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# Assessment of Flood Risk Reduction Through Integrated Dike and Dam Interventions: A Case from Northeastern Jordan

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**ABSTRACT**
Floods and flash floods are important natural hazards in arid and semi-arid regions, where intense rainfall events can generate rapid surface runoff and cause significant environmental and socioeconomic impacts. This study assessed peak flood discharges and evaluated proposed structural interventions for flood mitigation in the Faa catchment, Mafraq Governorate, northeastern Jordan. Geographic Information System (GIS) tools were used to delineate contributing sub-watersheds and determine key hydrological and topographical parameters, including flow-path length and watershed slope. The time of concentration was estimated using the Kirpich equation and used to calculate rainfall intensities for 10-, 25-, and 50-year return periods. Runoff coefficients were determined based on land use, soil characteristics, hydrologic soil group, slope, and storm recurrence intervals. Peak flood discharges were subsequently estimated using the Rational Method. Two scenarios were evaluated: individual implementation of the proposed dikes and dam and simultaneous implementation of all interventions. Under the individual-intervention scenario, the estimated peak discharge at the dam was 35.70 $m^3/s$ for the 25-year return period, whereas under the combined-intervention scenario it decreased to 17.64 $m^3/s$. The results demonstrate the potential of integrated dikes and dam interventions to reduce downstream flood flows and support flood mitigation and water harvesting in the Faa catchment.

***Key words*:** Flood Discharge; Flood Mitigation; Flash Floods; GIS; Rational Method.

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## I. Introduction:

Flash floods are an important hydrological hazard in arid and semi-arid regions, where intense rainfall events can generate rapid surface runoff and cause significant impacts on urban areas, agricultural land, and infrastructure. In Jordan, the limited and highly variable rainfall, together with the increasing pressure on land and water resources, makes effective flood management particularly important. Mafraq Governorate, located in the northern part of Jordan, experiences an arid to semi-arid climate characterized by relatively low annual rainfall and concentrated winter precipitation. In addition, changes in land use and the expansion of impervious surfaces can alter natural runoff processes and increase the volume and velocity of surface water during intense rainfall events.

Previous research reported that urban expansion within the Mafreq city has modified the natural surface hydrology and increased surface runoff, resulting in flooding in the western and central parts of Mafraq City. Al-Amoush *et al.* (2017) used GIS-based analysis to identify suitable locations for water-harvesting structures within the Wadi Al-Mafraq catchment, considering rainfall, soil texture, slope, vadose-zone materials, and drainage density. Their results demonstrated the potential of integrating GIS techniques with field-based geophysical investigations to support flood management and water-harvesting site selection.

Despite these efforts, there is a continuing need for quantitative assessment of flood discharges and the evaluation of structural measures that can reduce peak runoff and retain storm water within the catchment. The use of hydrological methods integrated with Geographic Information Systems (GIS) provides an effective approach for estimating flood flows, delineating drainage characteristics, and evaluating alternative flood-mitigation scenarios.

In Jordan, flash flood generation is an important concern because of the country's predominantly arid to semi-arid climate and the occurrence of intense winter rainfall events. AlMahasneh *et al.* (2023) applied a GIS-based hydrological assessment using the Rational Method to evaluate flash-flood hazard across Jordan, demonstrating the applicability of spatially distributed basin characteristics and hydrometeorological information for peak-discharge estimation and flood-hazard assessment. In Mafraq area, Al-Amoush *et al.* (2017) investigated the Wadi Al-Mafraq catchment and reported that changes in water flow, thereby reducing downstream peak discharge and potentially providing water for harvesting or other uses

This research aims to estimate the expected flood discharges and evaluate the effectiveness of proposed dikes and dam interventions in reducing flood risks and supporting sustainable water harvesting and watershed management.

## II. Methods And Material:

### 2.1 Study Area

The study area locates in Qada Hush, Qasbat Al-Mafraq, in east north of Jordan. The catchment lies between 411697 to 414894 E and 585410 to 589068 N (JTM), it is semi-arid to arid region with average annual rainfall less than 200mm and classified as Marginal area, (Fig1).

land cover and the expansion of impervious surfaces have altered surface runoff and contributed to flooding within Mafraq City. Despite these efforts, there remains a need to evaluate how alternative structural interventions, such as dikes, check dams, and earth dams, influence flood peak discharge under different return periods in the agricultural watersheds of northeastern Jordan. Therefore, the present study focuses on the Faa catchment in Mafraq governorate and applies the Rational Method within a GIS framework to estimate flood discharges and assess the effectiveness of alternative and combined structural-intervention scenarios for flood mitigation and water-resource management. So, dike is a raised embankment or barrier constructed along a river, channel, or flood-prone area to confine, divert, or prevent floodwater from spreading into surrounding areas. While the dam is a structure built across a river or drainage channel to store, regulate, or control

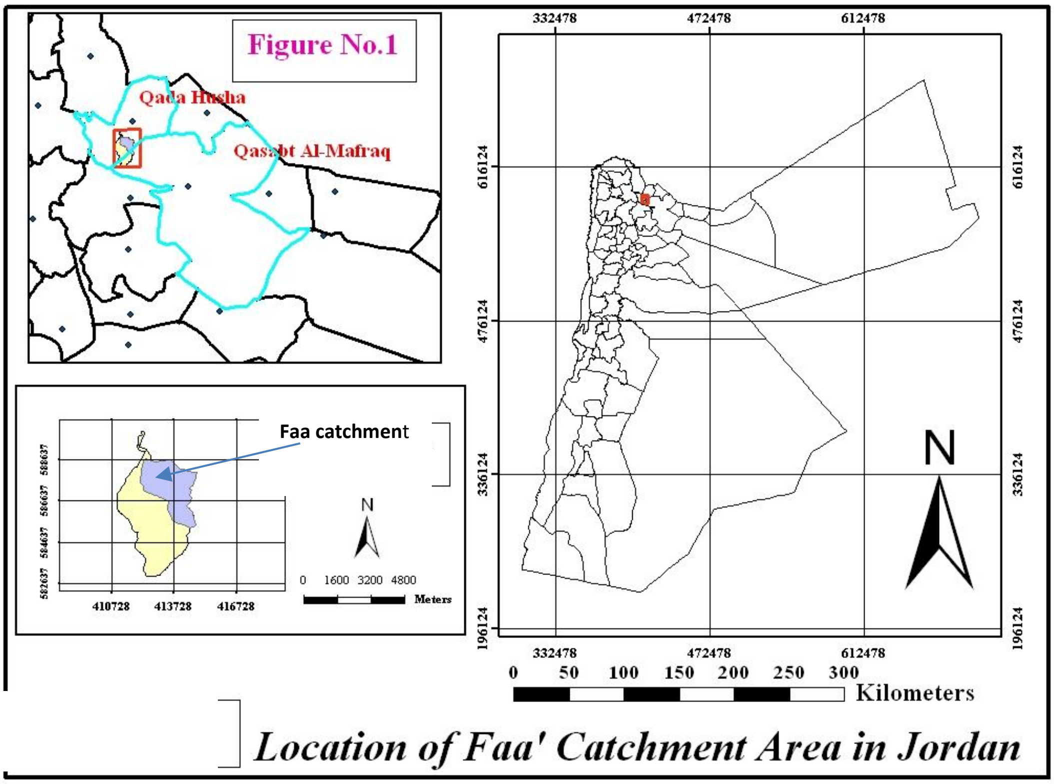


***Figure 1:*** *location map of the study area in Jordan*

catchment charectarized by hilly to undulating with frequent outcrops and colluvial cover on lower slopes, loamy soils of average composition and shallow to deep profiles prevail, about 5 -10% of the area is covered with stone and basalt rock. The slope ranges from 2-35% at the south and wadies, slope decrease at the north side. The climate of the area is semi-arid to arid, average annual rainfall in the area

The selected catchment named Faa with total area about 4456 Dunum. It is a marginal area between agricultural land and the desert areas, declining vegetation cover due to overgrazing and mismanagement contributes to land degradation, which has had a substantial impact on the production system, due to the moderate rainfall and runoff potential the area has potential for improvement, the

**2.3. Data Preparation, Processing, and Analysis**

The required datasets were collected from different sources and processed within a Geographic Information System (GIS) environment. The drainage network and sub-watersheds within the study area were delineated using the available topographic and spatial datasets. The area of each delineated sub-watershed was then calculated in square metres (m²) and used as an input for the flood discharge estimation (Fig 2).

Following the delineation and characterization of the sub-watersheds, potential locations for flood-mitigation interventions were identified. Two intervention scenarios were developed, considering the implementation of dikes and check dams at selected locations within the catchment (Figure 2). The proposed locations were selected based on the spatial characteristics of the drainage system and the suitability of the sites for reducing surface runoff and managing flood flows.

varies from 160 mm to 260 mm. The landuse classes were rangeland and annual crops as a dominant classes mixed by an olive farms and urbans.

**2.2. Flood Discharge Estimation**

The Rational Method was used to estimate the peak flood discharge generated from the selected sub-watersheds. This method is commonly applied for estimating peak runoff from relatively small catchments and is expressed as:

**Q = CiA**

where (Q) is the peak flood discharge, (C) is the runoff coefficient, (i) is the rainfall intensity corresponding to the time of concentration for the selected design storm, and (A) is the effective contributing catchment area. Rainfall intensity is expressed as rainfall depth per unit time, while the resulting peak discharge represents the maximum expected runoff rate from the contributing area.

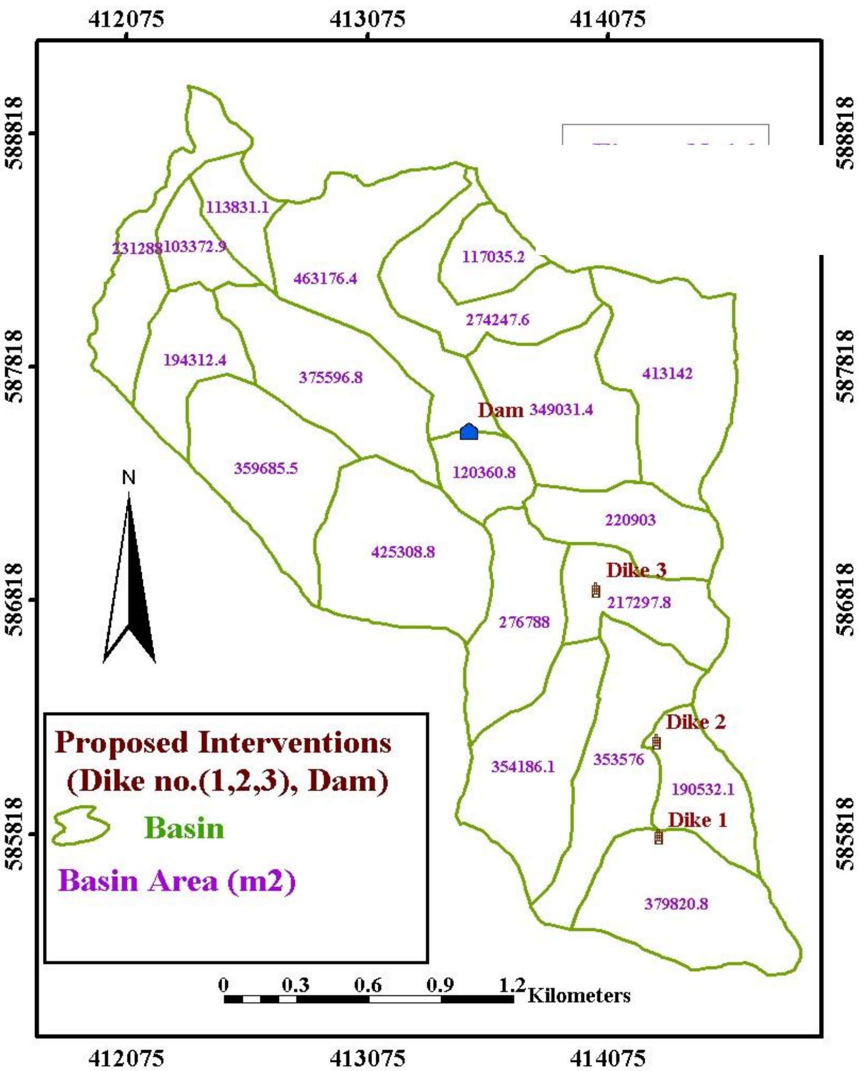


*Figure 2: Delineation of sub watersheds the location of the proposed interventions dikes and check dam were determined into two scenarios*

The Kirpich equation was used to estimate the time of concentration:

$T_c = 0.0078*(L^{0.77}/S^{0.385})$

where ($T_c$) is the time of concentration (min), (L) is the maximum hydraulic flow-path length (ft), and (S) is the average slope along the flow path (ft/ft).

GIS-based tools were used to delineate the flow paths and obtain the required topographic parameters for each proposed intervention location (AlMahasneh *et al.* 2025). The maximum flow-path length contributing to each proposed dike or check dam was identified and measured as (L) (Fig 3). The corresponding watershed slope along the selected flow path was then determined as (S). These values were substituted into the Kirpich equation to calculate the time of concentration for each intervention location. The calculated ($T_c$) values were subsequently used as the storm duration ((D)) in the respective rainfall intensity equations to estimate rainfall intensity for the 10, 25, and 50 year return periods.

**2.4. Rainfall Intensity and Time of Concentration**

Rainfall intensities corresponding to return periods (R.P) of 10, 25, and 50 years were estimated using empirical intensity duration relationships for the study area. The equations used to calculate rainfall intensity for the different return periods are presented in Table 8:

- R.P= 10 Years ----- i = (289.07/( 27.736+D))
- R.P= 25 years ----- i = (324.23/(27.969+D))
- R.P= 50 Years ---- i = 357.76/(26.864+D))

where (i) is the rainfall intensity and (D) is the storm duration, both expressed in consistent time units according to the empirical equations.

For application of the Rational Method, the storm duration was assumed to be equal to the time of concentration (($D=T_c$)). The time of concentration represents the travel time required for runoff generated at the hydraulically most distant point of a watershed to reach the outlet or the selected downstream intervention point (Chow et al., 1988).

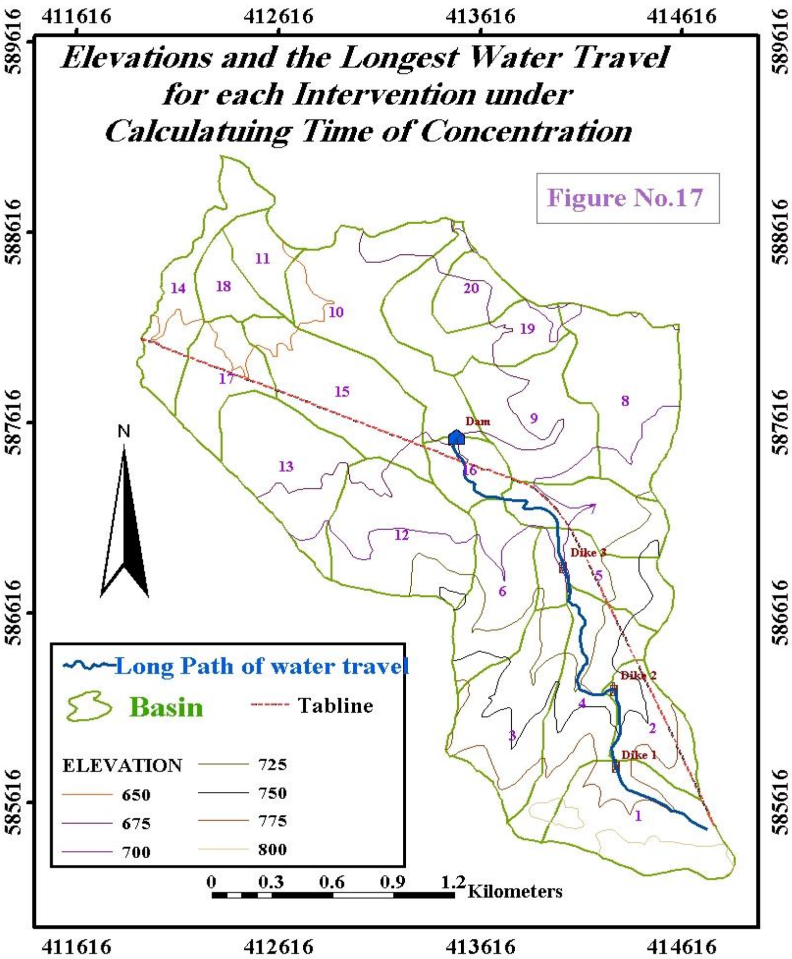


*Figure 3: longest path f water travel*

resulting (C) values were used together with rainfall intensity and contributing area in the Rational Method to estimate the peak flood discharge for each selected return period.

## III. Results And Discussion:

### 3.1 Flood Discharge Estimation

The calculated flow-path lengths and corresponding slopes varied among the proposed intervention locations (Table 7). Based on these parameters, the time of concentration ((T_c)) was calculated for each site using the Kirpich equation. The resulting (T_c) values were used as the storm duration in the rainfall intensity equations for the 10-, 25-, and 50-year return periods. The corresponding rainfall intensities and peak flood discharges calculated using the Rational Method are presented in Table 1.

Table1: required parameters length of water travel and slopes and number of feeding basins at each location of proposed interventions.

The runoff coefficient ((C)) used in the Rational Method represents the proportion of rainfall that contributes to direct surface runoff. The (C) values were selected based on the recommendations provided in Hydrologic Procedures for Computing Runoff from Small Watersheds. The selection of the runoff coefficient was supported by a biophysical characterization of the study watersheds, including slope, existing land use, and soil texture. The dominant soil textures in the study area range from silty clay loam to silty loam. The main land-use classes include annual crops, tree-covered areas, rangelands, and localized urban areas, while the watershed slopes generally range from 2% to 6%.

For each sub-watershed, the existing land-use and soil-texture characteristics were identified using GIS-based analysis. The hydrologic soil group (HSG) was subsequently determined based on the corresponding soil texture class and infiltration rate (IR), following the classification provided in the reference tables. These physical characteristics were then considered in the selection of appropriate runoff coefficients for the individual sub-watersheds. The

| Structure | ΔE (ft) | L (ft) | S (ft/ft) | $T_c$ = D (min) | No. of Feeding Basins |
|---|---|---|---|---|---|
| **Dam (R.P. = 50 years)** | 388.8 | 9,887.3 | 0.04 | 32.3 | 1 + 2 + 3 + 4 + 5 + 6 + 7 + 16 |
| **Dike 1** | 111.5 | 1,949.0 | 0.06 | 8.0 | 1 |
| **Dike 2** | 187.0 | 3,334.8 | 0.06 | 12.2 | 1 + 2 |
| **Dike 3** | 306.8 | 6,323.8 | 0.05 | 21.1 | 1 + 2 + 3 + 4 |
| **Dam (R.P. = 25 years)** | 388.8 | 9,887.3 | 0.04 | 32.3 | 1 + 2 + 3 + 4 + 5 + 6 + 7 + 16 |

by the 25 and 10 years storms. The resulting rainfall intensities were subsequently used in the Rational Method to estimate the peak flood discharge for each proposed intervention location.

The variation in rainfall intensity among the intervention sites was mainly associated with differences in the calculated time of concentration. Sites with shorter concentration times resulted in higher rainfall intensities for a given return period, whereas longer concentration times resulted in lower intensities.

These differences were subsequently reflected in the estimated peak flood discharges and were considered in evaluating the proposed dike and check-dam interventions. (Table2).

The time of concentration (($T_c$)) was calculated for each proposed intervention location using the Kirpich equation, with the storm duration assumed to be equal to ($T_c$), consistent with the application of the Rational Method. The calculated ($T_c$) values varied among the intervention sites according to differences in the maximum flow-path length and watershed slope.

Using the calculated time of concentration as the storm duration, rainfall intensities were estimated for the 10, 25, and 50 year return periods using the empirical intensity duration equations presented in Table 2. As expected, rainfall intensity increased with increasing return period, with the 50-year storm producing the highest intensity, followed

*Table 1: intensity*

| Structure | Tc = D (min) | Return Period (R.P., years) | Rainfall Intensity, I (inch/hr) |
|---|---|---|---|
| **Dam (R.P. = 50 years)** | 32.3 | 50 | 6.05 |
| **Dike 1** | 8.0 | 10 | 8.10 |
| **Dike 2** | 12.2 | 10 | 7.20 |
| **Dike 3** | 21.1 | 10 | 5.90 |
| **Dam (R.P. = 25 years)** | 32.3 | 25 | 5.70 |

and storm-frequency classes in the runoff coefficient tables.

The peak flood discharge was then estimated using the Rational Method by combining the corresponding rainfall intensity, runoff coefficient, and contributing area for each proposed intervention location. The resulting discharge estimates were used to evaluate the potential flood mitigation benefits of the proposed dikes and check dams under the selected design-storm conditions.

**3.2 Flood Discharge Estimation for Individual Interventions**

For the Faa catchment, flood discharge was initially estimated assuming that each proposed intervention would operate independently. Under this scenario, the estimated peak discharge at the proposed dam was 35.7 $m^3/s$ for the 25-year return period. At Dike 1, the estimated peak discharge was 7.38 $m^3/s$ for the 10-year return period. The calculated peak discharges and corresponding design conditions are presented in Table 3 and illustrated in Fig 4.

The Rational Method runoff coefficients ((C)) were selected based on the hydrologic characteristics of each sub-watershed, including land use, soil texture, hydrologic soil group, and slope, following the recommendations of *Hydrologic Procedures for Computing Runoff from Small Watersheds in Pennsylvania*.

The hydrologic soil group (HSG) of the study area was classified as Group C based on the soil characteristics reported in the available *Runoff Estimation Report*. Pasture was identified as the dominant land-use class within the Faa catchment. The watershed slope ranged from approximately 2 to 6%.

Based on the hydrologic characteristics of the catchment and the selected storm return periods, two runoff coefficient classes were considered. A runoff coefficient of 0.34 was applied for return periods of less than 25 years, whereas a coefficient of 0.42 was used for return periods of 25 years and longer. These values were obtained by intersecting the relevant hydrologic soil group, land-use, slope,

| Dike no. | A ($m^2$) | I (m/hr) | C | Q ($m^3$/hr) | Q ($m^3$/s) |
|---|---|---|---|---|---|
| Dam(R.P=50) | 2113464.8 | 0.15355872 | 0.42 | 136307.20 | 37.86 |
| Dike1 | 379820.00 | 0.206 | 0.34 | 26569.02 | 7.38 |
| Dike2 | 570352.9 | 0.18288 | 0.34 | 35464.09 | 9.85 |
| Dike3 | 1278115 | 0.14986 | 0.34 | 65123.03 | 18.09 |
| Dam(R.P=25) | 2113464.8 | 0.14478 | 0.42 | 128514.72 | 35.70 |

**Table 2: Assume every dike constructed alone**

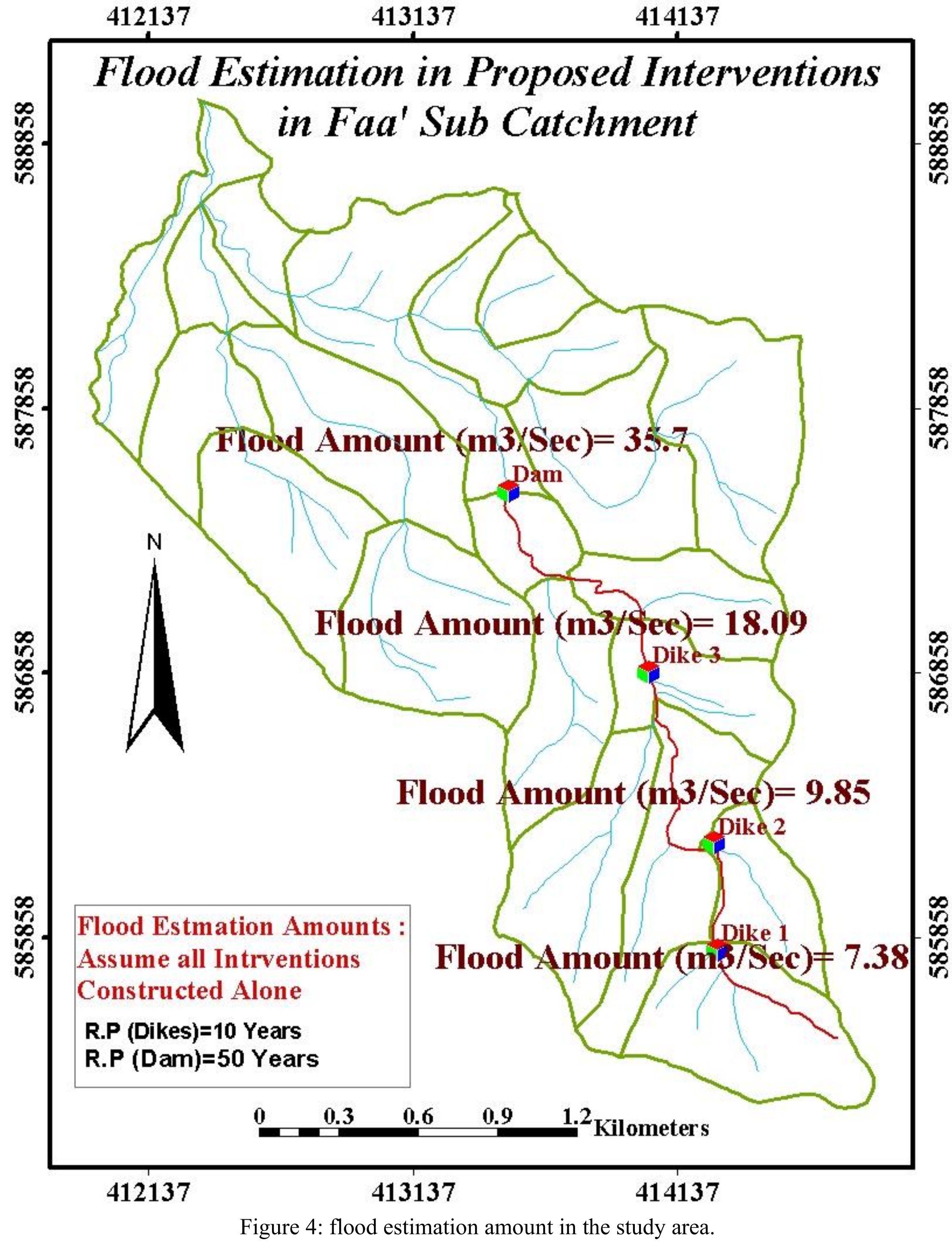


Figure 4: flood estimation amount in the study area.

was 17.64 m³/s for the 25-year return period. At Dike 1, the estimated peak discharge was 7.38 m³/s for the 10-year return period. The estimated discharges under this combined-intervention scenario are presented in Table 10 and illustrated in Figure 5.

**3.3 Flood Discharge under the Combined Intervention Scenario**

Under the second scenario, in which all proposed interventions were assumed to be constructed and operated simultaneously, the estimated peak flood discharge at the proposed dam

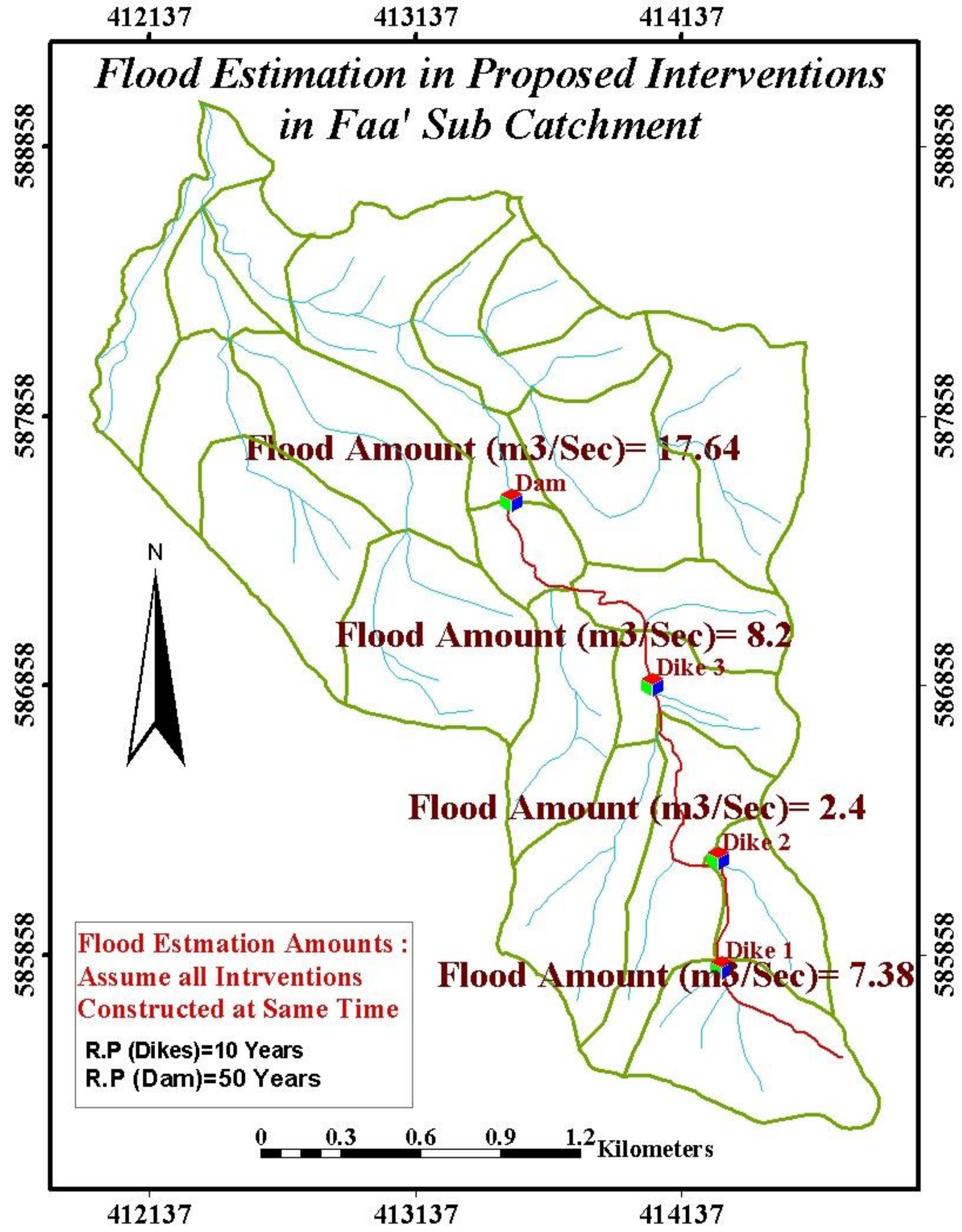


Table 3: Flood discharge (Assume all constructed at the same time)

| **Dike no.** | **Q ($m^3/s$)** | **NetQ ($m^3/s$)** |
|---|---|---|
| Dam(R.P=50) | 37.86 | 19.773 |
| Dike1 | 7.38 | 7.380 |
| Dike2 | 9.85 | 2.471 |
| Dike3 | 18.09 | 8.239 |
| Dam(R.P=25) | 35.73 | 17.64 |

reducing the volume of flow reaching the downstream dam.

The results also showed that the effect of the interventions differed among the proposed structures. Dike 1 retained its full estimated discharge of 7.38 $m^3$ $s^{-1}$ because it represents the first upstream intervention and does not receive the hydrological benefits of upstream structures. In contrast, the net discharge associated with Dike 2 was reduced from 9.85 to 2.47 $m^3/s$, while the discharge associated with Dike 3 was reduced from 18.09 to 8.24 $m^3/s$. These reductions demonstrate the cumulative effect of sequential interventions within the watershed and emphasize the importance of considering the hydrological connectivity between upstream and downstream structures.

Overall, the findings suggest that the proposed combination of dikes and a downstream dam could provide a more effective flood-management strategy than implementing individual structures independently. In addition to reducing downstream peak discharge, the proposed interventions could potentially contribute to water harvesting and improved utilization of stormwater in this arid environment. The integrated approach may therefore provide multiple benefits, including flood-risk reduction, runoff control, and increased opportunities for water storage and groundwater recharge. However, further hydrological modelling and field-based investigations are recommended to evaluate the storage capacity, hydraulic performance, and long-term effectiveness of the proposed structures under different rainfall events.

## IV. Conclusions

This study assessed peak flood discharges in the Faa catchment, Mafraq Governorate, using the Rational Method integrated with GIS-based spatial analysis. The results showed that the hydrological response of the catchment varied considerably among the proposed intervention locations due to differences in contributing area, flow-path length, watershed slope, time of concentration, and rainfall intensity.

The calculated time of concentration ranged from 8.0 to 32.3 min across the proposed intervention sites. These values were used to determine the corresponding design rainfall intensities for the selected return periods of 10, 25, and 50 years. The estimated peak flood discharges under the individual-intervention scenario ranged from 7.38 $m^3/s$ at Dike 1 to 37.86 $m^3/s$ at the dam site for the evaluated design conditions.

The results further demonstrated the advantages of implementing the proposed interventions simultaneously. Under the combined-intervention scenario, the net discharge reaching the dam was reduced to 19.77 $m^3/s$ for the 50-year return

The results demonstrate considerable spatial variation in the hydrological response of the proposed intervention sites within the Faa catchment. This variation was primarily associated with differences in contributing area, flow-path length, watershed slope, time of concentration, and rainfall intensity. The calculated time of concentration ranged from 8.0 min at Dike 1 to 32.3 min at the proposed dam site. As expected, shorter flow paths and higher slopes generally resulted in shorter concentration times. Consequently, Dike 1, which had the shortest time of concentration, was associated with the highest rainfall intensity among the sites evaluated under the 10-year return period.

Rainfall intensity varied according to both the selected return period and the calculated storm duration. The highest intensity was obtained for the 50-year return period at the dam site, reaching approximately 6.05 in $h^{-1}$, while the intensities estimated for the proposed dikes under the 10-year return period ranged from 5.90 to 8.10 in $h^{-1}$. The results confirm the importance of considering the time of concentration when estimating design rainfall intensity, as shorter storm durations were associated with higher rainfall intensities for a given return period.

The estimated peak flood discharges under the individual-intervention scenario showed substantial differences among the proposed sites. The largest peak discharge was estimated at the dam location, reaching 37.86 $m^3/s$ for the 50-year return period and 35.70 $m^3/s$ for the 25 year return period. This was mainly attributed to the large contributing area draining towards the dam site, which receives runoff from multiple upstream basins. In comparison, the estimated peak discharges at Dike 1, Dike 2, and Dike 3 were 7.38, 9.85, and 18.09 $m^3/s$, respectively. Although Dike 1 experienced the highest rainfall intensity among the dike locations, its relatively small contributing area resulted in the lowest estimated peak discharge. This highlights the combined influence of rainfall intensity, runoff coefficient, and contributing area on the peak discharge estimated using the Rational Method.

The combined-intervention scenario demonstrated the potential benefits of implementing the proposed structures as an integrated flood-management system (Giorgia *et al.* 2017). When all interventions were assumed to operate simultaneously, the net discharge reaching the downstream dam location was reduced from 37.86 to 19.77 $m^3$ $s^{-1}$ for the 50-year return period. Similarly, for the 25-year return period, the discharge at the dam was reduced from approximately 35.70 to 17.64 $m^3/s$. These results indicate that the upstream dikes could retain or divert part of the generated runoff, thereby period, compared with 37.86 m³/s when the structures were considered independently. For the 25-year return period, the estimated discharge at the dam was reduced from approximately 35.70 to 17.64 m³/s. These findings indicate that upstream dikes can substantially reduce the flood discharge reaching downstream areas when implemented as part of an integrated system.

The study confirms the usefulness of combining GIS analysis with the Rational Method for supporting preliminary flood-discharge estimation and evaluating potential structural interventions in small watersheds (AlMahasneh *et al.* 2025, Abuhamoor *et al.,* 2026). The proposed system of dikes and a downstream dam has the potential to reduce peak flood flows while improving storm water harvesting and watershed management in the Faa catchment (AlMahasneh *et al.* 2025). Future studies should incorporate detailed hydrological modelling, field validation, rainfall observations, and hydraulic analysis to further assess the design capacity and long-term performance of the proposed interventions.

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