All authors contributed equally to this work.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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