*8th International Conference on Water Resources and Arid Environments (ICWRAE 8): 21-30*
22-24 January 2019*, Riyadh, Saudi Arabia*

# Assessment of Flash Flood Hazards Using GIS in Wadi Nisah, Central Saudi Arabia

*Mahmoud M. Abdelkader, Ahmed I. Al-Amoud, Tarek Zin El-Abedin.*

Agricultural Engineering Department, College of Food Science and Agriculture,
King Saud University, Riyadh, Saudi Arabia

**Abstract:** The aims of this research is to predict and assess the flash floods hazards in Wadi Nisah area. This work was conducted based on Multi-criteria decision analysis. This analysis has been done using the integration for applications of Geographic Information System (GIS), Remote Sensing (RS) to reach for final flood hazard map. The criteria of flood hazard mapping were Elevation, Derange density, Slope, Direct runoff depth at 50 years return period, Topographic witness index and Curve Number. The weight of each criteria based on Analytical Hierarchy Process (AHP). For percentage describing in Multi-criteria decision analysis, 21.55% of the total area for Wadi Nisah were extremely dangerous and dangerous classes; 65.29% of the total area were located in moderate class; 13.15% of total area which in safe and very safe classes in flash flood hazard classes.

**Key words:** Geographic information system・Remote sensing・Multi criteria evaluation・Analytic hierarchy process・Flash flood hazard

## INTRODUCTION

Floods are considered as one of the most serious environmental problems, they are among the most catastrophic natural extreme events that present a potential threat to lives, property and cause economic damage in many parts of the world [1]. It is known that the hazard of floods will not subside in the future because climate change so the number of floods expected to occur is more than before and will threaten many areas around the world [2, 3]. In Saudi Arabia, flash floods occur periodically, due to several factors including its rugged topography and geological structures. Hence, precise assessment of floods becomes a more vital demand in development planning [4].

Flood hazard occurrence is a combination of natural and anthropogenic factors, which means that there is the need for knowledge about spatial extent of flooding areas, using multi data as drivers becomes a potential source for more reliable flood management and mitigation. For all that, Multi-criteria analysis (MCA) approach has become widely used to solve complex problems and to assess flood hazard [5, 6]. Analytic Hierarchy Process (AHP) developed by Saaty [7] is one of the best known and most widely used MCA approaches [8, 9]. It is used to solve a broad range of Multi-Criteria Decision-Making problems, with the pairwise comparison matrix calculating the weights for each criterion considered [9-11]. Theoretically, the AHP rather than prescribing a correct decision, aids decision makers find the one that best suits their needs and their understanding of the problem. This implies that AHP is a decision making approach based on the genuine ability of people to make critical decisions. It allows the active participation of decision makers in exploring all possible options in order to fully understand the underlying problems before reaching an agreement or arriving at a decision [12]. Therefore, the purpose of AHP is to judge the given alternatives for a particular goal by developing priorities for these alternatives and for the selected criteria. There are various criteria, which were selected for mapping the potential flash flood hazard and was entered to the AHP as a multi criteria decision model. These criteria are divided into two main components: topographic and hydrological, based on opinions of experts, end users and some previous studies such as: Ouma and Tateishi [13] integrated AHP and GIS to predict flood vulnerability by using six parameters: rainfall, drainage density, elevation, slope, soil and land use. While Siddayao, Valdez [14] investigated population density, distance from the river bank and site elevation as

**Corresponding Author:** Mahmoud M. Abdelkader, Agricultural Engineering Department, College of Food Science and Agriculture, King Saud University, Riyadh, Saudi Arabia. E-mail: m.abdelfattah88@yahoo.com.

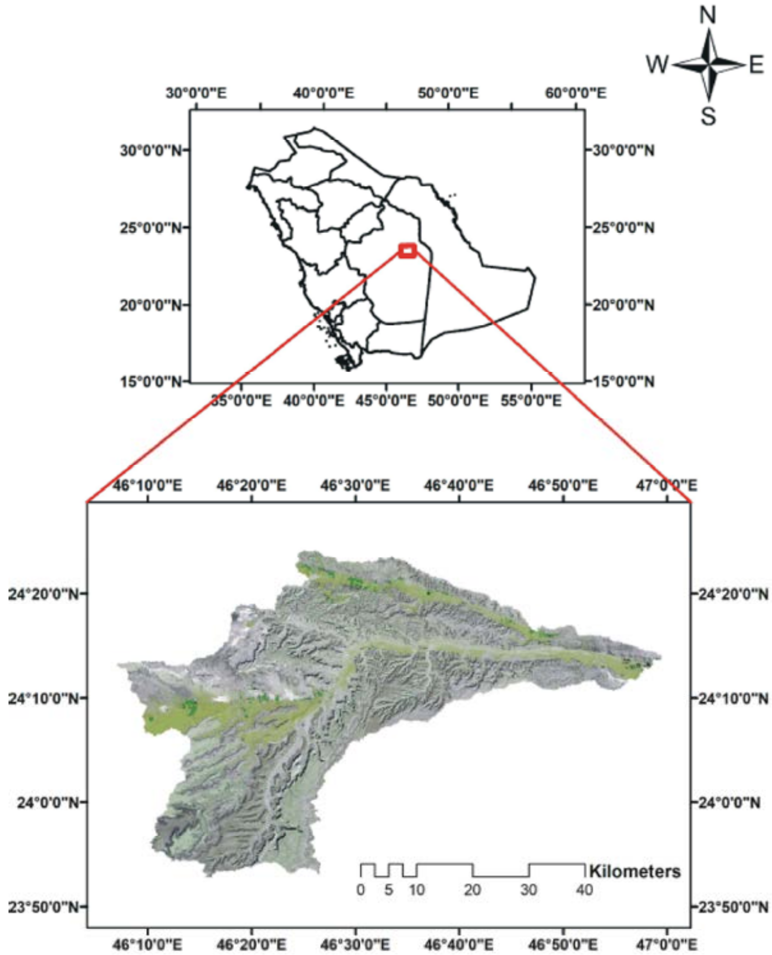


Fig. 1: Location map of Wadi Nisah

AHP parameters for flood vulnerability. But Kazakis, Kougias [15] calculated the flood hazard using seven parameters including rainfall intensity, slope, flow accumulation, elevation, distance from drainage network, land use and geology. Papaioannou *et al*., (2015) estimated potential flood prone areas using slope, elevation, aspect, flow accumulation, horizontal overland flow distance, vertical overland flow distance, Topographic Position Index, Topographic Wetness Index, Curve Number and Modified Fournier Index. Bathrellos, Karymbalis [16] investigated urban hazard assessment with the AHP procedure and utilized six parameters slope, elevation, distance from channel stream, distance from totally covered streams, hydro-lithological formation and land cover.

Applications of AHP with Geographic Information System (GIS) has been operated a lot since the beginning of 21st century [17]. The integration of AHP with GIS gives an efficient and user-friendly way for solving complex problems as it is a combination of decision making support method and tools with powerful capabilities of mass data computation, visualization and mapping [5, 18]. Therefore, we used multi-criteria analysis method within an analytic hierarchy process method (AHP) and geographical information systems (GIS) in this study to make an assessment on flood hazard.

**Study Area:** The study area lies between the latitudes 23°30’- 24°30’ N and the longitudes 46°00’- 47°00’ E as shown in Figure (1). The study area is approximately 2202 $km^2$ and nearly 90 km long and 56 km width. The study area grades upward from 492 meters in the low-lying area (southeast) to 1172 meters in the southwestern part as series of Najd plateau and Touaiq escarpment exist. The study area is located in the arid to arid belt, where annual rainfall is in the range of 100 mm/year and the average pan evaporation value is 4500 mm/year [19].

The rainfall in the study area is infrequent and erratic, with an average annual rainfall typically ranging from 80 to 120 mm [20]. Because of this rainfall and the topography of the study area, which make it more prone to flooding.

## MATERIALS AND METHODS

In this study, the implementation of AHP in Aeronautical Reconnaissance Coverage Geographic Information System (ArcGIS) was used, which is one of the most used GIS software globally, can be summarized according to Marinoni [18] as following procedure: Definition of objective; Criteria selection; Reclassify the selected criteria; Specification of weights for each criterion; Evaluation the weights of each criteria; Mapping for flash flood hazard.

**Definition of Objective:** A GIS-based spatial multi-criteria analysis method is developed and implemented to identify the flood prone area using (AHP) as a multi-criteria decision analysis Tool which provides users with a better focus on specific criteria and sub-criteria when allocating the weights. This approach is important, because a different structure may lead to a different final ranking [12]. The AHP structure that was used for flash flood hazard mapping as follow in Figure (2).

**Criteria Selection:** The assessment factors in our study are selected from the approaches outlined in previous mentioned studies. The selection is also based on the data availability in the study area. The criteria are divided into two components: topographic and hydrological. The factors include elevation, slope, topographic witness index, derange density, curve number and direct runoff depth at 50 years return period cell to cell raster data as following:

**Elevation:** Digital elevation model (DEM) is the digital representation of the earth surface terrain. The DEM of Wadi Nisah drainage basin was generated from the Shuttle Radar Topography Mission (SRTM) data as 30 m spatial resolution. It is available at the United States Geological Survey website (www.usgs.gov) as shown in Figure (3).

**Slope:** Slope was one of terrain analysis for DEM, which was generated by calculating the maximum rate of change elevation values over the distance between each cell and its eight neighbors cells in DEM. It can be derived from DEM by using Surface Analysis tool with the ArcGIS 10.3 software as Shown in Figure (3).

**Topographic Wetness Index map (TWI):** TWI was one of topographic indices, which measure the effect of local topography on hydrological process (Sørensen and Seibert, 2007). In additional it was designed for modelling the spatial distribution of soil moisture and surface saturation (Qin *et al*., 2011). TWI is defined according to BEVEN and Kirkby [21] as: Ln (a/tanB), where a is the upslope area draining through a certain point per unit contour length and B is the slope. TWI map was developed using multiple flow direction algorithm for elevation map and slope map in SAGA-GIS software as Shown in Figure (3).

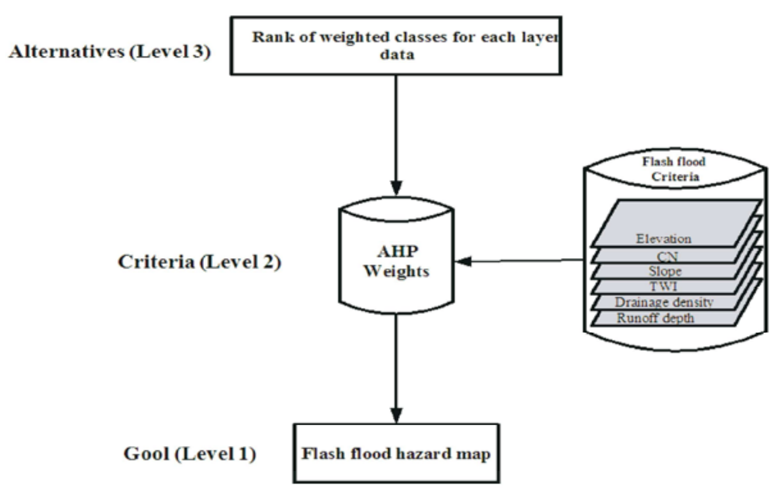


Fig. 2: Flowchart of AHP method for flash flood hazard

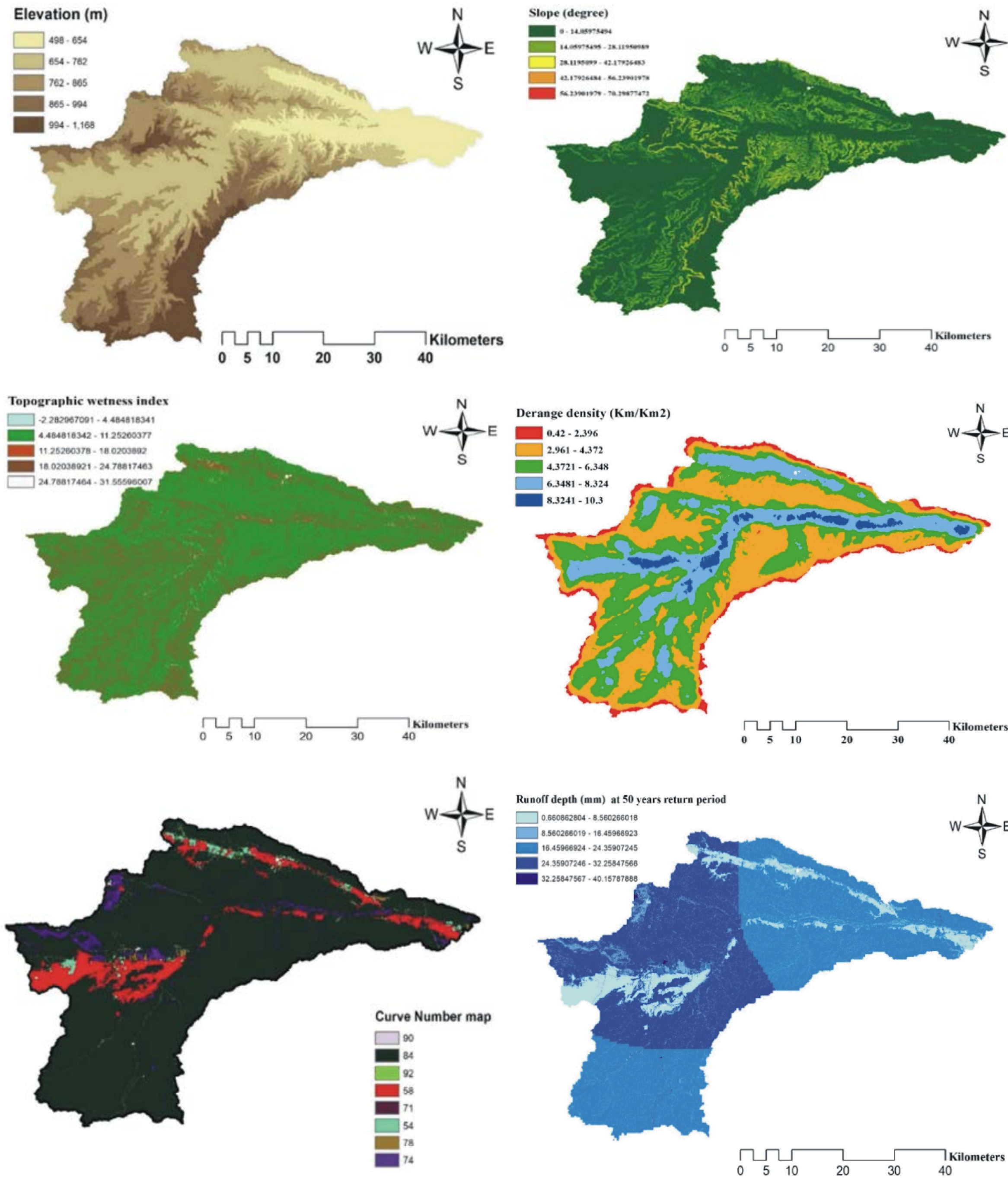


Fig. 3: The criteria maps for AHP of flash flood hazard in Wadi Nisah

**Derange Density:** Derange is a necessary ecosystem controlling the flood hazard. Therefore, its densities prevailed the natural over the soil and its geotechnical properties. This indicated that the higher the density area the higher the catchment area was prone in accordance with erosion, ensuing into sedimentation at lower grounds [13]. According to Greenbaum [22], Adiat, Nawawi [23] and Mogaji, Lim [24], derange density map was developed by overlaying the stream order map on main watershed map to find out the ratio of total length of streams in main basin to total area of Wadi Nisah . That have been done using the focal statistics tool in SAGA-GIS software as shown in Figure (3). The drainage density index was calculated for every cell through the following equation;

$$D_d = \sum_{i=1}^{i=n} \frac{Di}{A} \quad (1)$$

where Σ Di is the total length of all streams in the cell i (km) and A is the area of the grid ($km^2$).

**Curve Number:** The Soil Conservation Service-Curve Number (SCS-CN) was developed by the United States Department of Agriculture (USDA), which is an empirical parameter used in hydrology for predicting direct runoff or infiltration from rainfall excess . It is an efficient method for determining the approximate amount of direct runoff from a rainfall event [25]. The CN is based on the area's hydrologic soil type, land cover and soil moisture condition. The estimation of the curve number requires soil and land use information within the drainage basin. The soil type layer for Wadi Nisah was obtained from Ministry of Agriculture and Water in Kingdom Saud Arabia. In our study, regarding the land cover, we employed supervised classification method to classify the downloaded SPOT-5 satellite images, which were obtained from King Abdul-Aziz City for Science and Technology. The soil type and land use layers are reclassified according to the specification of unique soil types and unique land use categories. CN values were extracted to each cell in the study area from CN table according to McCuen [26] spatial composite tool in Arc GIS. The values of CN were 54, 58, 71, 74, 78, 84, 90 and 92 as CN map that was shwon in Figure (3).

**Direct Runoff Depth at 50 Years Return Period:** The potential runoff depth at 50-years return period was selected as one of criteria of AHP to extract the final hazard of flood map. It was calculated cell-to-cell based on SCS- CN method through solving its equations of the weighted Curve Number, the maximum soil moisture retention depth and 50-years return period rainfall depth. Therefore, the map of direct runoff depth at 50 years return period, was generated cell-to-cell as shown in figure (3).

**Reclassify the Selected Criteria:** The criteria data were reclassified into some of classes. Each class had been given a specific rank according to level of flash hazard for flash flood hazard criteria. These levels were called Alternatives or Decision sub-factors which at level three in AHP.

**Specification of Weights for Each Criterion:** In this step, the relative importance between each two criteria together was determined based on most opinions of experts, end users and similar previous studies such as, Ouma and Tateishi [13], Papaioannou, Vasiliades [27] and Kazakis, Kougias [15]. The intensity of this importance were taken from table (1). By determination of intensity of importance for each criteria, we compared between criteria and developed the pair wise comparison diagonal matrix. Then, the relative weights of these criteria were calculated by normalizing any rows and columns for pairwise comparison diagonal matrices, which mean divide each element in every column by the total of that column at new normalized matrix and found the Eigen vectors of these matrices which were computed by getting the average of each row values in the normalizing matrices. The Eigen vector of the normalizing matrices equal the weight values of each criteria.

**Evaluation the Weights of Each Criteria:** In this step, we needed to ensure the consistency of our judgments and get the sensitivity analysis for the weights of criteria. One of the consistent mathematic measures was consistency ratio (CR) which was defined a ratio between the consistency of a given comparison matrix and consistency of a random matrix. If CR is equal or less than 0.1, then the comparison is acceptable. When CR is greater than 0.1, the value is indicative of inconsistent judgment. Then the values in the pair wise comparisons were revised. [28]. Consistency ratio was expressed as the following equation;

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

where CR is a Consistency ratio, CI is a consistency index and RI is a Random index. The consistency index (CI) is defined as a factor which measure consistency of the diagonal comparison matrices. It was computed as the following equation;

$$CI = \frac{\lambda_{\max} - N}{N - 1} \quad (3)$$

where $\lambda_{max}$ is a largest eigenvalue of the comparison matrices and N is the dimension of the diagonal comparison matrices.

The Random index (RI) was obtained from the following Table (2) according to Saaty [28].

**Mapping for Flash Flood Hazard:** In this step, the AHP-GIS multi criteria model was developed by overlaying the classified weighted raster data of criteria, which obtained from previous steps with a weighted linear combination using raster calculator analyst tool in ArcMap. Then the overlay final maps were divided to five Classes according to the weighted linear combination method using the following equation;

Table 1: Nine-point intensity of importance scale

| Intensity of importance | Definition | Description |
|---|---|---|
| 1 | Equally important | Two factors contribute equally to the objective. |
| 3 | Moderately more important | Experience and judgment slightly favor one over the other. |
| 5 | Strongly more important | Experience and judgment strongly favor one over the other. |
| 7 | Very strong more important | Experience and judgment very strongly favor one over the other. Its importance is demonstrated in practice. |
| 9 | Extremely more important | The evidence favoring one over the other is of the highest possible validity. |
| 2, 4, 6, 8 | Intermediate values | When compromise was needed. |

Table 2: Random index values for each number of criteria

| N | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| RI | 0 | 0 | 0.85 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |

$$LC = \frac{1}{n}\sum_{i=1}^{n} D_i W_i \quad (4)$$

where LC is linear combination; Di is decision parameter; $W_i$ is AHP weight criteria; n is numbers of Criteria.

So the flash flood hazard final map was reclassified to five new classes based on its LC. These classes were extremely dangerous, dangerous, moderate, safe and very safe.

## RESULTS AND DISCUSSION

The AHP pairwise comparison and normalizing matrices for criteria of flash flood hazard were summarized at Tables (3 and 4). The principal eigenvector of the pairwise comparison matrix was figured out to produce a best fit to the weight set. Weight values represent the priorities which were absolute numbers between zero and one. Using a weighted linear combination, it implied that the weights sum to one. A summary of the flood causative factors or variables development showing the various factors, their respective weights and how they were ranked according to their influence to flood events in the study area is presented in Table (5). In Table (5), the sub-factors (J) are the ranges of decision factor (i) which contribute to the decision ranking values. Table (5) show how the three-level hierarchical structure was decomposed and how ranking decision was derived for the subsequent of flash flood hazard mapping. The procedure of this evaluation was directly processed using the weight decision support module at EDRISI software and the result of CR values for flash flood hazard comparison matrix was, 0.09 which mean that the obtained CR values were lower than the threshold value of 0.1 and indicated a high level of consistency in the pairwise judgments and implied that the determined weights of criteria were acceptable.

Table 3: Comparison Matrix for criteria of flash flood hazard

| Criteria | Runoff depth | Drainage density | Elevation | Slope | TWI | CN |
|---|---|---|---|---|---|---|
| Runoff depth | 1 | 2 | 3 | 1 | 1/3 | 1/2 |
| Drainage density | 1/2 | 1 | 1 | 1 | 1/5 | 1/3 |
| Elevation | 1/3 | 1 | 1 | 1/2 | 1/4 | 1/3 |
| Slope | 1 | 2 | 2 | 1 | 1/2 | 2 |
| TWI | 3 | 5 | 4 | 2 | 1 | 1 |
| CN | 2 | 3 | 3 | 1/2 | 2 | 1 |
| Total | 7.833333333 | 14 | 14 | 6 | 4.28333333 | 5.16666667 |

Table 4: Normalizing the columns of flash flood criteria to obtain the normalized matrix

| Criteria | Runoff depth | Drainage density | Elevation | Slope | TWI | CN | Egin vector |
|---|---|---|---|---|---|---|---|
| Runoff depth | 0.127659574 | 0.142857143 | 0.21428571 | 0.166666667 | 0.07782101 | 0.09677419 | 0.137677384 |
| Drainage density | 0.063829787 | 0.071428571 | 0.07142857 | 0.166666667 | 0.04669261 | 0.06451613 | 0.080760389 |
| Elevation | 0.042553191 | 0.071428571 | 0.07142857 | 0.083333333 | 0.05836576 | 0.06451613 | 0.065270926 |
| Slope | 0.127659574 | 0.142857143 | 0.14285714 | 0.166666667 | 0.11673152 | 0.38709677 | 0.180644803 |
| TWI | 0.382978723 | 0.357142857 | 0.28571429 | 0.333333333 | 0.23346304 | 0.19354839 | 0.29769677 |
| CN | 0.255319149 | 0.214285714 | 0.21428571 | 0.083333333 | 0.46692607 | 0.19354839 | 0.237949728 |
| Total | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

Table 5: Weighted flood hazard ranking for the case study

| Decision Factors at level 2 (i) | Relative Weight at level 2 of decision factor i $=RIW^2_i$ | Decision sub-factors (j) at level 3 (cell attribute) | Ranking decision |
|---|---|---|---|
| Elevation (meters) | 0.065 | 509.9349976 - 641.7545848 | 5 |
| | | 641.7545849 - 773.5741721 | 4 |
| | | 773.5741722 - 905.3937593 | 3 |
| | | 905.3937594 - 1, 037.213347 | 2 |
| | | 1, 037.213348 - 1, 169.032934 | 1 |
| Drainage density (km/km$^2$) | 0.081 | 0.42-2.396 | 1 |
| | | 2.3961-4.372 | 2 |
| | | 4.3721-6.348 | 3 |
| | | 6.3481-8.324 | 4 |
| | | 8.3241-10.3 | 5 |
| Slope (degrees) | 0.181 | 0 - 14.05975494 | 5 |
| | | 14.05975495 - 28.11950989 | 4 |
| | | 28.1195099 - 42.17926483 | 3 |
| | | 42.17926484 - 56.23901978 | 2 |
| | | 56.23901979 - 70.29877472 | 1 |
| Runoff depth (mm) at 50 years return period | 0.138 | 0.660862804 - 8.560266018 | 1 |
| | | 8.560266019 - 16.45966923 | 2 |
| | | 16.45966924 - 24.35907245 | 3 |
| | | 24.35907246 - 32.25847566 | 4 |
| | | 32.25847567 - 40.15787888 | 5 |
| Topographic Wetness Index (TWI) | 0.298 | -2.282967091 - 4.67674675 | 1 |
| | | 4.676746751 - 11.63646059 | 2 |
| | | 11.6364606 - 18.59617443 | 3 |
| | | 18.59617444 - 25.55588827 | 4 |
| | | 25.55588828 - 32.51560211 | 5 |
| Curve Number (CN) | 0.238 | 54 | 1 |
| | | 58 | 2 |
| | | 71 | 3 |
| | | 74 | 4 |
| | | 78 | 5 |
| | | 84 | 6 |
| | | 90 | 7 |
| | | 92 | 8 |

This overlay final map of flash flood hazard was divided to five classes according to the weighted linear combination. These classes were extremely dangerous, dangerous, moderate, safe and very safe as shown in Figure (4). It was observed that the extremely dangerous and dangerous classes were 21.55% of the total area as shown in Figure (5). These areas are those that are close to the main channel of stream order 7 and generally laying at low elevations within the settled regions. Nevertheless, the moderate hazard was 65.29% of the total area, while the safe and very safe classes were 13.15% of total area.

By comparing flood hazard map with elevation map, all the extremely dangerous and dangerous area has been found located in the area with lower elevation and most of them has been found with an elevation lower than 642 m. This is related to but not mainly caused by the negative correlation between elevation and precipitation.

By visual interpretation of flash hazard map and comparison between flash hazard map and slope map, cells with different hazard have been found highly mixed in a micro scale and it's mainly caused by change of slope, which is also highly mixed in theWadi Nisah study area.

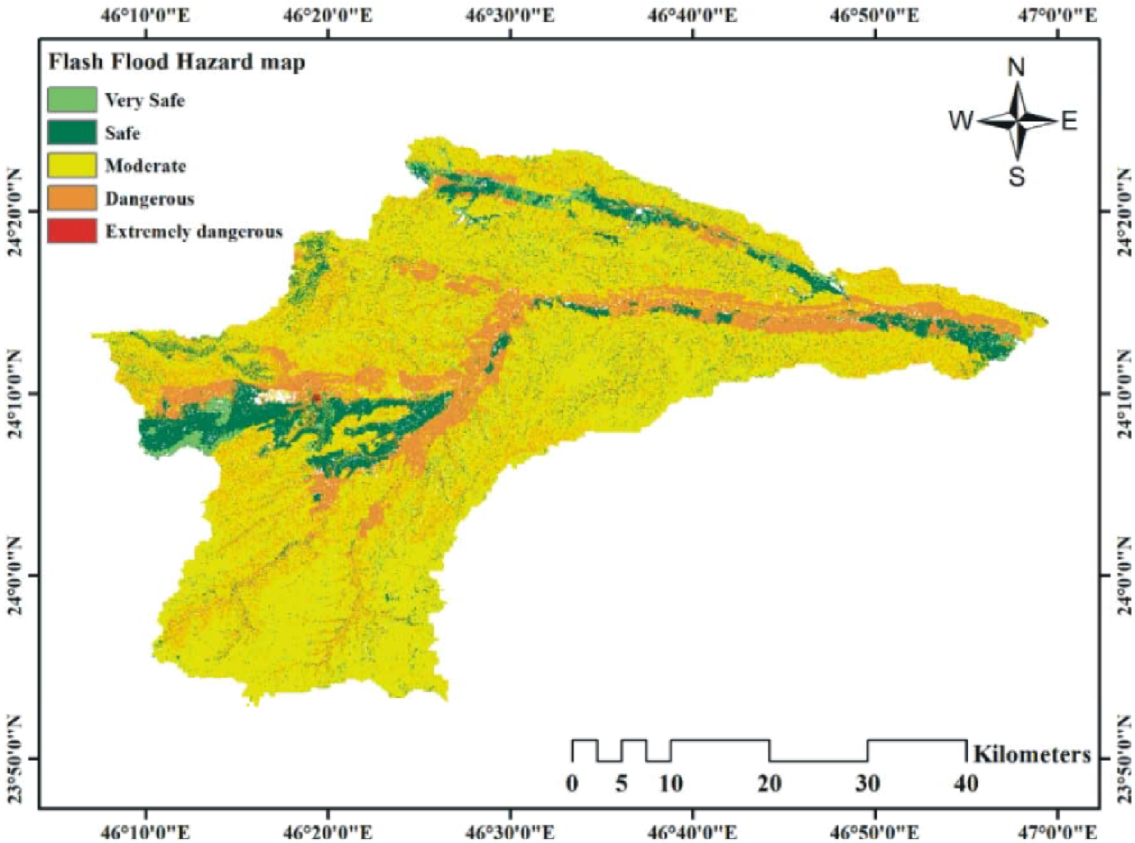


Fig. 4: Flash flood hazard map for Wadi Nisah

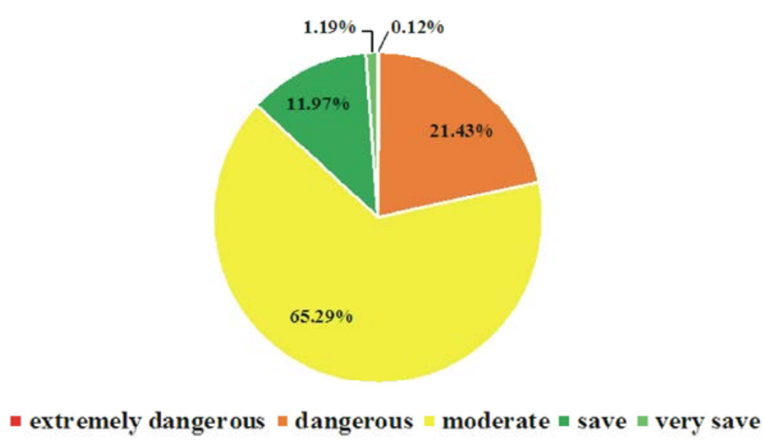


Fig. 5: Percentage of area chart covered by different classes of flood Hazard in Wadi Nisah

## CONCLUSION

GIS software and satellite imagery are widely used in the quantitative analysis to assessment flash flood hazard. A Multi-Criteria Decision Making (MCDM) method called Analytic Hierarchy Process (AHP) was used in this study for mapping the hazard of flood. The criteria of hazard were Elevation, Derange density, Slope, Direct runoff depth at 50 years return period, Topographic witness index and Curve Number. Raster layers of all criteria were integrated by a weighted summation using the weights generated by pairwise comparison. For percentage describing, 21.55% of the total area for Wadi Nisah were extremely dangerous and dangerous classes;

65.29% of the total area were located in moderate class; 13.15% of total area which in safe and very safe classes in flash flood hazard classes.

## REFERENCES


1. McCarthy, J.J., 2001. Climate change 2001: impacts, adaptation and vulnerability: contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change. 2001: Cambridge University Press.
2. Jonkman, S.N. and I. Kelman, 2005. An analysis of the causes and circumstances of flood disaster deaths. Disasters, 29(1): 75-97.
3. Khan, S.I., *et al*., 2011. Satellite remote sensing and hydrologic modeling for flood inundation mapping in Lake Victoria basin: Implications for hydrologic prediction in ungauged basins. IEEE Transactions on Geoscience and Remote Sensing, 49(1): 85-95.
4. Dawod, G.M., M.N. Mirza and K.A. Al-Ghamdi, 2011. GIS-based spatial mapping of flash flood hazard in Makkah City, Saudi Arabia. Journal of Geographic Information System, 3(3): 217.
5. Wang, Y., *et al*., 2011. A GIS-based spatial multi-criteria approach for flood risk assessment in the Dongting Lake Region, Hunan, Central China. Water Resources Management, 25(13): 3465-3484.
6. Rahaman, S.A., *et al*., 2015. Prioritization of Sub Watershed Based on Morphometric Characteristics Using Fuzzy Analytical Hierarchy Process and Geographical Information System – A Study of Kallar Watershed, Tamil Nadu. Aquatic Procedia, 4: 1322-1330.
7. Saaty, T.L., 1980. The analytic hierarchy process: planning, priority setting, resources allocation. New York: McGraw, pp: 281.
8. Yahaya, S., N. Ahmad and R.F. Abdalla, 2010. Multicriteria analysis for flood vulnerable areas in Hadejia-Jama'are River basin, Nigeria. European Journal of Scientific Research, 42(1): 71-83.
9. Orencio, P.M. and M. Fujii, 2013. A localized disaster-resilience index to assess coastal communities based on an analytic hierarchy process (AHP). International Journal of Disaster Risk Reduction, 3: 62-75.
10. Yalcin, A., 2008. GIS-based landslide susceptibility mapping using analytical hierarchy process and bivariate statistics in Ardesen (Turkey): comparisons of results and confirmations. Catena, 72(1): 1-12.
11. Pourghasemi, H.R., M. Beheshtirad and B. Pradhan, 2016. A comparative assessment of prediction capabilities of modified analytical hierarchy process (M-AHP) and Mamdani fuzzy logic models using Netcad-GIS for forest fire susceptibility mapping. Geomatics, Natural Hazards and Risk, 7(2): 861-885.
12. Estoque, R.C. and Y. Murayama, 2010. Suitability analysis for beekeeping sites in La Union, Philippines, using GIS and multi-criteria evaluation techniques. Res. J. Appl. Sci., 5(3): 242-253.
13. Ouma, Y.O. and R. Tateishi, 2014. Urban flood vulnerability and risk mapping using integrated multi-parametric AHP and GIS: methodological overview and case study assessment. Water, 6(6): 1515-1545.
14. Siddayao, G.P., S.E. Valdez and P.L. Fernandez, 2014. Analytic hierarchy process (AHP) in spatial modeling for floodplain risk assessment. International Journal of Machine Learning and Computing, 4(5): 450.
15. Kazakis, N., I. Kougias and T. Patsialis, 2015. Assessment of flood hazard areas at a regional scale using an index-based approach and Analytical Hierarchy Process: Application in Rhodope–Evros region, Greece. Science of the Total Environment, 538: 555-563.
16. Bathrellos, G., *et al*., 2016. Urban flood hazard assessment in the basin of Athens Metropolitan city, Greece. Environmental Earth Sciences, 75(4): 319.
17. Mardani, A., *et al*., 2015. Multiple criteria decision-making techniques and their applications–a review of the literature from 2000 to 2014. Economic Research-Ekonomska Istra_ivanja, 28(1): 516-571.
18. Marinoni, O., 2004. Implementation of the analytical hierarchy process with VBA in ArcGIS. Computers & Geosciences, 30(6): 637-646.
19. Almazroui, M., *et al*., 2012. Recent climate change in the Arabian Peninsula: annual rainfall and temperature analysis of Saudi Arabia for 1978–2009. International Journal of Climatology, 32(6): 953-966.
20. Alsharhan, A., *et al*., 2001. Hydrogeology of an arid region: the Arabian Gulf and adjoining areas, Elsevier.
21. Beven, K.J. and M.J. Kirkby, 1979. A physically based, variable contributing area model of basin hydrology/Un modèle à base physique de zone d'appel variable de l'hydrologie du bassin versant. Hydrological Sciences Journal, 24(1): 43-69.

22. Greenbaum, D., 1989. Hydrogeological applications of remote sensing in areas of crystalline basement. In: Proc Groundwater Exploration and Development in Crystalline Basement Aquifers, Zimbabwe.
23. Adiat, K., M. Nawawi and K. Abdullah, 2012. Assessing the accuracy of GIS-based elementary multi criteria decision analysis as a spatial prediction tool–a case of predicting potential zones of sustainable groundwater resources. Journal of Hydrology, 440: 75-89.
24. Mogaji, K., H. Lim and K. Abdullah, 2015. Regional prediction of groundwater potential mapping in a multifaceted geology terrain using GIS-based Dempster–Shafer model. Arabian Journal of Geosciences, 8(5): 3235-3258.
25. USDA, S., 1986. Urban hydrology for small watersheds. Technical Release, 55: 2-6.
26. McCuen, R.H., 1982. A guide to hydrologic analysis using SCS methods. Prentice-Hall, Inc.
27. Papaioannou, G., L. Vasiliades and A. Loukas, 2015. Multi-criteria analysis framework for potential flood prone areas mapping. Water Resources Management, 29(2): 399-418.
28. Saaty, T.L., 1990. How to make a decision: the analytic hierarchy process. European Journal of Operational Research, 48(1): 9-26.