Flood-based Critical Sub-Watershed Mapping: Comparative Application of MCDM and Hydrological Modeling Approach

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Abstract

The effects of Sub-Watersheds (SWs) on each other can be more important in Flood Generation Potential (FGP). Therefore, the present study aims for prioritizing SWs based on FGP using Multi-Criteria Decision Making (MCDM) Methods including Game Theory (GT), Best-Worst Method (BWM), Analytic Hierarchy Process (AHP), Analytical Network Process (ANP), Fuzzy Analytic Hierarchy Process (FAHP), Fuzzy Analytical Network Process (FANP) and comparing its results with Hydrological Modeling Approach (HMA) in the Cheshmeh-Kileh Watershed, Iran. In GT, Condorcet algorithm were used. The best and worst criteria were identified using the BWM and compared with other criteria. In AHP and ANP, expert opinions were used and the final weight of criteria and alternative was calculated using Expert Choice and Super Decision softwares. ArcGIS10.1 software was also used to fuzzy and provide FAHP and FANP. In HMA, HEC-HMS software was used to calculate the discharge with return periods of 10- and 100-year, and finally, in all methods, FGP maps were prepared in three classes and SWs were prioritized. Based on the results of different methods, SWs 9, 2, 7, 10 and 11 were given high FGP priority. Downstream SWs were also in a non-critical state due to dense forest cover and low slope. A comparative evaluation between the methods showed that BWM had the same result as the field evidence and HMA results and this method provided the best result. Based on SWs prioritization in BWM, high and low FGP were 33.33 and 46.67% of the study area, respectively. After BWM, GT gave a relatively good result. AHP, ANP, FAHP and FANP presented different results, but had poor performance in identifying critical areas. This study showed that optimal MCDM approaches can be used for flood management.

1. Introduction

Sustainable and integrated water resources in watersheds is one of the important issues around the world that requires comprehensive and scientific research (Li et al. 2022). One of the most important geohydrological and water resources-related disasters that also threatens the economic and social systems of watersheds is floods (Jothibasu and Anbazhagan 2016; Abdo 2020; Arora et al. 2021; Costache et al. 2021). The integration of several spatial variables such as lithology, faults, terrestrial features, climatic events and land use change causes floods (Blöschl et al. 2017; Hammad et al. 2018; Rahmoun et al. 2018). On the other hand, in recent years, rapid population growth and unplanned urban development have increased floods (Prinos 2009; Merz et al. 2014; El-Zein et al. 2021; Wu 2021). Floods can be periodic and seasonal and may occur infrequently. It may also be severe or short-lived and even have spatial effects (Yang et al. 2017; Marhaento et al. 2018; Pokhrel et al. 2018). Since flooding is a spatial phenomenon (Avand et al. 2021), a mapping of Flood Generation Potential (FGP) at Sub-Watershed (SW) scale can be crucial for decision making.

Watersheds are one of the best spatial systems for managing water and soil resources (Gajbhiye et al. 2013; Kumar et al. 2021) which for better management of this system is divided into homogeneous hydrological units or SWs (Aher et al. 2014; Lin et al. 2020). The effects of SWs on each other can be more important in FGP (Avand et al. 2021), which shows the importance of prioritizing SWs. The existence of different heterogeneities in watersheds, hydrological and water resources-related processes operate on a wide range of temporal and spatial scales (Birkel and Soulsby 2015). Therefore, it is necessary to adopt a practical and interdisciplinary approach (Qi et al. 2022) to integrate watershed management as well as flood management. In many studies, hydrological models have been used for flood analysis, but these models (Akbari et al. 2016; Costache et al. 2021; Hou et al. 2021; Kang et al. 2021) focus only on the movement of water. Therefore, to achieve a suitable result, different methods should be used to prioritize SWs, and this indicates the need to compare the results of hydrological models and other prioritization methods.

Due to the multidimensionality and complexity of factors in watersheds, it is necessary to use methods that lead to optimal decision making. Multi-Criteria Decision Making (MCDM) methods are among the multi-criteria evaluation methods that have many applications in various fields (Esangbedo and Bai 2019). On the other hand, the inability of conventional MCDM methods and the multiplicity of factors influencing the watershed system make it difficult for managers to understand the problem. Therefore, in issues related to watershed management such as SW prioritization and FGP, the application of MCDM such as Game Theory (GT), Best-Worst Method (BWM), Analytic Hierarchy Process (AHP), Analytical Network Process (ANP), Fuzzy Analytic Hierarchy Process (FAHP) and Fuzzy Analytical Network Process (FANP) can be effective.

Numerous studies have been performed in connection with flood using hydrological models such as Al-Abed et al., 2005; Du et al., 2012; Foody et al., 2004; Haibo et al., 2018; Halwatura & Najim, 2013; Ibrahim-Bathis & Ahmed, 2016; Jin et al., 2015; Kuntiyawichai, 2014; McColl & Aggett, 2007; Natarajan & Radhakrishnan, 2020; Oleyiblo & Li, 2010; Rahman et al., 2017; Tassew et al., 2019; Wang et al., 2011; Yusop et al., 2007; Zhang et al., 2019.

MCDM such as GT, BWM, AHP, ANP, FAHP and FANP have been used in various studies such as flood (Levy 2005; Sinha et al. 2008; Meyer et al. 2009; Qin et al. 2011; Álvarez et al. 2019; Janssen et al. 2020; Majumder et al. 2021b; Meshram 2021; Moosakhaani et al. 2021; Vreugdenhil et al. 2022); water (Gallego-Ayala and Juízo 2011; Chitsaz and Azarnivand 2017); river system (Hui et al. 2016); problem solving (Pamučar et al. 2020); renewable energy (Majumder et al. 2021a); protected area management (Foli Fiagbomeh and Bürger-Arndt 2015); strategic planning (Al-Abed et al. 2005); waste management (Li et al. 2021).

Summary of research background shows that hydrological models and MCDM have been used in watershed management as well as flood management. However, comparisons between different approaches such as Hydrological Modeling Approach (HMA), GT, BWM, AHP, ANP, FAHP and FANP have not been reported in discussing FGP and SW prioritization. On the other hand, in discussions related to FGP, AHP, ANP and HMA have often been used. But in the present study, in addition to these methods, new MCDM (GT and BWM) have been used in prioritizing SWs based on FGP. Also, regarding the reason for choosing the Cheshmeh-Kileh Watershed, it can be said that according to the reports of the General Department of Natural Resources and Watershed Management of West Mazandaran-Nowshahr, this watershed is one of the most critical watersheds in the west of Mazandaran Province. Also, in recent years, floods have caused a lot of damage to agricultural and residential lands in this watershed, which proves the need to prioritize SWs and determine critical areas based on FGP. Therefore, the present study was conducted with the aim of prioritizing SWs based on FGP with MCDM (GT, BWM, AHP, ANP, FAHP and FANP) and comparing its results with HMA in the Cheshmeh-Kileh Watershed, Iran.

2. Materials And Methods

2.1 Study area

The Cheshmeh-Kileh Watershed covers 733 km^2 located in the south of Tonekabon City in Mazandaran Province, Iran (Fig. 1) and is roughly circumscribed by a rectangle at 36°19’ and 46°38’ N and at 50°23’ and 50°59’ E. The elevation ranges from 131.67 m above sea level (a.m.s.l.) at the outlet of the watershed and 4756.06 m a.m.s.l. Dominant land uses include rangeland, forest, agriculture, water body, and residential development. Sehezar and Dohezar rivers are the most important rivers of the Cheshmeh-Kileh Watershed which originate from Takht-e-Soliman, Alamut and Khashchal mountain regions. The high capacity of the riverside lands and the limitation of suitable lands in the watershed have caused many agricultural activities to be concentrated along the river, which are severely affected by floods. A view of the Cheshmeh-Kileh Watershed is presented in Fig. 2.

Figure 1. Location of the Cheshmeh-Kileh Watershed in Mazandaran Province, Iran; Sentinel-2

Figure 2. View of the Cheshmeh-Kileh Watershed, Mazandaran Province, Iran

2.2 Data sources and analyses

In the present study, eight methods were used to prioritize SWs. Methods were divided into two categories. The first category, MCDM, included GT, BWM, AHP, ANP, FAHP and FANP. In the second category, HMA including HEC-HMS model was used. Data were collected based on the type of method used. According to available resources, important and effective physical and morphometric criteria (Amiri et al. 2019; Waiyasusri and Chotpantarat 2020) on FGP were determined. Criteria affecting FGP including Area (A), Curve Number (CN), Slope (Se), Time of Concentration (Tc), 24-hour Maximum Rainfall (Pmax24), percentage of Rangeland (Rl), Residential (Re) and Forest (F) lands (Seejata et al. 2018) were used to perform MCDM.

To obtain the CN values, a combination of land use map and soil hydrological groups map was used through HEC-GeoHMS extension of ArcGIS 10.1 (Te Chow et al. 1962; Vafakhah et al. 2018; Chezgi et al. 2020). Land use map (Fig. 3) was generated using the images of Landsat 8 satellite and OLI sensor related to 2019 in Google Earth Engine (GEE) system. To calculate rainfall characteristics, the data of raingauge stations in the study area (Gol Aliabad, Haratbar, Dalir, Shaneh-Tarash and Dinar-Sara) were used. To review the initial comparisons between the criteria used, experts and researchers completed the questionnaire with their expert opinions. In HMA, HEC-HMS software was used to determine flood at the watershed outlet. In this software, the basin model with river slope and width factors, Manning's rougness coefficient, area, stream length, land use, soil hydrological groups and hydrological conditions and meteorological model (Jin et al. 2015; Zhang et al. 2019) were used.

Figure 3. Land use map, 2019, the Cheshmeh-Kileh Watershed, Mazandaran Province, Iran

2.3 Research methodology

The research method was performed in three stages: (1) prioritization using MCDM including GT, BWM. AHP, ANP, FAHP and FANP (2) prioritization using HMA using HEC-HMC model (3) analysis and comparison of results of MCDM and HMA. The flowchart of the research methodology is presented in Fig. 4. In the following sections, the explanations and methodology of the eight methods are described:

Figure 4. Flowchart of research methodology, the Cheshmeh-Kileh Watershed, Mazandaran Province, Iran

2.3.1 Application of Condorcet algorithm based on GT

The Condorcet algorithm based on GT was used to prioritize SWs based on eight criteria studied. First, in each SW based on each criterion, prioritization preferences were determined based on the values of each criterion. The pairwise comparison matrix then related to the Condorcet algorithm was used to prioritize the SWs. The Condorcet algorithm was one of the few algorithms based on GT and decision making that selected the candidate who won the majority of votes in each head-to-head election (Gehrlein and Valognes 2001; Sheikhmohammady et al. 2010; Adhami et al. 2018).

The purpose of this method was to reach a level in which the maximum demand of each player (optimal prioritization of SWs based on physical criteria) was met, provided that the maximum needs of other actors were met (Skardi et al. 2013; Üçler et al. 2015). Regardless of the voting system, the winner (high FGP) was always the same and was determined for a set of candidates by counting the preferences of the voters two by two (Erdmann 2011). One of the main goals of the Condorcet algorithm was to create groups based on all individual priorities. This function selected the winner for each vote accounting for all pairs of options (Elkind et al. 2011). $O_j\left(A_j, A_k\right) = 1, ifandonlyif, A_j > i.\, A_k andO\left(A_j\right)$ were summed over n alternatives and m individuals as calculated (Eq. 1):

$$O\left(A_j\right) = \sum_{k=1}^{n} O_j\left(A_j, A_k\right) \; (1)$$

Rows of voter preferences from top to bottom are:

Voter 1: A B C

Voter 2: B A C

Voter 3: C B A

According to this formation, the framework of the Condorcet matrix is (Eq. 2):

$$\begin{bmatrix} ABC \\ A - BA \\ BB - B \\ CAB- \end{bmatrix} (2)$$

Based on pairwise comparisons, the winner was determined by the number of times it is present in the matrix (Adhami et al. 2019). In Eq. (2), option B is most numerous, so it is the winner. A schematic view of the voting and scoring system based on the Condorcet algorithm is presented in Fig. 3.

2.3.2 Application of BWM

BWM was used to prioritize the SWs based on FGP based on eight criteria studied. To employ BWM (Rezaei 2016), the determinant factors on FGP were selected at the first stage. The best ad the worst criteria were then chosen. The best and worst criteria were selected based on the opinions of academic experts and experts of the General Directorate of Natural Resources and Watershed Management. The preference of the best criterion over other criteria was introduced with a number between 1 and 9 based on Eq. (3):

$$AB = \left(a_{B1}, a_{B2}, \ldots, a_{Bn}\right)$$

3

where a_{Bj} indicates the superiority of the Best *B* criterion over *j* criteria.

The previous step was repeated for the worst criterion, and corresponding preference of other criteria over the worst criterion *W* was accordingly determined using Eq. (4):

$$AW = \left(a_{1w}, a_{2w}, \ldots, a_{mw}\right)^T$$

4

where a_{jw} expresses the degree of superiority of *j* criterion over the Worst criterion of *w*.

The optimal weight vector in the form of a vector $(w_1^*, w_2^*, \ldots, w_n^*)$ was formed as shown in Eq. (5) such that Eq. (6) gets satisfied:

$$\min max_j \left\{ \left| \frac{W_B}{W_j} - a_{Bj} \right|, \left| \frac{W_j}{W_w} - a_{jw} \right| \right\}$$

5

$$\sum_{\substack{j \\ w \geq 0}} w_j = 1$$

6

The min-max model in Eq. (5) was written as Eq. (7) to fulfill Eq. (8):

$$\min \xi$$

$$\left| \frac{W_B}{W_j} - a_{Bj} \right| \leq \xi Forallj$$

7

$$\left| \frac{W_j}{W_w} - a_{jw} \right| \leq \xi Forallj$$

$$\sum w_j = 1$$

8

$$w_j \geq 0, Forallj$$

2.3.3 Application of AHP and FAHP

The data source in this method was a questionnaire (Liang and Peng 2017; Moslem et al. 2020; Taherdoost 2020). In order to design the questionnaire, the goal (FGP), criteria (eight criteria) and alternatives (SWs) were identified. Nine experts were then asked to record their opinions regarding the pairwise comparison of criteria in the questionnaire (Saaty 1980). These experts included academics and watershed management technicians. Expert Choice software was used for analysis (Najafi and Karimi 2020; Siekelova et al. 2021). In this software, a hierarchical structure was designed (Fig. 5.) and the criteria and alternatives were compared in pairs. In each step, the inconsistency rate (Wubalem et al. 2021) was calculated. Finally, the weight of criteria and alternatives were calculated. ArcGIS 10.1 software was used to prepare the map and prioritize the SWs. By multiplying the weights of the criteria in the alternatives, the final weights of each SW were calculated based on the criteria. Finally, FGP map was derived based on AHP through a Raster Calculator.

Figure 5. Hierarchical structure of goals, criteria and alternatives, the Cheshmeh-Kileh Watershed, Iran

To fuzzy the maps, Fuzzy membership and Fuuzy overlay (Parsian et al. 2021) commands were used through ArcGIS10.1 software. The maps generated for each criterion were independently fuzzy by command of Fuzzy membership. Then, for spatial modeling and zoning, the Gamma fuzzy operator (Hasanloo et al. 2019; Parsian et al. 2021) was used to overlap the layers and criteria. Eventually a FAHP map was produced and the SWs were classified into three classes.

2.3.4 Application of ANP and FANP

In ANP, the dependencies and feedback between criteria and alternatives were systematically examined. Accordingly, all the interdependencies between the criteria as well as their direction were explained. In general, a criterion is related to other criteria when at least one of it's alternatives influences or is influenced by one of the other criteria (Saaty 1999). According to (Saaty 1996), the elements of a model can act as a source of effect and in other words be effective, be considered the destination of the effect and be influential or affect themselves. Each of these positions is represented by one-way, two-way, and loop arrows. The basis of prioritization in this method, like AHP, is to use the opinions of experts based on a questionnaire (Peng 2019; Liu et al. 2020). Therefore, the questionnaires of the previous stage were used to calculate the weight of ANP. Super Decision software (Augustin et al. 2019; Daneshparvar et al. 2022) was used for analysis (Fig. 6.). Based on this, the criteria and alternatives used in AHP were formulated and the relationships between the criteria and alternatives and their interactions were defined (Wolfslehner and Vacik 2008). After developing the network model, pairwise comparisons between criteria and related or interactive alternatives were performed using the relative importance scale (based on a questionnaire).

Figure 6. Relationships between criteria and alternatives in Super Decision software, ANP, the Cheshmeh-Kileh Watershed, Iran

In ANP, in addition to being compared like ANP, the criteria and alternatives were compared, but their feedback was compared and interconnected as a network. Therefore, first the criteria were compared, then based on the criteria, the alternatives were compared and finally their feedback was compared. Finally, the weight of criteria and alternatives were calculated. Multiplying the weights of each criterion in each alternative, the final weight of the ANP was obtained (Daneshparvar et al. 2022). The steps related to map preparation in the previous section (Section 2.4.3) were then used to prepare ANP and FANP maps throug ArcGIS10.1 software.

2.4 Application of HMA

In HMA, HEC-HMS model was used to model flood design (Tassew et al. 2019; Zhang et al. 2019; Wang et al. 2020). The design flood with 10- and 100-year return periods were obtained using this model. HEC-SSP (Statistical Software Package) software was also used to calculate the design flood based on different return periods. Rainfall temporal distribution was prepared using raingauge stations stations (Section 2.2) by calculating the percentage of rainfall at regular intervals. After calculating the rainfall temporal distribution in each SW, several hyetographs were prepared. These hyetographs became the basis for calculating SW floods. Intensity-Duration-Frequency (IDF) curves for rainfall extraction were calculated based on Tc in different return periods (Chezgi et al. 2020). The amount of runoff produced in each SW was determined using Soil Conservation Service (SCS) dimensionless unit hydrograph and routing using the Muskingham method, and finally by entering the information of the hyetographs, peak discharge and flood volume in 10- and 100-year return periods were estimated. In the present study, a Q100/Q10 (Q100, discharge with a return period of 100-year /Q10, discharge with a return period of 10-year) index was used. The reason for using the Q10 index is that vegetation only plays an important role in controlling and managing floods with a return period of 10-year. The Q100 index has also been used due to the high importance of discharges with a return period of 100-year in FGP.

After implementing MCDM and HMA, the results of each method were presented as a map. Three classes were used to map for FGP (Ghasemlounia and Utlu 2021). The first priority was related to SWs with high FGP, the second priority was SWs with moderate FGP and the third priority was SWs with low FGP. Also, in order to compare the results of MCDM with HMA, the correlation test package in R software was used and the final decision was made.

3. Results

3.1 Geo-environmental criteria

Quantitative values of the eight criteria used in the various methods are presented in Table 1. Based on the quantitative results of the criteria, in A criterion, SWs 3 and 7 with the values of 8450.4 and 2984.16 hectares, in CN criteria, SWs 1 and 14 with the values of 78.93 and 59.58, in Se criterion, SWs of 10 and 14 with values of 73.56 and 51.91%, in Tc criterion, SWs 4 and 7 with the values of 2.38 and 0.73, in P criterion, SWs 7 and 11 with the values of 113.3 and 40. 78 mm, in Rl criteria, SWs 3 and 5 with values of 7414.17 and 302.46 hectares, in Re criteria, SWs 8 and 7 (10, 11 and 12) with values of 83.89 and 0 hectares and in F criteria, SWs 5 and 1 (9) with values of 4168.81 and 0 hectares, respectively, had the highest and lowest values of each criterion.

Table 1
Quantitative values of the studied criteria in each SW, the Cheshmeh-Kileh Watershed, and Mazandaran Province, Iran

SW	Criteria							
	A	CN	Se	T_C	P	Rl	Re	F
1	5713.94	78.93	62.98	1.42	83.25	5702.86	0.41	-
2	4222.77	78.81	55.98	1.13	75.63	4028.36	49.00	2.09
3	8450.4	71.98	64.41	2.05	69.08	7414.17	0.40	1027.21
4	5876.79	66.49	64.67	2.38	90.99	3980.95	0.48	1887.43
5	4662.09	61.88	53.20	2.07	105.9	302.46	14.24	4168.81
6	5182.43	68.90	68.68	1.40	105.9	2469.33	2.81	2581.21
7	2984.16	76.95	69.62	0.73	113.3	2919.09	-	46.82
8	5444.01	71.40	69.25	1.86	98.63	4064.17	83.89	617.10
9	3780.8	78.92	68.41	0.97	97.37	3771.91	0.39	-
10	3168.33	76.87	73.56	0.80	40.78	3056.48	-	110.48
11	5263.19	78.53	66.09	0.90	40.78	5218.88	-	42.80
12	3228.03	78.11	58.09	0.86	68.68	2802.41	-	388.08
13	6410.41	70.99	69.92	1.75	68.68	3788.27	21.13	2262.40
14	5909.77	59.58	51.91	2.29	98.63	1417.41	45.86	3991.80
15	5518.12	68.04	66.02	2.06	60.50	4005.38	6.30	1426.59

*A = Area, CN = Curve Number, Se = Slope, Tc = Time of concentration, P = P_{max} 24hr, Rl = Rangeland, Re = Residential, F = Forest

Table 1. Quantitative values of the studied criteria in each SW, the Cheshmeh-Kileh Watershed, and Mazandaran Province, Iran

3.2 Results of MCDM

The results related to the initial weighting of SWs based on GT in Sehezar and Dohezar Rivers were presented in Tables 2 and 3. Also, in Tables 4 and 5, a pairwise comparison matrix based on Condorcet algorithm was placed in Sehezar and Dohezar Rivers.

Table 2

Initial weighting of SWs based on selected criteria for GTA, Sehezar River, Iran

Criteria	**SWs sorting** ***(From more to less)***								
A	7	9	2	5	6	8	1	4	3
CN	1	9	2	7	3	8	6	4	1
Se	7	8	6	9	4	3	1	2	1
Tc	7	9	2	6	1	8	3	5	4
P	7	6	5	8	9	4	1	2	3
Rl	3	1	8	2	4	9	7	6	1
Re	8	2	5	6	4	1	3	9	7
F	9	1	2	7	8	3	4	6	1

* See Table 1 for criteria specifications.

Table 3

Initial weighting of SWs based on selected criteria for GTA, Dohezar River, Iran

Criteria	**SWs sorting** ***(From more to less)***					
A	10	12	11	15	14	13
CN	11	12	10	13	15	14
Se	10	13	11	15	12	14
Tc	10	12	11	13	15	14
P	12	10	11	13	15	14
Rl	14	12	13	15	10	11
Re	11	15	13	10	12	14
F	14	13	15	12	10	11

* See Table 1 for criteria specifications.

Table 4

SW pairwise comparison matrix using Condorcet algorithm based on GTA, Sehezar River, Iran

SW	1	2	3	4	5	6	7	8	9
1	-	1	1	1	1	5	7	1	9
2	1	-	2	2	2	2	2	2	9
3	1	2	-	3	3	5	7	8	9
4	1	2	3	-	5	6	7	8	9
5	1	2	3	5	-	6	7	8	5
6	6	2	6	6	6	-	7	8	9
7	7	2	7	7	7	7	-	7	7
8	1	2	8	8	8	8	7	-	9
9	9	9	9	9	9	9	7	9	-
Final weight	10	12	4	0	2	8	14	6	14

Table 5

SW pairwise comparison matrix using Condorcet algorithm based on GT, Dohezar River, Iran

SW	10	11	12	13	14	15
10	-	10	10	10	10	10
11	10	-	12	11	11	11
12	10	12	-	12	12	12
13	10	11	12	-	13	13
14	10	11	12	13	-	15
15	10	11	12	13	15	-
Final weight	10	6	8	4	0	2

Table 2. Initial weighting of SWs based on selected criteria for GTA, Sehezar River, Iran

Table 3. Initial weighting of SWs based on selected criteria for GTA, Dohezar River, Iran

Table 4. SW pairwise comparison matrix using Condorcet algorithm based on GTA, Sehezar River, Iran

Table 5. SW pairwise comparison matrix using Condorcet algorithm based on GT, Dohezar River, Iran

The results of BWM in prioritizing SWs are presented in Table 6. Also, the results of the initial weighting of AHP and ANP methods based on each criterion and inconsistency rate are shown in Table 7. Based on the presented results, the inconsistency rate based on the results of Expert Choice (AHP) and Super Decision (ANP) software was less than 0.1. Table 8 shows the final weights of the SWs in each criterion and based on AHP and ANP methods.

Table 6
The final weights of the SWs in each criterion based on BWM, the Cheshmeh-Kileh Watershed, Mazandaran Province, Iran

SW	**BWM weight**							
	Criteria							
	A	**CN**	**Se**	**T_C**	**P**	**Rl**	**Re**	**F**
1	0.056	0.360	0.041	0.089	0.060	0.227	0.041	0.233
2	0.130	0.155	0.036	0.149	0.034	0.060	0.227	0.155
3	0.028	0.051	0.048	0.035	0.030	0.348	0.035	0.042
4	0.031	0.032	0.057	0.027	0.045	0.091	0.049	0.036
5	0.097	0.028	0.032	0.030	0.135	0.027	0.151	0.028
6	0.078	0.036	0.121	0.061	0.165	0.057	0.062	0.032
7	0.320	0.063	0.389	0.345	0.344	0.034	0.027	0.063
8	0.065	0.042	0.153	0.041	0.105	0.080	0.350	0.051
9	0.195	0.233	0.123	0.223	0.084	0.076	0.057	0.360
10	0.379	0.148	0.379	0.379	0.089	0.111	0.089	0.221
11	0.148	0.379	0.148	0.148	0.053	0.379	0.053	0.379
12	0.221	0.221	0.089	0.221	0.221	0.089	0.111	0.148
13	0.053	0.111	0.221	0.111	0.148	0.148	0.221	0.089
14	0.089	0.053	0.053	0.053	0.379	0.053	0.379	0.053
15	0.111	0.089	0.111	0.089	0.111	0.221	0.148	0.111
Inconsistency	0.069	0.091	0.084	0.095	0.074	0.089	0.092	0.091

* See Table 1 for criteria specifications.

Table 7
Initial weight of each criterion based on AHP, ANP and inconsistency values, the Cheshmeh-Kileh Watershed, Mazandaran Province, Iran

Criteria	**AHP weight**	**Inconsistency**	**ANP weight**	**Inconsistency**
A	0.076	0.010	0.289	0.015
CN	0.189	0.040	0.351	0.050
Se	0.124	0.098	0.365	0.034
Tc	0.113	0.031	0.265	0.031
LU	0.139	0.040	0.387	0.022
P	0.359	0.022	0.342	0.033

* See Table 1 for criteria specifications.

Table 8
The final weights of the SWs in each criterion based on AHP and ANP, the Cheshmeh-Kileh Watershed, Mazandaran Province, Iran

SW	AHP weight						ANP weight					
	Criteria											
	A	CN	Se	Tc	LU	P	A	CN	Se	Tc	LU	P
1	0.002	0.032	0.003	0.007	0.002	0.018	0.005	0.041	0.008	0.012	0.006	0.011
2	0.007	0.023	0.003	0.008	0.024	0.015	0.018	0.027	0.009	0.017	0.061	0.009
3	0.001	0.009	0.004	0.005	0.008	0.013	0.003	0.011	0.012	0.007	0.024	0.007
4	0.002	0.005	0.005	0.002	0.006	0.020	0.005	0.007	0.014	0.003	0.017	0.013
5	0.006	0.005	0.007	0.002	0.003	0.045	0.014	0.004	0.006	0.005	0.008	0.032
6	0.005	0.006	0.011	0.007	0.005	0.055	0.011	0.007	0.024	0.014	0.011	0.043
7	0.013	0.013	0.015	0.019	0.016	0.062	0.031	0.017	0.045	0.039	0.042	0.055
8	0.003	0.008	0.013	0.004	0.010	0.037	0.008	0.010	0.037	0.008	0.029	0.026
9	0.008	0.027	0.009	0.010	0.003	0.025	0.020	0.032	0.027	0.024	0.006	0.019
10	0.011	0.010	0.020	0.017	0.013	0.006	0.063	0.033	0.067	0.046	0.032	0.009
11	0.004	0.019	0.008	0.011	0.019	0.005	0.025	0.066	0.026	0.028	0.060	0.009
12	0.009	0.016	0.004	0.013	0.012	0.011	0.051	0.051	0.011	0.036	0.034	0.024
13	0.002	0.008	0.015	0.005	0.007	0.009	0.008	0.022	0.054	0.013	0.027	0.018
14	0.002	0.003	0.002	0.002	0.003	0.030	0.010	0.009	0.007	0.006	0.010	0.054
15	0.003	0.005	0.006	0.003	0.007	0.008	0.016	0.014	0.019	0.008	0.022	0.013

* See Table 1 for criteria specifications.

Table 6. The final weights of the SWs in each criterion based on BWM, the Cheshmeh-Kileh Watershed, Mazandaran Province, Iran

Table 7. Initial weight of each criterion based on AHP, ANP and inconsistency values, the Cheshmeh-Kileh Watershed, Mazandaran Province, Iran

Table 8. The final weights of the SWs in each criterion based on AHP and ANP, the Cheshmeh-Kileh Watershed, Mazandaran Province, Iran

3.3 Results of HMA

In HMA, peak discharge was calculated with 10- and 100-year return periods per SW. Then, from the division of Discharge with a 100- to a 10-year return period, the Q100/Q10 index in each SW was quantified. Finally, with the intermittent removal of SWs, the most critical SWs were identified. The results of HMA are presented in Table 9.

Table 9

Values of Q100/Q10 with repeat method for individual removal of SWs, the Cheshmeh-Kileh Watershed, and Mazandaran Province, Iran

SWs	Peak Discharge (Cubic meters per second)		Q100/Q10
	10-year	100-year	
1	71.50	202.10	2.83
2	71.50	203.90	2.85
3	71.70	195.80	2.73
4	78.90	214.20	2.71
5	80.50	220.60	2.74
6	72.10	200.80	2.79
7	56.60	178.40	3.15
8	72.70	202.00	2.78
9	74.80	211.10	2.82
10	31.80	96.20	3.03
11	25.20	81.70	3.24
12	30.80	94.40	3.06
13	32.00	89.90	2.81
14	38.70	108.20	2.80
15	35.50	97.60	2.75

Table 9. Values of Q100/Q10 with repeat method for individual removal of SWs, the Cheshmeh-Kileh Watershed, and Mazandaran Province, Iran

Spatial arrangement and prioritization of SWs based on FGP using MCDM and HMA were presented in Fig. 7. Based on the presented results, FGP was classified into three priorities. The first priority was high-potential SWs, the second priority was medium-potential SWs, and the third priority was low-potential SWs based on generation flood.

Figure 7. SW prioritization, A: GTA, B: BWM, C: AHP, D: ANP, E: FAHP, F: FANP, G: HMA

3.4 Results of comparative evaluation of the methods used

The results of correlation analysis and comparison between MCDM and HMA were presented in Fig. 8.

Figure 8. Correlation analysis of HMA and MCDM methods, the Cheshmeh-Kileh Watershed, Iran

4. Discussion

SW Prioritization is one of the important efforts for soil and water conservation as well as identification of critical area based on environmental stresses (hc et al. 2021). SW prioritization is also the most important task in achieving the goals of sustainable development and Integrated Watershed Management (IWM), which helps managers in optimal decision making (Rahaman et al. 2015). Therefore, in the present study, using different approaches, SWs were prioritized based on FGP, which is discussed below the results of the methods used:

4.1 MCDM and HMA: Analysis of SW prioritization

4.1.1 GTA

The results of the Condorcet algorithm based on GT showed that SWs 7, 9, 10 and 12 had a high priority based on FGP (Table 4). This was while the lowest FGP was related to SWs 4, 5, 3, 14 and 15 (Table 5). The main reason for the high FGP in SW 7 was related to A, CN, Se and P and Tc. However, the reason for the high FGP in SW 9 was the lack of forest lands (Table 2). In SW 10 (A, Se and Tc) and in SW 12 (P) was the main cause of high FGP (Table 3). The main reasons for low FGP values were in SW 4 (CN and Tc) SW 5 (Tc), SW 3 (P and A), SW 14 (CN, Se and P) and SW 15 (CN, Tc and P). According to the results of Fig. 7.A, 26.67% of the study watershed was high priority in terms of FGP. 40.00% was in moderate priority and 33.33% was in low priority.

4.1.2 BWM

In this method, geo-environmental criteria had different effects on watersheds and finally on FGP. Based on A criterion, SW 10, CN criterion, SW 11, Se criterion, SW 7, Tc criterion, SW 10, P criterion, SW 14, Rl criterion, SW 11, Re criterion, SW 14 and SW 1, Had the highest weight. Also, based on A, CN, Se, Tc, P, Rl, Re and F, SWs 3, 5, 5, 4, 3, 5, 7, and 5, respectively, gained the lowest weight related to FGP (Table 6). According to the final results of BWN, SWs 1, 9, 7, 10 and 11 had the highest FGP and SWs 3, 4, 5, 6, 13, 14 and 15 had the lowest FGP. Based on the spatial arrangement of SWs in this method, the high, medium and low potentials in the FGP were 33.33, 20.00 and 46.67% of the study area, respectively (Fig. 7.B).

4.1.3 AHP and FAHP

According to Table 7, the initial weights of AHP and ANP, based on experts in Expert Choice and Super software, showed that in AHP, P criterion with a weight of 0.359 and A criterion with a weight of 0.076 had the most and the least impact in FGP, respectively. Based on the final weights of criteria and alternatives in AHP, in A criterion, SW 7 (0.013), in CN criterion, SW 1 (0.032), in Se criterion, SW 10 (0.02), in Tc criterion, SW 7 (0.019), in LU criterion, SW 2 (0.024) and in P criterion, SW 7 (0.062) had the highest weight (Table 8). In this method, 40% of the region was in a critical situation in terms of FGP. Meanwhile, 46.67 and 13.33% of the watershed were in the moderate and low priorities (Fig. 7.C). The FAHP method had different results than the AHP and ANP methods. High, medium and low priority based on FGP accounted for 33.33, 26.67 and 40% of the watershed, respectively (Fig. 7.E).

4.1.4 ANP and FANP

The results of the initial weights of ANP were different from those of AHP, so that the LU criterion with a weight of 0.387 gained the most weight. However, the Tc criterion with a weight of 0.265 had the least effect on FGP. Also based on the A, CN, Se, Tc, P, Rl, Re and F criteria, SWs 10 (0.063), 11 (0.066), 10 (0.067), 10 (0.046), 2 (0.061), 7 (0.055), gained the highest weight related to FGP (Table 8). In this method, as in the AHP method, 40% of the watershed was in critical condition, but the moderate and low priorities were 33.33% and 26.67%, respectively. (Fig. 7.D). The results of SW prioritization by FANO method were different from FAHP method. So that 40% of the watershed was in a critical situation in terms of FGP. Also, 20 and 40% of the watershed in moderate and low priorities were based on FGP, respectively (Fig. 7.F).

4.1.5 HMA

In this approach (Table 9), the peak discharge with 10-year return period in SWs 5 and 11 basins with values of 80.5 and 25.2 cubic meters per second, respectively, had the highest and lowest values. Also, SWs 5 and 11 based on peak discharge with 100-year return period with values of 220.6 and 81.7 cubic meters per second, respectively, had the highest and lowest values. While the basis of comparison was Q100/Q10 index, which based on the values presented in Table 9, SWs 11 and 7 with values of 3.24 and 3.15, had the highest FGP. The HMM method had different results than other methods in prioritizing SWs. In general, 13.33%, 33.33% and 53.33% of the study watershed were in the first, second and third priorities, respectively (Fig. 7.G).

4.2 Comparative analysis and decision-making process

The basis for comparing MCDM and choosing the best method was field observations, anecdotal evidence (Ghaleno et al. 2020) and HMA. A noteworthy point in the selection of critical SWs was that in all methods used, SW 7 was the first priority based on FGP. Also, in MCDM, SW 10 was in a critical situation. In most methods, downstream SWs had low priority in based on FGP (Avand et al. 2021). Correlation analysis between different methods showed that BWM, GT and ANP, had a high correlation with HMA. The highest correlation was related to BWM (0.87) with HMA, but this high correlation was due to the similar prioritization of downstream SWs. The most different prioritization algorithms compared to HMA were the AHP and ANH methods. In AHP method in the Dohezar River, a high percentage of SWs were given the first priority. Also, according to field evidence and anecdotal evidence in the Cheshmeh-Kileh Watershed, SWs 9 had a high potential due to the heights of Takht-e-Soliman, lack of forest lands and also glaciers (white area under SW 9 in the land use map). According to the technical experts of the General Department of Natural Resources and Watershed Management of West Mazandaran, two types of floods occur in the study area. The first type of flood was related to the glacial regime. In SW 9, Takht-e-Soliman glacier has caused a lot of floods in this watershed in the warm season due to the coincidence of snowmelt with the natural flow of the Sehezar River. On the other hand, the heavy seasonal rains that were related to SWs 9, 1, 10 and 11 have caused many floods. In relation to SW 7, the area of this SW was less and due to the existence of impenetrable lands and sometimes significant rainfall was in the first priorities. Therefore, it can be concluded that based on the land use map, field evidence and the results of HMA, SWs 9, 1, 7, 10 and 11 were at high potential based on flood generation. Also, according to the land use map and field evidence, downstream SWs in the Sehezar and Dohezar Rivers had low potential due to dense forest cover and low slope.

Based on prioritization patterns using MCDM, BWM had a similar result to the field evidence and HMA and it can be said that this method gave the best result (Mishra and Satapathy 2020; Meshram 2021). After BWM, GT provided a relatively good result (Avand et al. 2021). Regarding the structural and practical nature of GT, it can be said that in addition to the advantages, there were also disadvantages, which were to provide quantitative information only at the SWs level and at the pixel level could not provide more accurate information that was consistent with the results. GT, however, yielded better results than the AHP and ANP methods, and best reflected the behavior of the criteria involved in the decision, which Madani, 2010 endorsed. One of the reasons for choosing the Condorcet algorithm based on GT and its appropriateness is that based on (Mahjouri and Bizhani-Manzar 2013; Adhami and Sadeghi 2016), this algorithm was a simple and easy method and was able to apply the effect of the majority of criteria in SW prioritization. Janssen & Hermans, 2017 and Machac et al., 2018 confirmed the appropriate application of GT in flood management.

Unfortunately, the methods of AHP, FAHP (Contrary to Akay & Baduna Koçyi\ugit, 2020; Amiri et al., 2019 results), ANP and FANP (Contrary to Balogun et al., 2021 results) presented different results than the results of HMA and had poor performance in identifying areas with high FGP. The uncertainties of the questionnaires and the opinions of experts were among the most important reasons that AHP and ANP methods presented different results than other methods, which confirmed Mendoza & Martins, (2006) and Balasubramanian et al., (2017) results. Adhami & Sadeghi, (2016), Janssen et al., (2010); Kruse et al., (2012); Rahmati et al., (2019) also showed that the process of SW prioritization in most of the methods mentioned is based on the experiences of experts, a specific factor and a data set, and methods based on expert knowledge have high uncertainty. Also, the application of methods based on questionnaires requires specialized knowledge of the watershed (Ahmed et al. 2018; Jhariya et al. 2020). Another disadvantage of the AHP and ANP methods was the lack of accurate knowledge, the relationship between the criteria and their complexity, which was confirmed by Toosi & Samani, (2017); Y. Wu et al., (2018). In general, it can be said that due to the multidimensionality and complexity of the factors affecting the watershed, the use of different methods with comprehensive and complete data can be effective in flood management. Studying and prioritizing SWs reduces the time and cost of watershed management programs and strategies and increases the effectiveness of these programs. The spatial distribution of SWs and the contribution of the effect of each SW have an important function in flood management.

5. Conclusion

The purpose of this study was to prioritize SWs based on FGP using MCDM including GT and BWM, AHP, ANP, FAHP and FANP and compare their results with HMA using HEC-HMS software in the Cheshmeh-Kileh Watershed, Iran. First, the criteria affecting FGP including A, CN, Se, Tc, P, Rl, Re and F in each SW were calculated. In GT, the Condorcet algorithm and comparative preferences between criteria were used. In BWM, best and worst criteria in each SW were determined and based on these criteria, other options were weighed. The basis of work in AHP,ANP, FAHP and FANP was the use of questionnaires and expert opinions. To determine the weight of criteria and alternatives in AHP and ANP, Expert Choice and Super Decision software were used, respectively, and the SWs were weighed. ArcGIS 10.1 software was used to fuzzy FAHP and FANP. In HMA, HEC-HMS software was used to calculate discharges with a return period of 10- and 100-year, and by alternating removal of SWs, the impact of each SW on the outflow was determined, and finally the Q100/Q10 index was used to prioritize SWs. In all the mentioned methods, ArcGIS10.1 software was used to produce the map and FGP maps were produced in three classes (first priority with high potential, second priority with moderate potential and third priority with low potential for flood generation). Field evidence and HMA were used to compare the results of prioritization of MCDM and selection of the optimal method. Based on the results of different methods, SWs 9, 2, 7, 10 and 11 were given high priority in terms of FGP. Downstream SWs were also in a non-critical state due to dense forest cover and low slope.

A comparative evaluation between the methods showed that BWM had the same result as the field evidence and the results of HMA and this method provided the best result. After BWM, GT gave a relatively good result. AHP, ANP, FAHP and FANP presented different results, but had poor performance in identifying areas based on prioritization. This study showed that optimal MCDM approaches can be used for efficient watershed management as well as flood management based on soil and water conservation. The results of the present study can also help managers and decision makers of the Cheshmeh-Kileh Watershed to prevent and manage floods. It is suggested that in future studies, in addition to physical criteria, economic, social and environmental issues be used in prioritizing SWs and watershed management with more complete and comprehensive data.

Declarations

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Credit author statement

Ali Nasiri Khiavi: Conceptualization, Methodology, Software, Writing; Mehdi Vafakhah: Supervision, Writing–original draft, Validation; Seyed Hamidreza Sadeghi: Conceptualization, Writing–original draft, Validation.

Declaration of Competing Interest

The authors declare no conflict of interest.

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Figures

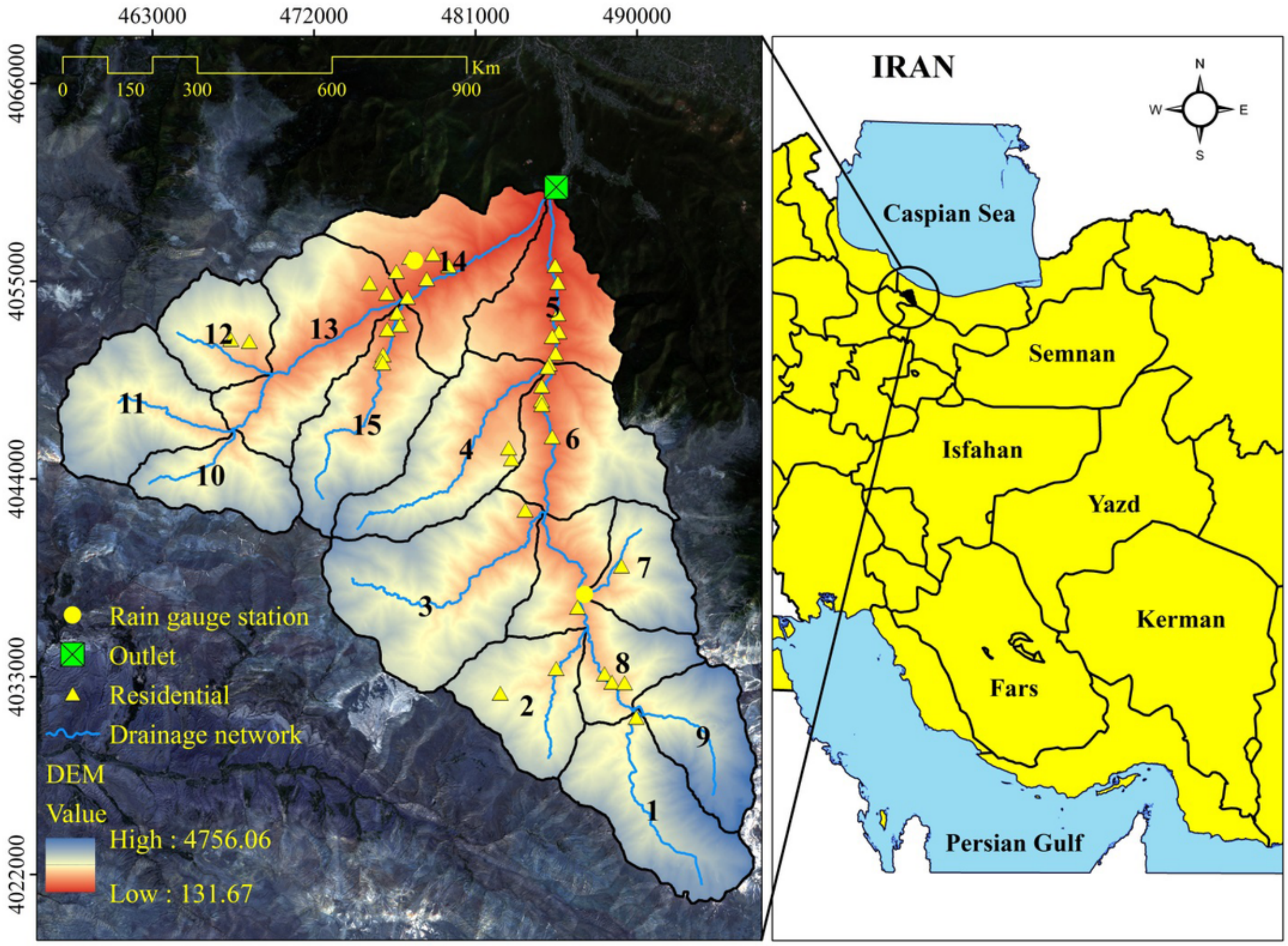


Figure 1

Location of the Cheshmeh-Kileh Watershed in Mazandaran Province, Iran; Sentinel-2

Figure 2

View of the Cheshmeh-Kileh Watershed, Mazandaran Province, Iran

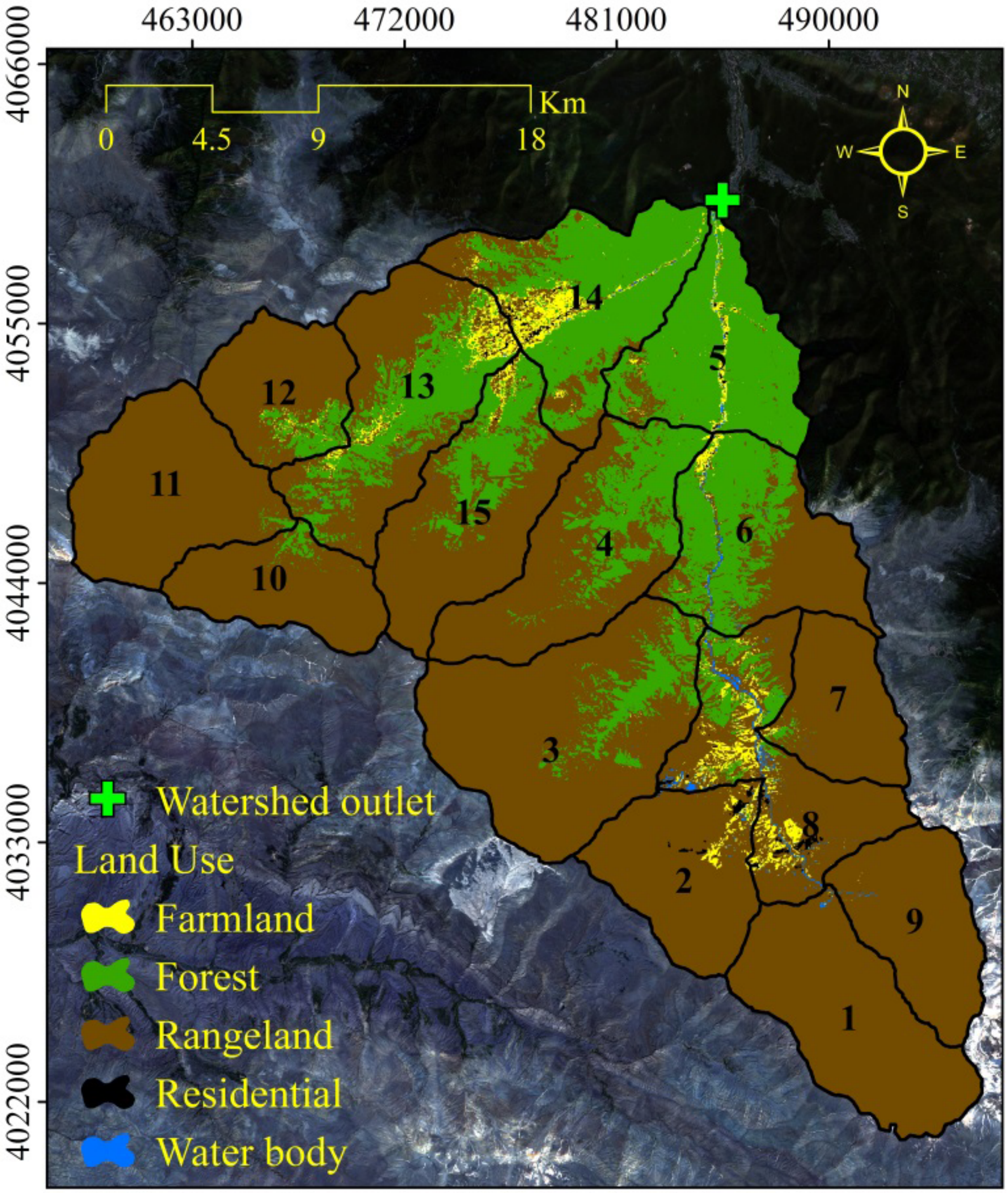


Figure 3

Land use map, 2019, the Cheshmeh-Kileh Watershed, Mazandaran Province, Iran

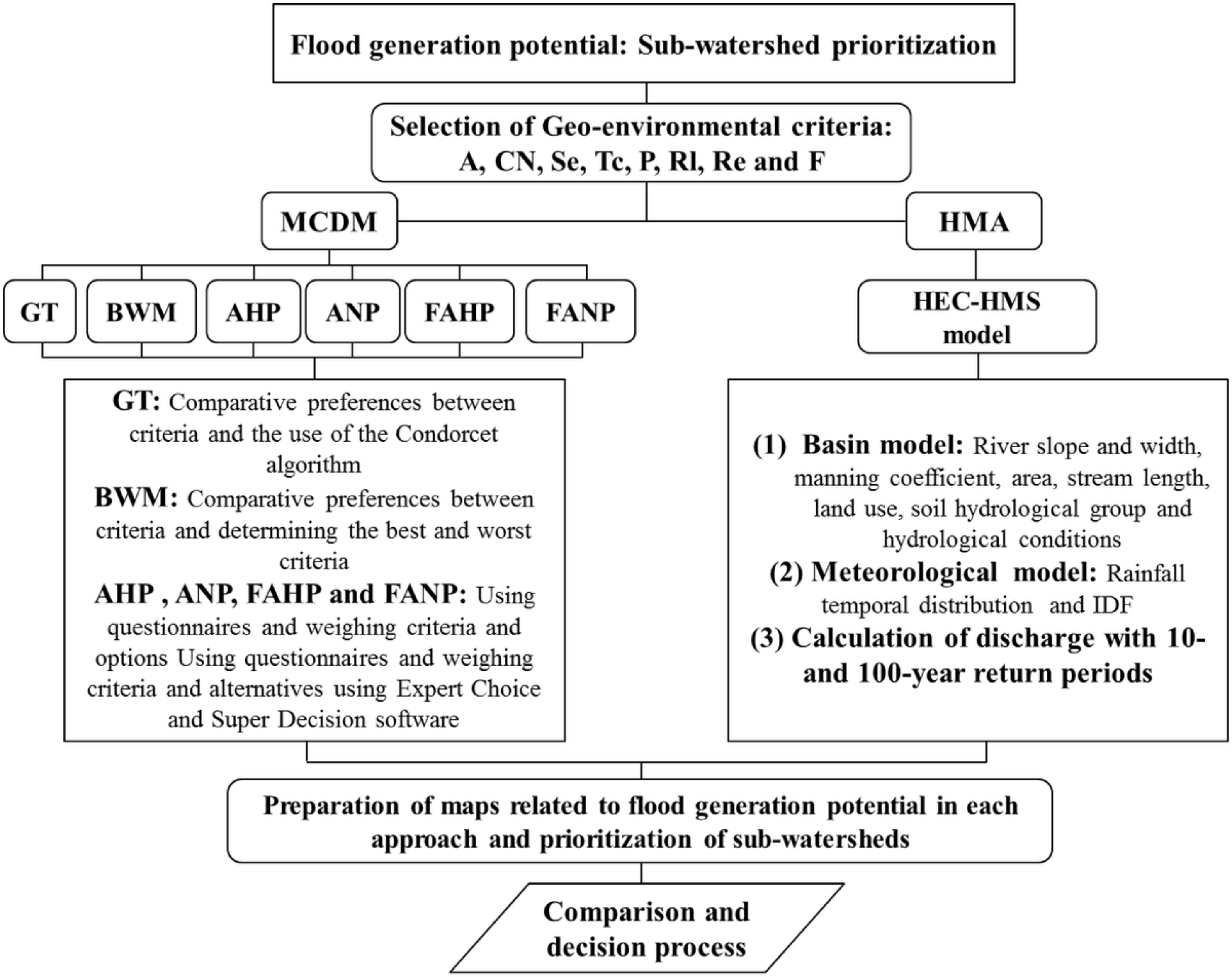


Figure 4

Flowchart of research methodology, the Cheshmeh-Kileh Watershed, Mazandaran Province, Iran

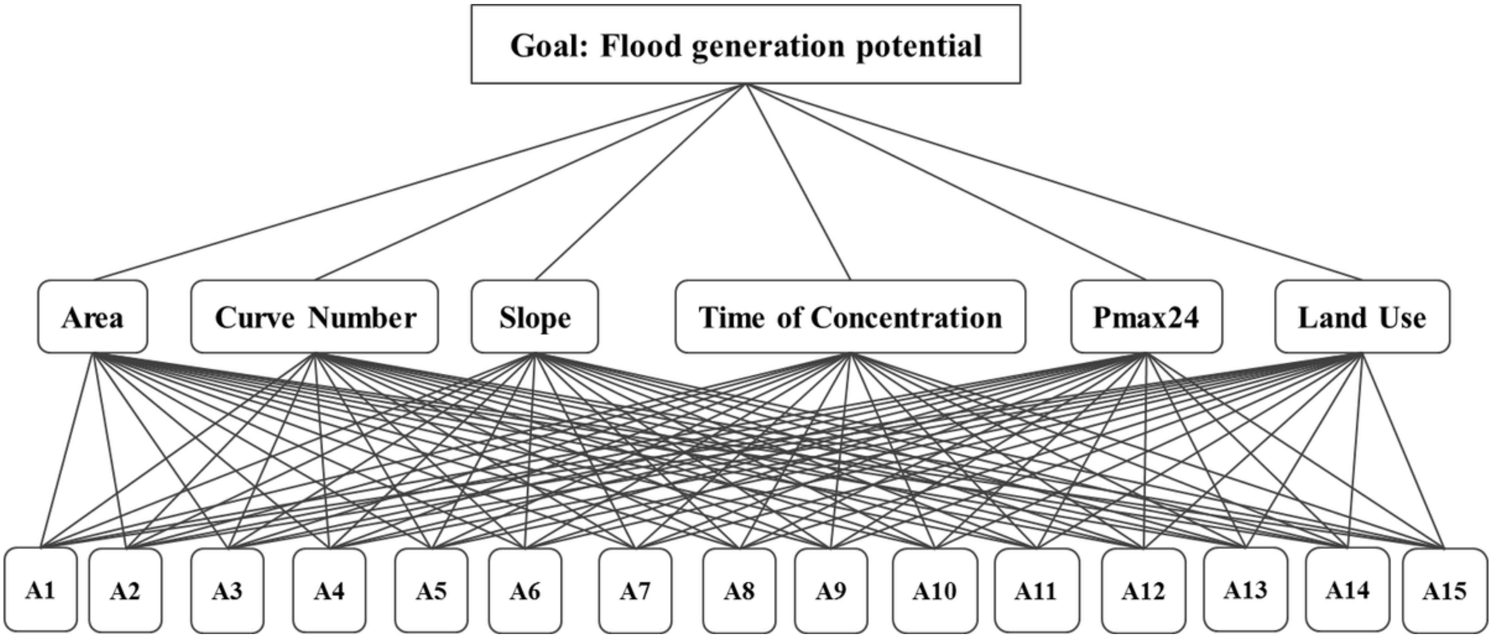


Figure 5

Hierarchical structure of goals, criteria and alternatives, the Cheshmeh-Kileh Watershed, Iran

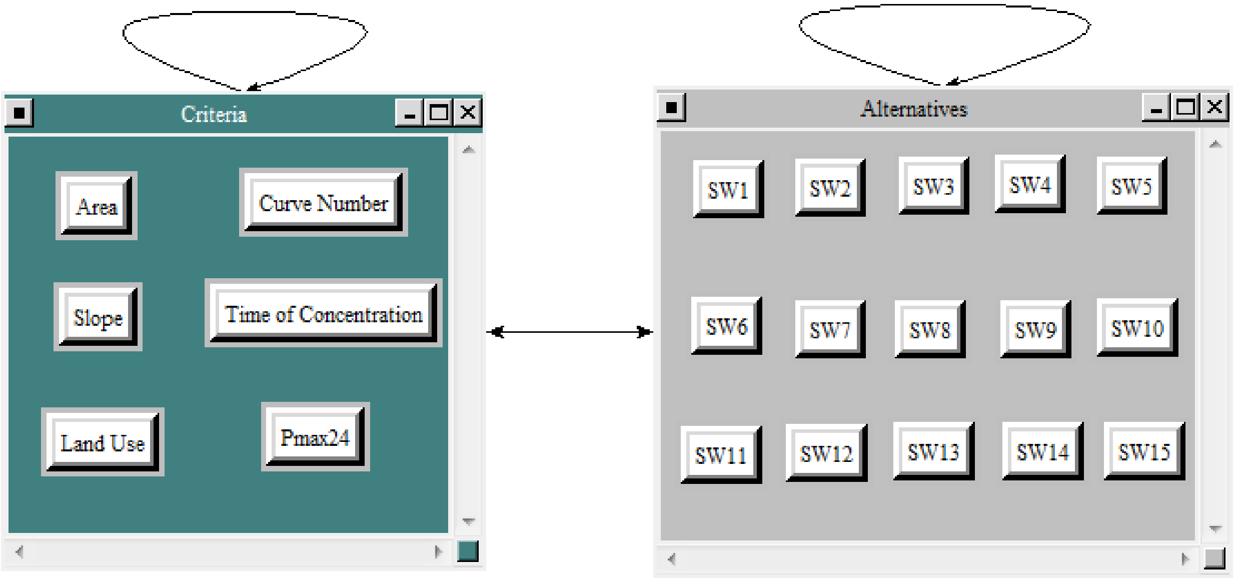


Figure 6

Relationships between criteria and alternatives in Super Decision software, ANP, the Cheshmeh-Kileh Watershed, Iran

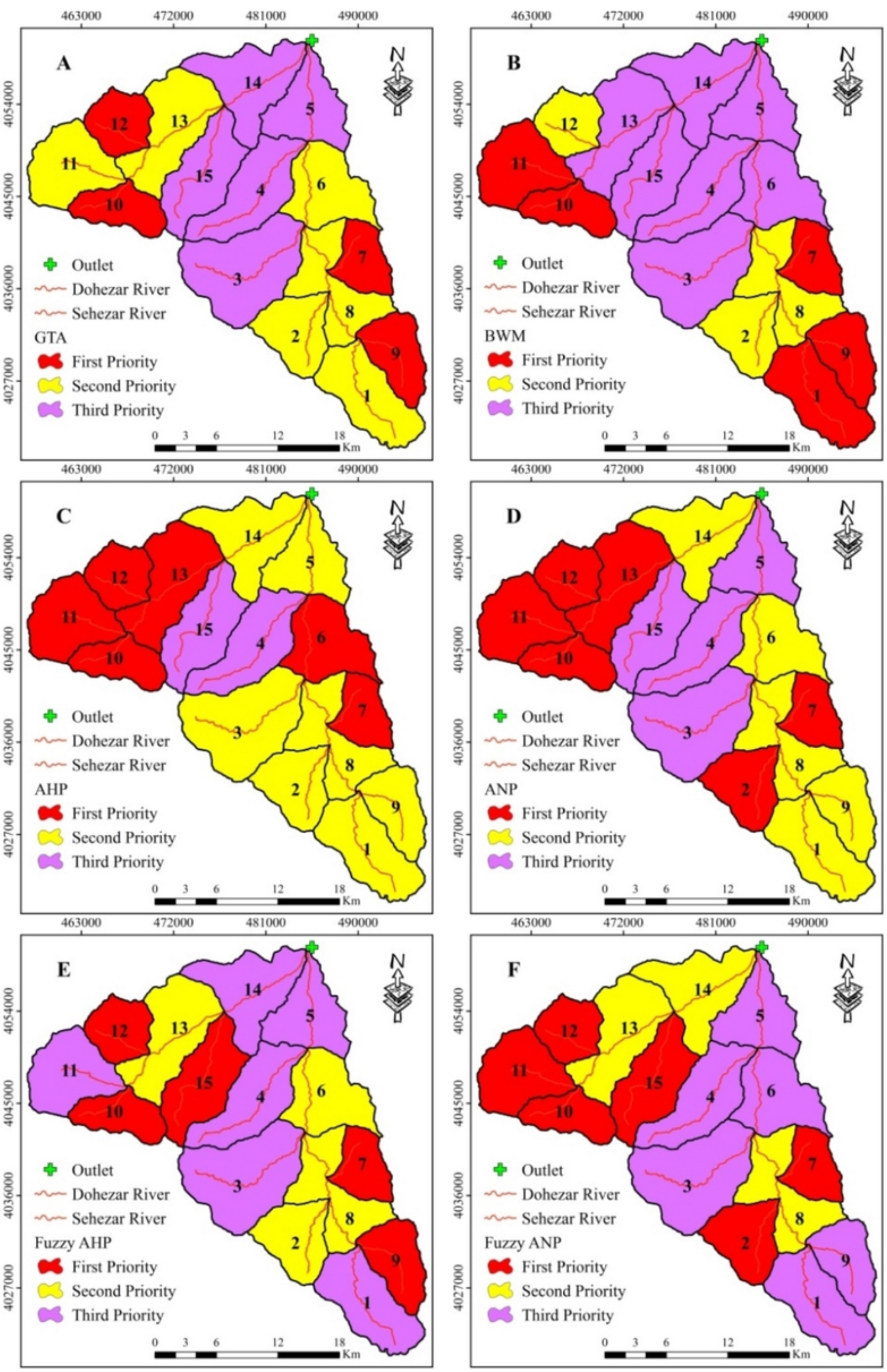
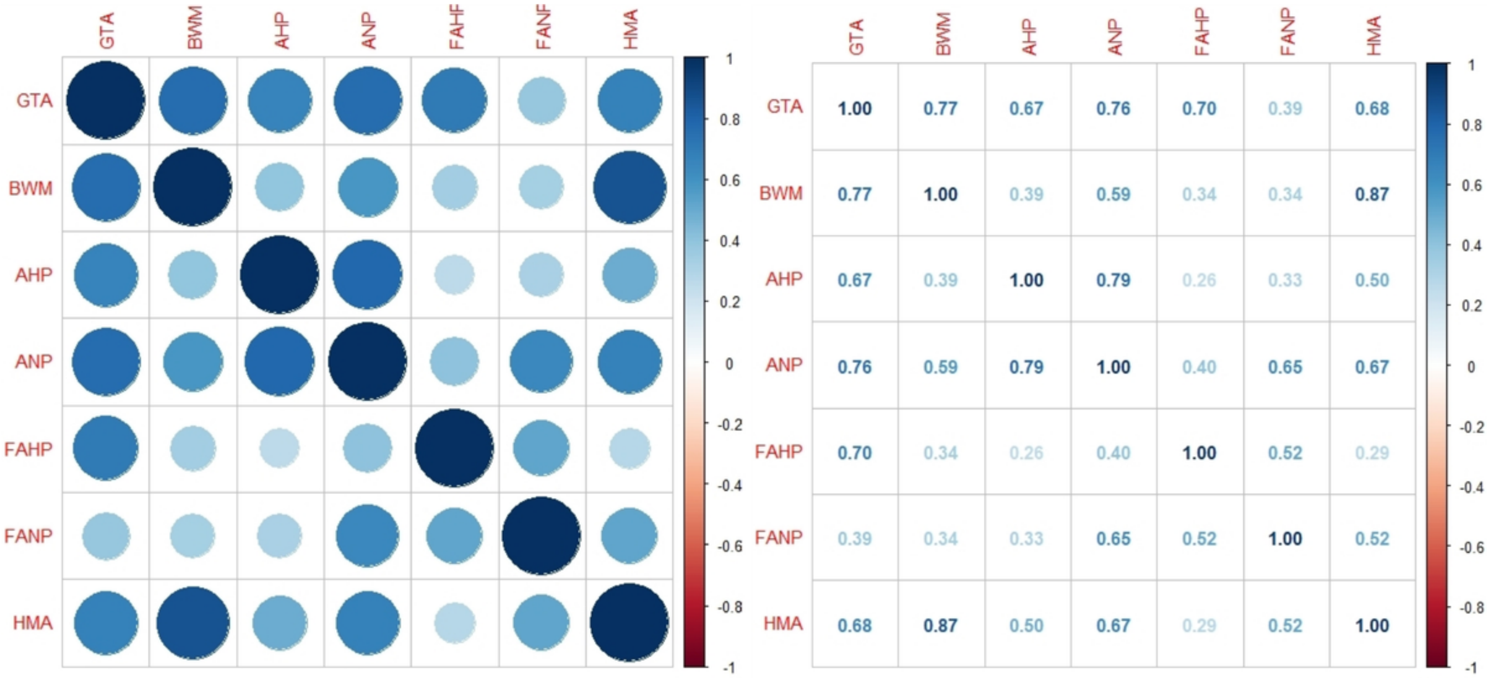


Figure 7

SW prioritization, A: GTA, B: BWM, C: AHP, D: ANP, E: FAHP, F: FANP, G: HMA



	GTA	BWM	AHP	ANP	FAHP	FANP	HMA
GTA	1.00	0.77	0.67	0.76	0.70	0.39	0.68
BWM	0.77	1.00	0.39	0.59	0.34	0.34	0.87
AHP	0.67	0.39	1.00	0.79	0.26	0.33	0.50
ANP	0.76	0.59	0.79	1.00	0.40	0.65	0.67
FAHP	0.70	0.34	0.26	0.40	1.00	0.52	0.29
FANP	0.39	0.34	0.33	0.65	0.52	1.00	0.52
HMA	0.68	0.87	0.50	0.67	0.29	0.52	1.00

Figure 8

Correlation analysis of HMA and MCDM methods, the Cheshmeh-Kileh Watershed, Iran